APPENDIX D

Hydrologic Modeling

Includes the following:

- Hydrologic Modeling Methodology and Technical Details

APPENDIX D
Hydrologic Modeling Methodology and Technical Details

Event-Based Modeling

Single event computer modeling of the Innisfil Creek Subwatershed was conducted to characterize the existing “local” hydrologic regime. Single event modeling uses discrete design storm events derived from rainfall statistics obtained from local climate station data to simulate the runoff response of the basin. Generally each storm represents a specific return period frequency (i.e. probability of occurrence) based on the individual characteristics of the rainfall such as maximum average intensity, rainfall volume and storm duration. In this way event modeling is advantageous for the assessment of potential impacts and for engineering design of drainage facilities as it represents the accepted and commonly applied engineering method for design and performance assessment.

Also, modeling of discrete events permits the simulation of accepted Provincial flood standards based on a previously experienced historical storm, such as the Timmins storm, a summer storm that occurred over Timmins, Ontario on September 1, 1961. This storm event is applied by the Nottawasaga Valley Conservation Authority as the Regulatory storm for the delineation of natural hazards associated with flooding.

The **I**ntegrated **S**tormwater and **W**atershed **M**anagement **S**ystem (**ISWMS**®) by Greenland, was utilized to develop the existing conditions hydrologic model. The initial phase (i.e. flood forecasting) of the new software system was developed for the Nottawasaga Valley Conservation Authority, and combines the usefulness of both unit hydrograph runoff generation methods and USEPA’s SWMM based models. This study applies the unit hydrograph runoff generation methods, typically used in similar subwatershed planning studies across Ontario, to model the hydrology of the Innisfil Creek Subwatershed.

The use of ISWMS to model the hydrology of the Innisfil Creek Subwatershed facilitates the required updating of the model based on ever-changing land use and development patterns within the Subwatershed.

The following sections describe the steps taken towards the development of the existing hydrologic model for the Innisfil Creek Subwatershed.

<u>Model Parameters</u>

Digital elevation mapping (DEM) was completed by MNR and reviewed by the NVCA. Using the DEM, catchment areas within the Innisfil Creek Subwatershed were revised from the original 1988 MacLaren Plansearch study. Various model parameter values were calculated based on information provided by the NVCA, including:

- existing land use information (see **Map 4**;

- digital elevation mapping (DEM);
- LandSAT imagery;
- soils mapping (see **Map 3**); and
- Ontario Base Maps (OBMs).

The existing conditions models for the Innisfil Creek Subwatershed were determined using the latest digital soils and landuse information. Digital soils information was provided by the NVCA. The current landuse information was also provided by the NVCA and was an unsupervised classification of generalized landuse based on the most recent LandSAT image. The existing landuse and soils information is shown in **Maps 4 and 3**, respectively. Using Ministry of Transportation Drainage Manual guidelines the appropriate Hydrologic Soils Group (HSG) was assigned to each soil type. Composite SCS curve numbers (CN) for each sub-catchment were calculated using the above information and the Modified SCS method was used to determine CN*.

The total Innisfil Creek Subwatershed area of approximately 491 km^2 was broken down into 39 smaller sub-catchment areas to ensure that the ISWMS models accurately reflect the response characteristics of the watercourse systems. The recently completed “hydrologically correct” Digital Elevation Model (DEM) produced by the Ministry of Natural Resources in cooperation with the NVCA was used to determine and verify sub-catchment boundaries. The finalized sub-catchment boundaries and the locations of ISWMS model flow nodes are illustrated in **Map 10**.

All parameters were measured or calculated using well-established protocols and procedures. Hydrologic modeling schematics and parameter values for existing conditions can be found in **Figure D.1** and **Tables D.1** through **D.3**.

Design Storms

Single event design storm intensities were derived from total precipitation volumes measured from the Barrie WPCC climate station. Existing conditions were evaluated using different distributions and several different storm durations ranging from 6 hour to 24 hours. The results of these simulations are located in **Table D.4**. The AES 24-hr distribution was found to produce the highest (i.e. critical) peak flow for all design events from the 2-year to the 100-year. Therefore, the AES 24-hr distribution and duration was used to calculate peak flows for this study. Pre-development and post-development flows were evaluated using the critical duration AES storms for the 2, 5, 10, 25, 50 and 100-year storm events. Flows calculated using the Regional Storm (Timmins Storm) were also calculated.

Model Calibration

To improve the accuracy of our hydrologic model we initially intended to calibrate the model using available precipitation and streamflow data. Unfortunately suitable data was not available and the model was therefore not calibrated.

Comparison of Flows with Previous Studies

The peak flows calculated using the ISWMS model were compared to flows from the 1988 MacLaren Plansearch study. Flows calculated with ISWMS were higher than those calculated in the MacLaren study. As a check, an hydrologic model was also coded for existing conditions using Visual OTTHYMO. A Table comparing peak flows at several nodes within the Subwatershed is provided in **Table D.5**. Generally, the flows calculated using Visual OTTHYMO were similar to those calculated using ISWMS. Reasons for the difference between flows calculated using ISWMS and those calculated in the MacLaren study may include the following:

- The MacLaren design flows were calculated based on continuous modeling using historical precipitation data and a subsequent frequency analysis on the resulting estimated flow data.
- ISWMS flows were calculated using design storms generated based on intensity-duration-frequency analysis of historical precipitation data.
- Peak flows using ISWMS were calculated based on the critical design storm distribution and duration.
- The ISWMS model is not calibrated.
- Hydrologic modeling was completed for the MacLaren study using QUALHYMO which uses a different parameter set for calculating peak flows.
- The flows generated in the MacLaren study were based on land use information from nearly 15 years ago.
- The catchment areas have been updated for the ISWMS model based on recently completed digital elevation mapping.
- The land use for the ISWMS model is based on up-to-date LandSAT imagery.
- In determining peak flows for the Timmins Storm, the MacLaren study applied the same reduction factor for the entire Innisfil Creek Subwatershed, whereas the ISWMS Regional flows were calculated using a variable reduction factor dependent on the upstream drainage area for any given node.

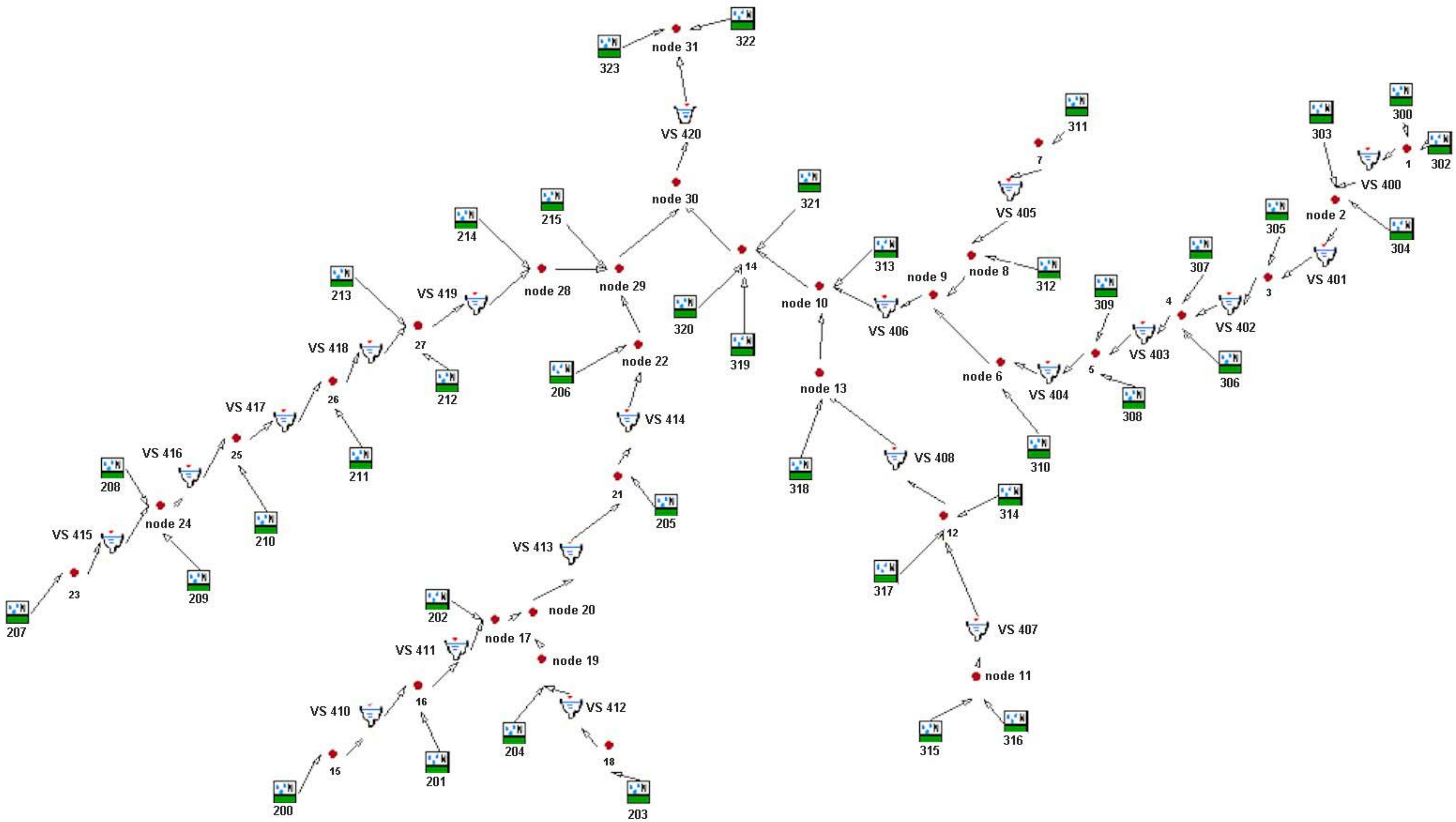

Figure D.1: INNISFIL CREEK SWS - EXISTING CONDITIONS ISWMS MODEL SCHEMATIC

TABLE D.1: EXISTING CONDITIONS - CATCHMENT PARAMETERS

CATCHMENT	200	201	202	203	204	205	206	207	208	209	210	211	212
COMMAND	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd
AREA (ha)	1178.58	834.39	1366.10	1159.26	2700.79	781.47	965.78	1527.69	1863.32	996.75	263.96	2083.38	3078.44
DWF (m^3/s)	0	0	0	0	0	0	0	0	0	0	0	0	0
CN*(AMC II)	61	61	75	70	70	73	78	57	61	61	78	69	67
tp (hr)	2.65	2.05	3.75	2.48	3.06	5.08	2.06	3.37	3.25	3.50	1.95	2.85	3.83
Ia (mm)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
N	3	3	3	3	3	3	3	3	3	3	3	3	3

CATCHMENT	213	214	215	300	302	303	304	305	306	307	308	309	310
COMMAND	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd
AREA (ha)	1635.90	340.61	245.70	2341.32	2397.86	1436.12	842.00	1199.18	976.25	966.37	386.06	531.91	437.17
DWF (m^3/s)	0	0	0	0	0	0	0	0	0	0	0	0	0
CN*(AMC II)	75	64	67	69	70	69	64	54	67	57	61	69	70
tp (hr)	3.51	3.84	3.67	1.82	2.86	2.02	2.86	2.49	6.35	2.37	1.90	2.14	3.13
Ia (mm)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
N	3	3	3	3	3	3	3	3	3	3	3	3	3

CATCHMENT	311	312	313	314	315	316	317	318	319	320	321	322	323
COMMAND	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd	Nashyd
AREA (ha)	1944.32	1402.54	1431.28	1132.86	1809.49	1660.94	1221.35	116.35	700.1	2327.31	355.37	935.01	1532.26
DWF (m^3/s)	0	0	0	0	0	0	0	0	0	0	0	0	0
CN*(AMC II)	75	73	73	73	80	80	75	75	78	78	70	69	63
tp (hr)	2.61	2.46	1.69	2.24	1.84	2.76	2.30	2.24	2.38	2.73	1.17	1.07	6.92
Ia (mm)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
N	3	3	3	3	3	3	3	3	3	3	3	3	3

TABLE D.2: SOIL TYPES AND HYDROLOGIC SOIL GROUPS

MAP SYMBOL	SOIL SERIES	TYPE	HYDROLOGIC SOILS GROUP
Stsl	Sargent	gravelly sandy loam	A
Tisl	Tioga	sandy loam	A
Tis	Tioga	loamy sand	A
Ans	Alliston	sandy loam	AB
Bs	Bondhead	sandy loam	AB
Bes	Berrian	sandy loam	AB
Bs-s	Bondhead	sandy loam-steep	AB
Bos	Bookton	sandy loam	AB
Df	Dundonald	fine sandy loam	AB
Ds	Dundonald	sandy loam	AB
Tis-Bl	Tioga-Brisbane	loamy sand-loam sand	AB
Tis-s-Bl-s	Tioga-Brisbane	loamy sand-loam sand	AB
Psl	Pontypool	sandy loam	AB
Bl	Bondhead	loam sand	B
Gsl	Granby	sandy loam	B
Gul	Guerin	loam sand	B
M	Muck	organic	B
Sis	Simcoe	silt loam	BC
Shs	Schomberg	silt loam	BC
Shsc	Schomberg	silty clay loam	C
Sisc	Simcoe	silty clay loam	C
Sms	Smithfield	silt loam	C
Smsc	Smithfield	silty clay loam	CD

TABLE D.3: LANDUSE AND CN NUMBERS

LAND USE DESCRIPTION	HYDROLOGIC SOIL GROUP								Special conditions for Muck Soils
	A	AB	B	BC	C	CD	D	MUCK	
Water	50	50	50	50	50	50	50	50	HSG B with AMC III conditions
Swamp/Meadow (Wetland Area)	25	40	55	63	70	74	77	74	HSG B with AMC III conditions
Forest	50	54	58	65	71	74	77	74	HSG B with AMC III conditions
Open, Pasture or Range Land	58	62	65	71	76	79	81	74	HSG B with AMC III conditions
Impervious Areas (Rock, Infrastructure)	98	98	98	98	98	98	98	N/A	
Agricultural	66	70	74	78	82	84	86	74	HSG B with AMC II conditions
Pits and Quarries	70	70	N/A	N/A	N/A	N/A	N/A	N/A	

TABLE D.4: CRITICAL DISTRIBUTION DETERMINATION

Flow at Node 31	6 hr SCS II (m^3/s)	12 hr SCS II (m^3/s)	24 hr SCS II (m^3/s)	6hr AES (m^3/s)	12 hr AES (m^3/s)	24 hr AES (m^3/s)
2-Year	109.4	114.5	132.7	122.2	131.8	159.2
5-Year	229.9	224.8	308.3	254.7	252.0	354.9
10-Year	323.9	306.6	438.4	358.0	343.3	499.3
25-Year	455.4	431.8	621.2	503.8	471.0	705.9
50-Year	561.7	521.9	766.3	620.4	572.7	865.8
100-Year	671.5	616.2	914.8	741.6	677.9	978.9

TABLE C.5: PEAK FLOW COMPARISON FOR SELECTED NODES

MACLAREN PLANSEARCH REPORT (1988)					ISWMS MODEL (2002)					VISUAL OTTHYMO MODEL (2002)				
FLOW NODE	DRAINAGE AREA	RETURN PERIOD/ EVENT PEAK FLOWS			FLOW NODE	DRAINAGE AREA	RETURN PERIOD/ EVENT PEAK FLOWS			FLOW NODE	DRAINAGE AREA	RETURN PERIOD/ EVENT PEAK FLOWS		
		5 YEAR	100 YEAR	REGIONAL			5 YEAR	100 YEAR	REGIONAL			5 YEAR	100 YEAR	REGIONAL
	(km2)	(m^3/s)	(m^3/s)	(m^3/s)		(km2)	(m^3/s)	(m^3/s)	(m^3/s)		(km2)	(m^3/s)	(m^3/s)	(m^3/s)
260	112.7	17.6	36.5	129.6	6	115.1	79.5	238.7	286.3	6	115.1	76.7	217.0	333.7
1044	149.5	28.3	58.5	196.5	9	148.6	109.9	283.4	288.6	9	148.6	106.6	296.5	450.6
1045	218.6	45.7	94.6	274.6	10	222.3	188.4	494.4	546.6	10	222.3	181.7	494.5	664.8
1028	52.4	8.6	18.6	76.7	24	43.9	20.4	66.4	128.1	24	43.9	22.1	67.3	128.8
1041	454.8	98.6	187.3	449.1	30	466.4	346.5	955.9	1102.9	30	466.4	329.7	930.9	1165.1
320	472.2	93.0	192.3	458.5	31	491.1	354.9	978.9	1138.8	31	491.1	336.7	954.2	1199.7

APPENDIX E

Water Balance Calculations

Includes the following

- Water Balance Methodology and Results

APPENDIX E
Water Balance Calculations

Water Balance Methodology

The existing monthly water balance was calculated for the study area using an approach developed by Greenland International Consultants. As shown in **Figure E.1**, the approach combines existing methods of water balance modeling with available HYDAT streamflow data. The model provides output for various water balance components including, rainfall, snowmelt, actual evapotranspiration, runoff, baseflow and deep groundwater storage, as well as water extracted from surface and ground water by Permit-to-Take-Water (PTTW) and redirected as input to the system.

The first step of the water balance method utilized Environment Canada's *AES Water Balance Model* to generate surplus water quantities on a monthly basis for the period of continuous climate data available (1973-1996) from the Alliston Nelson climate station (Environment Canada DC 20492), located in Alliston. The AES Water Balance Model is a modified approach to water budgeting and expands upon earlier techniques developed by Thornthwaite and Mather, whereby air temperature and precipitation are used to calculate the various additions, losses, and changes associated with the water budget. The AES Water Balance Model uses daily temperature and precipitation for the period of interest, which allows for improved modeling of snow storage and budget breakdown in either weeks or months. The output data from the AES Water Balance Model for the Innisfil Creek Subwatershed included the following components for the selected time-step:

- temperature
- precipitation;
- rain;
- snow storage;
- snow melt;
- potential evapotranspiration;
- water holding capacity and soil storage;
- actual evapotranspiration;
- moisture deficit; and
- accumulated precipitation.

Using a range of water holding capacities (50 mm through 400 mm) and regression analysis for pervious areas, various relationships between monthly water holding capacity, infiltration, water surplus and actual evapotranspiration were calculated using the period of record for the Alliston climate station.

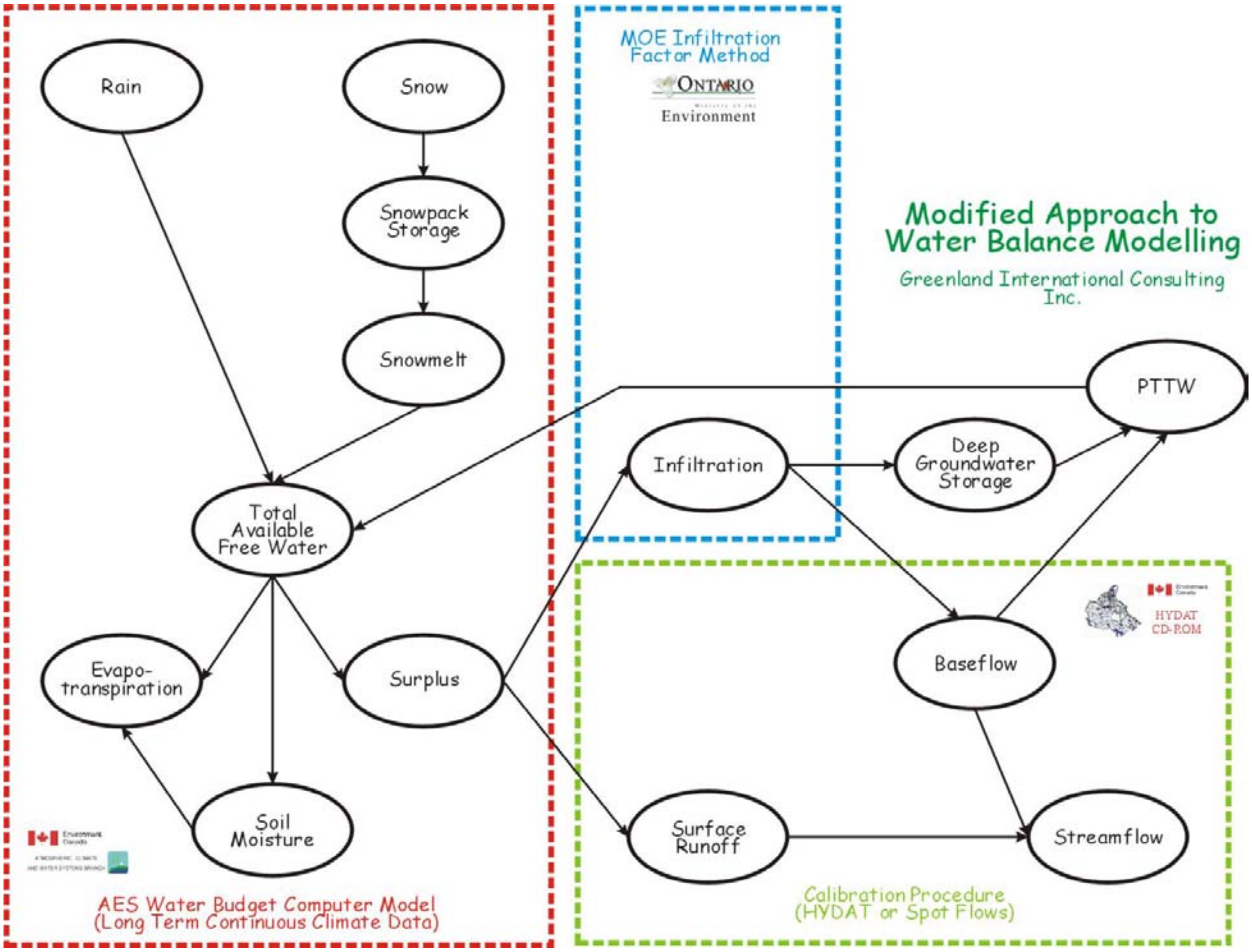

Figure D.1: Modified Approach to Water Balance Modeling Used for Innisfil Creek Subwatershed.

Water holding capacity for each catchment is a function of both soil texture and land uses. Soil texture and land uses were determined based on GIS information provided by the NVCA and is provided in **Table E.1**. Using weighted water-holding capacities and the methodology presented in the *Stormwater Management Planning and Design Manual* (MOE, 2003), monthly water surplus quantities were calculated for each catchment within the Innisfil Creek Subwatershed using regression equations generated earlier. Monthly actual evapotranspiration for each catchment is presented in **Table E.2**. Monthly surplus is presented in **Table E.3**.

The change in soil moisture is expressed as a negative quantity when water is withdrawn from soil storage and is expressed as a positive quantity when water is added to soil storage.

TABLE E.1 WATER HOLDING CAPACITY CALCULATIONS FOR INNISFIL CREEK WATERSHED – Catchments 200 to Gauge Station

WATER HOLDING CAPACITY CALCULATIONS (EXISTING CONDITIONS) **JULY**

Soil Type	HSG	WHC (mm)	Catchment 200 (ha)	Catchment 201 (ha)	Catchment 202 (ha)	Catchment 203 (ha)	Catchment 204 (ha)	Catchment 205 (ha)	Catchment 206 (ha)	Catchment 207 (ha)	Catchment 208 (ha)	Catchment 209 (ha)	Catchment 210 (ha)	Catchment 211 (ha)	Subtotals 212 (ha)	Catchment 213 (ha)	Catchment 214 (ha)	Catchment 1/2 215 (ha)	Subtotals to WSC Gauge (ha)
Urban Lawns/Shallow Rooted Crops (spinach, beans, beets, carrots)																			
Fine Sand	A	50	0.00	0.00	0.00	42.16	54.41	0.00	47.89	0.00	0.00	0.00	0.00	22.08	188.62	7.98	40.24	0.30	403.68
	AB	63	0.00	0.00	61.10	19.58	95.36	20.47	29.13	0.00	0.00	116.20	24.54	47.53	259.17	52.03	197.77	26.10	948.97
Fine Sandy Loam	B	75	0.00	0.00	55.81	44.89	163.06	12.40	45.04	3.89	0.00	3.14	0.00	5.30	208.41	19.89	0.00	0.00	561.83
	BC	100	0.00	0.00	41.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	41.98
Silt Loam, Muck	C	125	0.82	0.00	108.92	89.72	249.61	55.31	132.32	0.00	0.00	0.00	67.58	61.29	277.90	165.74	1.14	6.77	1217.10
Clay Loam	CD	100	0.00	0.00	5.31	63.44	39.64	3.85	4.11	0.00	0.00	0.00	0.00	3.57	194.23	28.96	0.00	0.00	343.11
Clay	D	75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Moderately Rooted Crops (corn and cereal grains)																			
Fine Sand	A	75	0.00	0.00	0.00	98.38	126.96	0.00	86.12	0.00	0.00	0.00	0.00	198.76	125.74	31.92	10.06	0.69	678.63
	AB	113	673.89	353.61	167.38	45.70	222.50	117.34	67.97	405.63	699.20	278.06	36.82	427.73	172.78	208.13	49.44	60.89	3987.06
Fine Sandy Loam	B	150	0.00	72.41	155.06	104.73	395.92	70.28	105.08	97.53	0.00	7.33	0.00	47.68	95.63	79.55	0.00	0.00	1231.21
	BC	175	0.00	51.84	97.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	149.80
Silt Loam,Muck	C	200	0.00	0.00	278.98	201.96	506.82	313.40	296.07	2.36	183.36	0.00	104.18	679.94	185.26	676.92	0.15	15.79	3445.20
Clay Loam	CD	200	0.00	0.00	12.39	148.02	92.49	21.84	9.58	0.00	0.00	0.00	0.00	32.17	129.48	115.83	0.00	0.00	561.80
Clay	D	150	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pasture and Shrubs																			
Fine Sand	A	100	0.00	0.00	0.00	15.03	26.46	0.00	6.68	0.00	0.00	0.00	0.00	42.27	45.59	0.37	6.19	0.00	142.59
	AB	125	243.39	125.06	129.69	10.50	55.80	24.73	0.85	533.08	522.49	280.98	1.65	190.86	119.78	4.62	18.34	2.13	2263.95
Fine Sandy Loam	B	150	0.00	19.63	37.35	22.72	63.74	10.65	6.60	57.55	0.00	11.78	0.00	2.36	38.88	6.00	0.00	0.00	277.26
	BC	200	0.00	23.15	24.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	48.09
Silt Loam, Muck	C	250	0.00	0.00	33.03	20.76	101.36	33.03	15.85	0.76	18.46	0.00	8.88	48.09	23.38	82.86	0.00	2.03	388.49
Clay Loam	CD	250	0.00	0.00	1.93	12.96	32.34	0.00	3.53	0.00	0.00	0.00	0.00	3.23	16.91	2.96	0.00	0.00	73.86
Clay	D	200	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mature Forests																			
Fine Sand	A	250	0.00	0.00	0.00	76.31	56.84	0.00	2.70	0.00	0.00	0.00	0.00	29.25	49.32	29.25	10.97	0.00	254.64
	AB	275	260.75	144.82	69.99	72.71	144.79	65.63	1.18	387.37	427.13	244.32	0.46	137.48	213.06	26.82	5.04	8.06	2209.61
Fine Sandy Loam	B	300	0.00	35.50	6.44	43.48	134.06	5.53	12.51	15.82	0.00	2.40	0.00	15.98	206.33	22.53	0.00	0.00	500.58
	BC	350	0.00	4.54	15.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.52
Silt Loam, Muck	C	400	0.00	0.00	9.68	18.84	87.40	26.92	10.81	5.18	11.61	0.00	17.97	34.94	528.03	60.61	1.60	0.06	813.65
Clay Loam	CD	400	0.00	0.00	1.90	7.36	11.35	0.00	0.00	0.00	0.00	0.00	0.00	37.42	0.00	8.21	0.00	0.00	66.24
Clay	D	350	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Swamp/Fen/Marsh																			
			0.00	0.00	0.00	0.00	0.85	0.00	0.00	0.00	0.00	2.12	0.00	1.10	0.00	1.23	0.00	0.00	5.30
Open Water																			
			0.28	0.00	18.38	0.00	0.00	0.00	0.00	4.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.85
Impervious Urban Area (assumed 50% of total urban area)																			
			0.00	3.81	31.71	0.00	39.59	0.00	78.28	0.00	0.00	2.19	1.72	14.68	0.00	2.08	0.00	0.00	174.07
Sand/Gravel/Rock Pits																			
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	14.00	0.00	47.45	0.00	0.00	0.00	0.00	0.00	0.00	61.45
Total Others Areas (ha)			**0.3**	**3.8**	**0.3**	**0.0**	**40.4**	**0.0**	**78.3**	**18.2**	**0.00**	**51.76**	**1.72**	**15.78**	**0.00**	**3.31**	**0.00**	**0.00**	**263.67**
Total Pervious Area (ha)			**1178.8**	**830.6**	**1315.8**	**1159.3**	**2660.9**	**781.4**	**884.0**	**1509.2**	**1862.25**	**944.21**	**262.08**	**2067.92**	**3078.50**	**1631.18**	**340.94**	**122.81**	**20629.84**
Total Area (ha)			**1179**	**834**	**1316**	**1159**	**2701**	**781**	**962**	**1527**	**1862.25**	**995.97**	**263.80**	**2083.70**	**3078.50**	**1634.49**	**340.94**	**122.81**	**20893.51**
Weighted WHC (mm) (pervious area)			**151.32**	**162.74**	**160.29**	**172.32**	**171.52**	**184.02**	**148.50**	**165.68**	**165.24**	**153.43**	**170.68**	**167.05**	**188.81**	**182.15**	**84.08**	**127.09**	**168.26**
Actual Evapotranspiration (mm)			119.53	122.22	121.67	124.23	124.07	126.38	118.82	122.86	122.76	120.05	123.90	123.15	127.17	126.06	97.37	112.80	123.40

TABLE E.1 WATER HOLDING CAPACITY CALCULATIONS FOR INNISFIL CREEK WATERSHED – Catchments 215 to 323

WATER HOLDING CAPACITY CALCULATIONS (EXISTING CONDITIONS)

Soil Type	HSG	WHC (mm)	Catchment 215 (ha)	Catchment 300 (ha)	Catchment 302 (ha)	Catchment 303 (ha)	Catchment 304 (ha)	Catchment 305 (ha)	Catchment 306 (ha)	Catchment 307 (ha)	Catchment 308 (ha)	Catchment 309 (ha)	Catchment 310 (ha)	Catchment 311 (ha)
Urban Lawns/Shallow Rooted Crops (spinach, beans														
Fine Sand	A	50	0.59	56.62	34.90	5.56	0.00	0.65	0.00	49.60	0.98	0.44	0.00	23.98
	AB	63	52.19	97.39	230.85	218.22	92.30	61.69	159.20	144.63	5.99	21.20	25.76	63.44
Fine Sandy Loam	B	75	0.00	289.18	513.81	217.51	107.97	91.93	179.32	5.47	7.52	39.06	2.74	85.36
	BC	100	0.00	0.58	0.00	0.00	0.00	0.00	0.04	0.45	0.82	3.75	17.89	0.00
Silt Loam, Muck	C	125	14.49	54.64	361.43	91.84	35.30	1.22	4.28	2.82	0.85	3.47	18.67	115.39
Clay Loam	CD	100	0.00	38.37	118.15	9.70	16.12	10.31	0.00	0.00	0.00	0.00	0.00	85.47
Clay	D	75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Moderately Rooted Crops (corn and cereal grains)														
Fine Sand	A	75	1.39	132.12	14.96	5.56	0.00	1.51	0.00	49.60	18.54	2.49	0.00	95.90
	AB	113	121.78	227.25	98.93	218.80	92.30	143.93	159.68	144.63	113.89	120.16	106.28	253.77
Fine Sandy Loam	B	150	0.00	674.74	220.21	217.51	89.54	107.86	179.32	3.16	70.82	215.82	10.96	341.45
	BC	175	0.00	1.36	0.00	0.00	0.00	0.00	0.04	0.45	15.51	21.23	71.56	0.00
Silt Loam,Muck	C	200	31.58	98.51	154.90	91.84	35.30	2.85	4.28	2.82	16.06	19.64	74.68	313.11
Clay Loam	CD	200	0.00	89.53	50.63	9.70	16.12	24.05	0.00	0.00	0.00	0.00	0.00	341.86
Clay	D	150	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pasture and Shrubs														
Fine Sand	A	100	0.00	11.70	5.89	1.36	0.00	0.28	0.00	10.71	4.32	1.08	0.00	3.22
	AB	125	4.26	25.50	27.26	89.79	74.11	83.22	33.66	217.95	14.48	15.89	20.00	15.70
Fine Sandy Loam	B	150	0.00	105.55	90.91	66.71	16.93	110.53	27.25	14.36	6.88	15.77	0.16	13.82
	BC	200	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.90	1.71	12.69	0.00
Silt Loam, Muck	C	250	4.06	18.86	20.82	12.88	17.86	2.61	0.88	2.49	0.91	0.07	9.46	37.18
Clay Loam	CD	250	0.00	21.58	25.88	0.02	0.00	6.14	0.00	0.00	0.00	0.00	0.00	48.94
Clay	D	200	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mature Forests														
Fine Sand	A	250	0.00	16.23	8.80	0.08	0.00	13.16	0.00	21.43	3.99	1.75	0.00	0.12
	AB	275	16.11	45.57	32.73	62.53	143.66	352.75	141.96	234.56	78.44	26.33	9.03	27.32
Fine Sandy Loam	B	300	0.00	123.14	99.32	23.28	13.84	132.01	30.05	1.24	24.67	22.56	0.00	5.05
	BC	350	0.00	2.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	44.22	0.00
Silt Loam, Muck	C	400	0.12	167.80	235.59	88.65	85.00	31.79	7.12	42.86	0.00	0.06	12.28	24.17
Clay Loam	CD	400	0.00	27.04	37.93	0.26	0.16	0.30	0.00	0.00	0.00	0.00	0.00	24.42
Clay	D	350	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Swamp/Fen/Marsh			0.00	16.66	11.69	2.62	4.78	14.98	4.51	8.81	0.00	0.34	0.00	0.00
Open Water			0.00	0.00	1.15	1.10	0.00	6.39	0.00	0.00	0.00	0.00	0.00	0.00
Impervious Urban Area (assumed 50% of total urban			0.00	0.00	0.00	1.00	0.00	0.00	0.87	0.00	0.00	0.00	0.00	25.34
Sand/Gravel/Rock Pits			0.00	0.00	0.00	0.00	0.00	0.00	44.23	8.77	0.00	0.00	0.00	0.00
Total Others Areas (ha)			**0.00**	**16.66**	**12.84**	**4.72**	**4.78**	**21.37**	**49.61**	**17.58**	**0.00**	**0.34**	**0.00**	**25.34**
Total Pervious Area (ha)			**246.56**	**2326.24**	**2383.89**	**1431.78**	**836.51**	**1178.78**	**927.06**	**949.21**	**385.56**	**532.47**	**436.38**	**1919.67**
Total Area (ha)			**246.56**	**2342.90**	**2396.73**	**1436.50**	**841.30**	**1200.16**	**976.66**	**966.79**	**385.56**	**532.81**	**436.38**	**1945.02**
Weighted WHC (mm) (pervious area)			**127.09**	**162.85**	**158.55**	**143.33**	**177.01**	**196.70**	**139.41**	**160.18**	**170.24**	**146.80**	**177.28**	**159.94**
Actual Evapotranspiration (mm)			112.80	122.24	121.27	117.47	125.13	128.35	116.40	121.64	123.81	118.38	125.18	121.59

Soil Type	HSG	WHC (mm)	Catchment 312 (ha)	Catchment 313 (ha)	Catchment 314 (ha)	Catchment 315 (ha)	Catchment 316 (ha)	Catchment 317 (ha)	Catchment 318 (ha)	Catchment 319 (ha)	Catchment 320 (ha)	Catchment 321 (ha)	Catchment 322 (ha)	Catchment 323 (ha)	Total Watershed (ha)
Urban Lawns/Shallow Rooted Crops (spinach, beans															
Fine Sand	A	50	22.39	0.00	4.60	10.61	4.14	0.00	0.00	0.00	0.00	0.00	50.08	417.91	1086.70
	AB	63	46.18	56.66	7.23	3.00	0.00	4.89	1.55	2.29	49.56	6.96	223.01	438.56	2961.71
Fine Sandy Loam	B	75	38.63	97.69	40.24	137.49	119.47	152.53	0.42	24.83	51.71	29.49	66.07	12.90	2873.15
	BC	100	4.11	120.19	0.00	0.00	0.00	0.00	0.79	21.92	20.38	3.38	0.00	0.00	236.26
Silt Loam, Muck	C	125	102.26	65.41	36.77	315.35	630.37	128.18	7.22	77.92	372.52	18.28	93.46	0.00	3769.21
Clay Loam	CD	100	0.00	0.00	7.32	47.43	130.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	805.99
Clay	D	75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Moderately Rooted Crops (corn and cereal grains)															
Fine Sand	A	75	89.56	0.00	75.92	32.39	2.76	0.00	0.00	0.00	0.00	0.00	50.08	278.60	1530.01
	AB	113	304.73	132.22	65.11	7.00	0.00	14.66	23.72	9.16	217.72	27.85	223.01	292.37	7105.98
Fine Sandy Loam	B	150	154.50	225.58	362.17	320.81	79.64	428.13	3.74	99.34	155.14	116.44	66.07	7.18	5381.33
	BC	175	16.44	280.44	0.00	0.00	0.00	0.00	7.07	87.67	61.13	13.50	0.00	0.00	726.21
Silt Loam,Muck	C	200	409.04	152.62	330.89	735.81	419.45	355.09	65.00	308.61	1117.55	73.14	93.16	0.00	8351.09
Clay Loam	CD	200	0.00	0.00	65.85	110.66	86.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1356.90
Clay	D	150	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Pasture and Shrubs															
Fine Sand	A	100	10.23	0.00	21.25	5.73	0.71	0.00	0.00	0.00	0.00	0.00	6.97	11.30	237.34
	AB	125	25.86	9.25	5.39	1.50	0.00	0.24	0.00	0.35	20.17	3.77	31.74	16.07	3000.11
Fine Sandy Loam	B	150	13.67	30.73	21.74	11.19	19.05	26.80	0.46	18.30	34.13	8.02	1.34	0.16	931.72
	BC	200	0.75	22.89	0.00	0.00	0.00	0.00	0.33	1.06	2.33	0.65	0.00	0.00	91.40
Silt Loam, Muck	C	250	62.48	23.74	18.47	9.05	41.91	18.48	1.16	20.35	59.64	7.79	6.97	0.00	786.61
Clay Loam	CD	250	0.00	0.00	4.55	0.67	36.33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	217.97
Clay	D	200	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mature Forests															
Fine Sand	A	250	2.56	0.00	24.39	0.00	0.10	0.00	0.00	0.00	0.00	0.00	3.21	2.91	353.37
	AB	275	28.57	2.16	1.87	0.00	0.00	5.31	0.00	0.05	17.79	0.79	18.66	55.29	3511.09
Fine Sandy Loam	B	300	3.64	26.80	18.66	23.32	17.98	80.68	0.00	18.98	56.14	2.09	0.97	0.00	1225.00
	BC	350	1.44	66.52	0.00	0.00	0.00	0.00	0.61	4.50	16.90	0.67	0.00	0.00	158.36
Silt Loam, Muck	C	400	31.42	116.92	15.46	10.77	52.50	25.33	3.19	5.55	46.24	42.93	0.54	0.00	1859.94
Clay Loam	CD	400	0.00	0.00	1.11	12.52	21.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	190.98
Clay	D	350	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Swamp/Fen/Marsh			0.77	0.44	0.00	10.26	0.00	0.00	0.00	0.00	1.43	0.00	0.00	0.00	82.60
Open Water			3.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	34.76
Impervious Urban Area (assumed 50% of total urban			29.37	0.00	3.69	4.37	0.00	0.00	0.00	0.00	6.82	0.00	0.00	0.00	245.52
Sand/Gravel/Rock Pits			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	114.45
Total Others Areas (ha)			**33.41**	**0.44**	**3.69**	**14.63**	**0.00**	**0.00**	**0.00**	**0.00**	**8.25**	**0.00**	**0.00**	**0.00**	**477.32**
Total Pervious Area (ha)			**1368.45**	**1429.81**	**1128.99**	**1795.29**	**1662.13**	**1240.31**	**115.25**	**700.88**	**2299.05**	**355.75**	**935.31**	**1533.25**	**48748.43**
Total Area (ha)			**1401.86**	**1430.25**	**1132.68**	**1809.91**	**1662.13**	**1240.31**	**115.25**	**700.88**	**2307.30**	**355.75**	**935.31**	**1533.25**	**49225.75**
Weighted WHC (mm) (pervious area)			**156.28**	**177.95**	**165.11**	**165.44**	**163.44**	**168.61**	**177.90**	**177.68**	**176.96**	**182.37**	**110.91**	**80.61**	**162.68**
Actual Evapotranspiration (mm)			120.74	125.31	122.73	122.80	122.37	123.47	125.30	125.26	125.12	126.10	107.52	95.94	122.20

TABLE E.2 - MONTHLY ACTUAL EVAPOTRANSPIRATION (mm)

MONTH	Catchment 200	Catchment 201	Catchment 202	Catchment 203	Catchment 204	Catchment 205	Catchment 206	Catchment 207	Catchment 208	Catchment 209	Catchment 210	Catchment 211	Catchment 212	Catchment 213	Catchment 214	Catchment 1/2 215	Subtotals to WSC Gauge
JANUARY	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
FEBRUARY	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
MARCH	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
APRIL	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	33.7	34.0	34.0
MAY	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	78.7	79.5	80.0
JUN	112.0	112.0	112.0	112.0	112.0	112.0	112.1	112.0	112.0	112.0	112.0	112.0	112.0	112.0	106.4	112.8	112.0
JULY	119.5	122.2	121.7	124.2	124.1	126.4	118.8	122.9	122.8	120.1	123.9	123.1	127.2	126.1	97.4	112.8	123.4
AUGUST	95.3	96.1	95.9	96.7	96.6	97.4	95.1	96.2	96.2	95.4	96.6	96.3	97.7	97.3	89.2	93.4	96.4
SEPTEMBER	71.1	71.6	71.5	72.0	72.0	72.5	71.0	71.8	71.7	71.2	72.0	71.8	72.7	72.4	71.0	71.0	71.9
OCTOBER	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	38.7	39.0	39.0
NOVEMBER	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
DECEMBER	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

MONTH	Catchment 215	Catchment 300	Catchment 302	Catchment 303	Catchment 304	Catchment 305	Catchment 306	Catchment 307	Catchment 308	Catchment 309	Catchment 310	Catchment 311	Catchment 312	Catchment 313	Catchment 314	Catchment 315	Catchment 316
JANUARY	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
FEBRUARY	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
MARCH	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
APRIL	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0	34.0
MAY	79.5	80.0	80.0	79.9	80.0	80.0	79.8	80.0	80.0	79.9	80.0	80.0	80.0	80.0	80.0	80.0	80.0
JUN	112.8	112.0	112.0	112.5	112.0	112.0	112.7	112.0	112.0	112.3	112.0	112.0	112.0	112.0	112.0	112.0	112.0
JULY	112.8	122.2	121.3	117.5	125.1	128.4	116.4	121.6	123.8	118.4	125.2	121.6	120.7	125.3	122.7	122.8	122.4
AUGUST	93.4	96.1	95.8	94.7	97.0	98.1	94.4	95.9	96.5	95.0	97.0	95.9	95.6	97.0	96.2	96.2	96.1
SEPTEMBER	71.0	71.6	71.5	71.0	72.2	73.0	71.0	71.5	72.0	71.0	72.2	71.5	71.4	72.3	71.7	71.8	71.7
OCTOBER	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0	39.0
NOVEMBER	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
DECEMBER	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

MONTH	Catchment 317	Catchment 318	Catchment 319	Catchment 320	Catchment 321	Catchment 322	Catchment 323	Total Watershed
JANUARY	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
FEBRUARY	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
MARCH	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
APRIL	34.0	34.0	34.0	34.0	34.0	34.0	33.6	34.0
MAY	80.0	80.0	80.0	80.0	80.0	79.2	78.6	80.0
JUN	112.0	112.0	112.0	112.0	112.0	111.6	105.5	112.0
JULY	123.5	125.3	125.3	125.1	126.1	107.5	95.9	122.2
AUGUST	96.4	97.0	97.0	97.0	97.3	92.0	88.8	96.1
SEPTEMBER	71.9	72.3	72.3	72.2	72.4	71.0	71.0	71.6
OCTOBER	39.0	39.0	39.0	39.0	39.0	39.0	38.6	39.0
NOVEMBER	13.0	13.0	13.0	13.0	13.0	13.0	13.0	13.0
DECEMBER	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0

TABLE E.3 - MONTHLY SURPLUS (mm)

MONTH	Catchment 200	Catchment 201	Catchment 202	Catchment 203	Catchment 204	Catchment 205	Catchment 206	Catchment 207	Catchment 208	Catchment 209	Catchment 210	Catchment 211	Catchment 212	Catchment 213	Catchment 214	Catchment 1/2 215	Subtotals to WSC Gauge
JANUARY	24.4	23.8	23.9	23.3	23.4	22.8	24.6	23.7	23.7	24.3	23.4	23.6	22.6	22.9	30.2	26.0	23.5
FEBRUARY	38.7	37.4	37.7	36.5	36.5	35.3	39.0	37.1	37.2	38.4	36.6	37.0	34.9	35.5	44.0	41.4	36.9
MARCH	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0
APRIL	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0
MAY	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
JUN	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
JULY	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.3	1.0	1.0
AUGUST	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SEPTEMBER	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	5.3	4.0	4.0
OCTOBER	3.0	3.0	3.0	3.0	3.0	3.0	3.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	7.4	4.0	3.0
NOVEMBER	25.7	24.6	24.8	23.7	23.8	22.8	26.0	24.3	24.4	25.5	23.9	24.2	22.5	23.0	36.7	28.6	24.1
DECEMBER	29.4	28.8	28.9	28.3	28.3	27.7	29.6	28.6	28.6	29.3	28.4	28.5	27.5	27.8	35.0	31.0	28.5

MONTH	Catchment 215	Catchment 300	Catchment 302	Catchment 303	Catchment 304	Catchment 305	Catchment 306	Catchment 307	Catchment 308	Catchment 309	Catchment 310	Catchment 311	Catchment 312	Catchment 313	Catchment 314	Catchment 315	Catchment 316
JANUARY	26.0	23.8	24.0	24.9	23.1	22.2	25.2	23.9	23.4	24.7	23.1	24.0	24.2	23.1	23.7	23.7	23.8
FEBRUARY	41.4	37.4	37.9	39.5	36.0	34.1	40.0	37.7	36.7	39.2	36.0	37.7	38.1	35.9	37.2	37.2	37.4
MARCH	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0
APRIL	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0
MAY	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
JUN	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
JULY	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
AUGUST	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SEPTEMBER	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
OCTOBER	4.0	3.0	3.0	3.3	3.0	3.0	3.5	3.0	3.0	3.2	3.0	3.0	3.0	3.0	3.0	3.0	3.0
NOVEMBER	28.6	24.6	25.0	26.6	23.4	21.9	27.0	24.8	23.9	26.2	23.3	24.8	25.2	23.3	24.4	24.3	24.5
DECEMBER	31.0	28.8	29.0	29.9	28.0	27.2	30.1	28.9	28.4	29.7	28.0	28.9	29.1	28.0	28.6	28.6	28.7

MONTH	Catchment 317	Catchment 318	Catchment 319	Catchment 320	Catchment 321	Catchment 322	Catchment 323	Total Watershed
JANUARY	23.5	23.1	23.1	23.1	22.8	27.4	30.7	23.8
FEBRUARY	36.8	35.9	35.9	36.0	35.5	43.4	44.0	37.4
MARCH	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0
APRIL	38.0	38.0	38.0	38.0	38.0	38.0	38.0	38.0
MAY	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
JUN	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0
JULY	1.0	1.0	1.0	1.0	1.0	1.0	1.4	1.0
AUGUST	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SEPTEMBER	4.0	4.0	4.0	4.0	4.0	4.0	5.6	4.0
OCTOBER	3.0	3.0	3.0	3.0	3.0	4.9	7.9	3.0
NOVEMBER	24.1	23.3	23.3	23.4	22.9	31.0	37.6	24.6
DECEMBER	28.5	28.0	28.0	28.0	27.8	32.3	35.5	28.8

In accordance with the MOE-approved water balance techniques, monthly infiltration factors were then calculated and monthly surplus quantities were split into runoff and infiltration components. The monthly infiltration factor is a function of topography, soil texture and soil cover, as shown in **Table E.4**, and was evaluated using the NVCA GIS shapefiles. Infiltration quantities were further separated into baseflow and deep groundwater storage components based on a calibration procedure using historical flow data (Environment Canada's HYDAT).

Once the model was adjusted to simulate existing water balance conditions for land uses and soils, monthly water extractions by PTTW from the deep groundwater storage and surface water were added to the water balance calculations, based on PTTW database provided by NVCA. The approach used is illustrated in **Figure E.1**.

Maximum permissible extractions from surface waters were limited by an "environmental" or "threshold" flow rate, which is the minimum in-stream flow required to maintain healthy aquatic life. The in-stream flow was calculated using the Tennant Method. Using the Tennant Method, streamflow requirements are based on the observation that aquatic habitat conditions are similar in streams carrying the same proportion of the mean annual flow (MAF). The MAF was calculated using the historical flow data for the Bailey Station (Environment Canada's HYDAT) and transposed to represent the discharges from the entire watershed using methodology presented in the *Drainage Management Manual* (MTO, 1997). During the summer months in which extractions by PTTW take place (April-September), a minimum in-stream flow requirement of 30 percent of the daily MAF was applied, as recommended by the Tennant Method to provide a "fair" habitat condition. Extractions from surface waters were also limited to the baseflow component of the monthly streamflow (i.e. irrigation is typically required during baseflow conditions and not often during runoff conditions), which was estimated in the water balance.

Maximum permissible surface extractions were added to the water extractions from deep groundwater storage and computed as additional available input to the system. Since all water derived from extractions is used to irrigate agricultural and recreational (golf courses) land uses, the additional available water was applied to the pervious areas of the watershed, altering the existing rates of Δ soil moisture, evapotranspiration and surplus. Initially, the input of water from PTTW was added to fill the available Δ soil moisture storage up to the limit of the soil Water Holding Capacity (WHC) for each month. Excess additional water was then added to the actual evapotranspiration (AE) until AE was equal to the monthly Potential Evapotranspiration (PE). Any excess after both the soil storage and the evapotranspiration needs have been met was then added to the monthly surplus. Typically, irrigation does not result in much, if any, surplus water.

Results of the monthly water balance analysis are presented in **Table E.5**.

TABLE E.4 MONTHLY INFILTRATION FACTOR

1. INFILTRATION FACTOR FOR LAND COVER		
Shallow Crops		0.1
Pasture		0.15
Woodland		0.2
Month	**Cropping Seasons**	**INFILTR FACTOR**
1	Frozen Soil	0.000
2	Frozen Soil	0.000
3	Frozen Soil	0.000
4	Bare Soil	0.050
5	Planted Soil	0.100
6	Planted Soil	0.100
7	Planted Soil	0.100
8	Planted Soil	0.100
9	Planted Soil	0.100
10	Planted Soil	0.100
11	Planted Soil	0.100
12	Frozen Soil	0.000
Month	**Pasture Seasons**	**INFILTR FACTOR**
1	Frozen Soil	0.000
2	Frozen Soil	0.000
3	Frozen Soil	0.000
4	Pasture	0.150
5	Pasture	0.150
6	Pasture	0.150
7	Pasture	0.150
8	Pasture	0.150
9	Pasture	0.150
10	Pasture	0.150
11	Saturated Soil	0.075
12	Frozen Soil	0.000
Month	**Woodland**	**INFILTR FACTOR**
1	Frozen Soil	0.000
2	Frozen Soil	0.000
3	Frozen Soil	0.000
4	Woodland	0.200
5	Woodland	0.200
6	Woodland	0.200
7	Woodland	0.200
8	Woodland	0.200
9	Woodland	0.200
10	Woodland	0.200
11	Saturated Woo	0.100
12	Frozen Soil	0.000

2. INFILTRATION FACTOR FOR TOPOGRAPHY		
Flat Land		0.3
Rolling Land		0.15
Hilly Land		0.1
Month	**Flat Land**	**INFILTR FACTOR**
1	Frozen Soil	0.000
2	Frozen Soil	0.000
3	Frozen Soil	0.000
4	Unfrozen Soil	0.300
5	Unfrozen Soil	0.300
6	Unfrozen Soil	0.300
7	Unfrozen Soil	0.300
8	Unfrozen Soil	0.300
9	Unfrozen Soil	0.300
10	Unfrozen Soil	0.300
11	Unfrozen Soil	0.300
12	Frozen Soil	0.000
Month	**Rolling Land**	**INFILTR FACTOR**
1	Frozen Soil	0.000
2	Frozen Soil	0.150
3	Frozen Soil	0.000
4	Unfrozen Soil	0.150
5	Unfrozen Soil	0.150
6	Unfrozen Soil	0.150
7	Unfrozen Soil	0.150
8	Unfrozen Soil	0.150
9	Unfrozen Soil	0.150
10	Unfrozen Soil	0.150
11	Unfrozen Soil	0.150
12	Frozen Soil	0.000
Month	**Hilly Land**	**INFILTR FACTOR**
1	Frozen Soil	0.000
2	Frozen Soil	0.000
3	Frozen Soil	0.000
4	Unfrozen Soil	0.100
5	Unfrozen Soil	0.100
6	Unfrozen Soil	0.100
7	Unfrozen Soil	0.100
8	Unfrozen Soil	0.100
9	Unfrozen Soil	0.100
10	Unfrozen Soil	0.100
11	Unfrozen Soil	0.100
12	Frozen Soil	0.000

*****"Infiltration RationxAvailable Storage- Estimating Areal Snowmelt Infiltration into Frozen Soils, pp15"

3. INFILTRATION FACTOR FOR SOIL TYPE								
WHC =	162.68	SOIL HSG** / INFILTRATION FACTOR						
MONTH	MAXIMUM SOIL STORAGE*	A*** open sandy loam	AB	B	BC	C	CD medium clay and loam	D*** tight impervious clay
1	156	0.025	0.021	0.016	0.012	0.008	0.004	0.004
2	160	0.008	0.007	0.005	0.004	0.002	0.001	0.001
3	160	0.011	0.009	0.007	0.005	0.003	0.002	0.002
4	158	0.015	0.013	0.010	0.007	0.005	0.002	0.002
5	140	0.080	0.066	0.051	0.038	0.024	0.012	0.011
6	104	0.209	0.172	0.134	0.098	0.062	0.031	0.030
7	60	0.368	0.302	0.236	0.173	0.110	0.054	0.053
8	51	**0.400**	0.329	0.257	0.188	0.120	0.059	**0.057**
9	64	0.355	0.292	0.228	0.167	0.106	0.053	0.051
10	95	0.244	0.200	0.157	0.115	0.073	0.036	0.035
11	133	0.108	0.088	0.069	0.051	0.032	0.016	0.015
12	147	0.056	0.046	0.036	0.026	0.017	0.008	0.008
Shallow Crops (1)		276	252	228	205	182	164	145
Pasture (2)		307	284	261	239	217	197	179
Woodland (3)		315	294.5	274	254	234	215	196
Average Infiltration** (Avr 1,2,3)		299	277	254	233	211	192	173
Variation of Inflitration vs. HSG		7.000	5.750	4.500	3.296	2.093	1.037	1.000

TABLE E.5 MONTHLY WATER BALANCE QUANTITIES FOR INNISFIL CREEK SUBWATERSHED

	JANUARY		
Water Balance Component	Depth (mm)	Volume (m3)	Percent (%)
Inputs			
Rainfall	18	8,860,635	49.94
Snowmelt	18	8,860,635	49.94
[1]PTTW (Surface & Groundwater)	0.04	19,613	0.11
TOTAL	**36.04**		**100**
Outputs			
Actual ET	1.04	509,857	33.73
Soil Moisture	11.12	5,473,721	
Runoff	23.50	11,566,094	65.19
DGWS	0.14	68,656	0.39
Baseflow - PTTW	0.25	122,556	0.69
[2]Permissible PTTW (Surface Extraction)	0.00	0	0.00
TOTAL	**36.04**		**100**

	FEBRUARY		
Water Balance Component	Depth (mm)	Volume (m3)	Percent (%)
Inputs			
Rainfall	17	8,368,378	36.92
Snowmelt	29	14,275,468	62.99
[1]PTTW (Surface & Groundwater)	0.04	19,615	0.09
TOTAL	**46.04**		**100**
Outputs			
Actual ET	2.04	1,004,404	18.62
Soil Moisture	6.53	3,215,203	
Runoff	34.81	17,136,606	75.61
DGWS	0.96	474,576	2.09
Baseflow - PTTW	1.69	832,672	3.68
[2]Permissible PTTW (Surface Extraction)	0.00	216	0.00
TOTAL	**46.04**		**100**

	MARCH		
Water Balance Component	**Depth (mm)**	**Volume (m3)**	**Percent (%)**
Inputs			
Rainfall	34	16,736,755	45.22
Snowmelt	41	20,182,558	54.53
[1]PTTW (Surface & Groundwater)	0.19	19,692	0.05
TOTAL	**75.19**		**100**
Outputs			
Actual ET	9.02	4,442,086	10.94
Soil Moisture	-0.80	-392,898	
Runoff	66.47	32,722,366	88.41
DGWS	0.18	86,266	0.23
Baseflow - PTTW	0.16	81,110	0.22
[2]Permissible PTTW (Surface Extraction)	0.15	74,974	0.20
TOTAL	**75.19**		**100**

	APRIL		
Water Balance Component	**Depth (mm)**	**Volume (m3)**	**Percent (%)**
Inputs			
Rainfall	62	30,519,965	87.95
Snowmelt	8	3,938,060	11.35
[1]PTTW (Surface & Groundwater)	0.50	244,922	0.71
TOTAL	**70.50**		**100**
Outputs			
Actual ET	33.84	16,655,589	45.89
Soil Moisture	-1.48	-730,046	
Runoff	32.70	16,096,196	46.38
DGWS	1.98	973,835	2.81
Baseflow - PTTW	3.01	1,482,068	4.30
[2]Permissible PTTW (Surface Extraction)	0.46	225,310	0.65
TOTAL	**70.50**		**100**

	MAY		
Water Balance Component	**Depth (mm)**	**Volume (m3)**	**Percent (%)**
Inputs			
Rainfall	74	36,427,055	98.64
Snowmelt	0	0	0.00
[1]PTTW (Surface & Groundwater)	1.03	503,643	1.36
TOTAL	**75.03**		**100**
Outputs			
Actual ET	79.49	39,129,165	83.56
Soil Moisture	-16.79	-8,271,075	
Runoff	10.05	4,949,239	13.40
DGWS	0.83	406,873	1.10
Baseflow - PTTW	0.54	263,888	0.72
[2]Permissible PTTW (Surface Extraction)	0.92	452,611	1.24
TOTAL	**75.03**		**100**

	JUNE		
Water Balance Component	**Depth (mm)**	**Volume (m3)**	**Percent (%)**
Inputs			
Rainfall	83	40,857,373	98.63
Snowmelt	0	0	0.00
[1]PTTW (Surface & Groundwater)	1.17	568,206	1.37
TOTAL	**84.17**		**100**
Outputs			
Actual ET	111.21	54,744,525	92.34
Soil Moisture	-33.50	-16,493,744	
Runoff	4.81	2,366,540	5.71
DGWS	0.59	291,982	0.70
Baseflow - PTTW	0.50	244,360	0.60
[2]Permissible PTTW (Surface Extraction)	0.55	271,919	0.67
TOTAL	**84.17**		**100**

JULY			
Water Balance Component	Depth (mm)	Volume (m3)	Percent (%)
Inputs			
Rainfall	80	39,380,600	98.87
Snowmelt	0	0	0.00
[1]PTTW (Surface & Groundwater)	0.93	451,709	1.13
TOTAL	**80.93**		**100**
Outputs			
Actual ET	121.30	59,713,019	98.17
Soil Moisture	-41.86	-20,609,054	
Runoff	1.06	520,359	1.31
DGWS	0.15	73,635	0.18
Baseflow - PTTW	0.27	134,354	0.34
[2]Permissible PTTW (Surface Extraction)	0.00	0	0.00
TOTAL	**80.93**		**100**

AUGUST			
Water Balance Component	Depth (mm)	Volume (m3)	Percent (%)
Inputs			
Rainfall	95	46,764,463	99.39
Snowmelt	0	0	0.00
[1]PTTW (Surface & Groundwater)	0.59	289,094	0.61
TOTAL	**95.59**		**100**
Outputs			
Actual ET	95.46	46,992,147	99.39
Soil Moisture	-0.45	-224,612	
Runoff	0.50	247,971	0.53
DGWS	0.02	11,416	0.02
Baseflow - PTTW	0.05	26,638	0.06
[2]Permissible PTTW (Surface Extraction)	0.00	0	0.00
TOTAL	**95.59**		**100**

	SEPTEMBER		
Water Balance Component	**Depth (mm)**	**Volume (m3)**	**Percent (%)**
Inputs			
Rainfall	88	43,318,660	99.67
Snowmelt	0	0	0.00
[1]PTTW (Surface & Groundwater)	0.29	142,432	0.33
TOTAL	**88.29**		**100**
Outputs			
Actual ET	71.24	35,067,320	94.88
Soil Moisture	12.53	6,167,152	
Runoff	3.05	1,502,297	3.46
DGWS	0.53	261,312	0.60
Baseflow - PTTW	0.94	463,014	1.07
[2]Permissible PTTW (Surface Extraction)	0.00	0	0.00
TOTAL	**88.29**		**100**

	OCTOBER		
Water Balance Component	**Depth (mm)**	**Volume (m3)**	**Percent (%)**
Inputs			
Rainfall	72	35,442,540	99.94
Snowmelt	0	0	0.00
[1]PTTW (Surface & Groundwater)	0.04	19,613	0.06
TOTAL	**72.04**		**100**
Outputs			
Actual ET	38.80	19,100,056	95.16
Soil Moisture	29.75	14,644,142	
Runoff	2.58	1,270,542	3.58
DGWS	0.33	160,962	0.45
Baseflow - PTTW	0.58	286,455	0.81
[2]Permissible PTTW (Surface Extraction)	0.00	0	0.00
TOTAL	**72.04**		**100**

	NOVEMBER		
Water Balance Component	**Depth (mm)**	**Volume (m3)**	**Percent (%)**
Inputs			
Rainfall	66	32,488,995	89.14
Snowmelt	8	3,938,060	10.80
[1]PTTW (Surface & Groundwater)	0.04	20,909	0.06
TOTAL	**74.04**		**100**
Outputs			
Actual ET	12.99	6,396,129	66.30
Soil Moisture	36.10	17,769,443	
Runoff	20.17	9,927,180	27.24
DGWS	1.74	855,110	2.35
Baseflow - PTTW	3.04	1,498,810	4.11
[2]Permissible PTTW (Surface Extraction)	0.00	1,296	0.00
TOTAL	**74.04**		**100**

	DECEMBER		
Water Balance Component	**Depth (mm)**	**Volume (m3)**	**Percent (%)**
Inputs			
Rainfall	27	13,290,953	59.95
Snowmelt	18	8,860,635	39.96
[1]PTTW (Surface & Groundwater)	0.04	19,613	0.09
TOTAL	**45.04**		**100**
Outputs			
Actual ET	3.03	1,492,473	35.92
Soil Moisture	13.15	6,472,187	
Runoff	27.86	13,716,497	61.87
DGWS	0.36	177,164	0.80
Baseflow - PTTW	0.64	312,882	1.41
[2]Permissible PTTW (Surface Extraction)	0.00	0	0.00
TOTAL	**45.04**		**100**

Notes: 1. PTTW (Input) is the water extracted from surface and groundwater and used to irrigate agricultural and recreational land uses.
2. Permissible PTTW (Output) is the water available for extraction from baseflow taking into account a critical minimum flow to be maintained in the stream based on Tennant's Method.

APPENDIX F

Nutrient Budget and Water Quality Modeling

Includes the following:

- Introduction
- Background: Nutrient Management Pilot Project Objectives
- Model Selection
- Model Setup for Pilot Watersheds
- CANWET Model Features and New Components
- Calibration of CANWET for the Innisfil Creek and Black River Basins
- Summary of Model Application Results
- Recommendations and Future CANWET Model Development
- **Literature Cited**
- Calibration Results for Beeton Creek and Black River

APPENDIX F
Nutrient Budget and Water Quality Modeling

1.0 Introduction

Resource management agencies need to comprehend the complex inter-relationship between environmental health, the local economy, and social conditions. The application of computer models combined with monitoring results has been widely accepted as the standard tool used by resource managers to predict the change in water quality associated with human activities and altered landscapes.

The **C**anadian **A**rcView **N**utrient and **W**ater **E**valuation **T**ool (CANWET Version 1.0) was developed in 2004 by Greenland International Consulting as a new source protection tool to accurately estimate surface water budgets and nutrient loadings within a watershed or subwatershed. Some features of **CANWET** include the development of a spatial dataset for pilot basins in Southern Ontario; customization of Best Management Practice (BMP) costs and efficiencies for Ontario conditions; integration of surface water quality algorithms with a daily water balance model; and, Microsoft graphical user interface. The water balance module utilizes Environment Canada's climate station records; accounts for depression storage in hummocky terrains (including the Oak Ridges Moraine in Ontario) and agricultural tile-drainage flow; and, imports surface and groundwater extractions records, including Permit To Take Water (PTTW) databases for Ontario.

With nutrient loading, erosion sediment, water balance and BMP evaluation modules fully coupled within ArcView GIS, CANWET incorporates practical and efficient spatially-distributed parameterization capabilities with defendable process-based algorithms for modeling surface waters systems. CANWET also includes predictive modeling capabilities for evaluating the implementation of both agricultural and urban pollution reduction strategies. This functionality was incorporated to reflect current Canadian practices and associated nutrient and sediment load reductions.

CANWET is a modified version of the ArcView Generalized Watershed Loading Function (AVGWLF) model developed by Evans et al (2003) at Penn State University. AVGWLF is based on the original Haith and Shoemaker (1987) GWLF model developed at Cornell University and was selected for the project. The model was adapted by Greenland for Southern Ontario conditions by increasing the functionality of the water balance and other components by adding a more comprehensive set of algorithms.

New GIS data layers were initially developed for three (3) pilot basins. This included the Innisfil Creek Subwatershed. The modeling package features a predictive modeling component for evaluating the implementation of both agricultural and non-agricultural pollution reduction strategies at the sub-watershed level. This tool was upgraded to reflect practices in Ontario and associated nutrient and sediment load reductions.

These sections provide an update up to and including the final stages of the CANWET project and nutrient budget/water quality modelling results for the Innisfil Creek Subwatershed Study by the NVCA. Calibrated model data for a nearby basin (i.e. Black River in the Lake Simcoe Basin) is also provided for discussion.

2.0 Background: Nutrient Management Pilot Project Objectives

To address source protection and nutrient management issues a steering committee was formed with representation from the Ontario Ministry of the Environment, Ontario Ministry of Agriculture and Food, Ontario Ministry of Natural Resources, Conservation Ontario, Lake Simcoe Region Conservation Authority (LSRCA), Nottawasaga Valley Conservation Authority, Kawartha Region Conservation Authority, Environment Canada, Department of Fisheries and Oceans, Trent University, Regional Municipality of York, Simcoe County and Greenland International Consulting (Greenland). The LSRCA was given the role of project administrator. Greenland was contracted to manage and complete the 2-year project (2003-2004).

The project built on source water protection and watershed management capacity within each of the Conservation Authorities by providing the tools and knowledge transfer needed to initiate sub-watershed scale nutrient management plans. Members of the Steering Committee identified the following as the top four (4) priority capabilities for the resulting nutrient management model. The software should assist the user to:

- Identify priority areas for restoration and remediation efforts;
- Calculate nutrient loading from rural areas within a subwatershed to the receiving waters;
- Evaluate the effectiveness of various non-structural, alternative, rural land management practices within the sub-watershed; and,
- Evaluate the impacts of future development and/or land use scenarios with respect to loading of nutrients to receiving waters

The current version of CANWET (1.0) CD was developed for datasets of the basins shown on **Figure 2.1**.

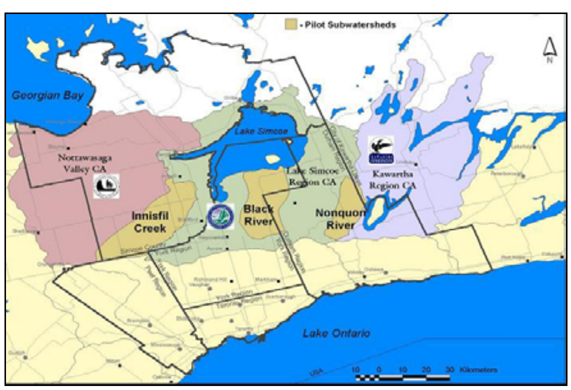

Figure 2.1: Location of the Innisfil Creek Subwatershed in Relation to CANWET Project

3.0 Model Selection

The initial evaluation of the modeling options near the start of the pilot project was based on a combination of professional judgment and input from members of the Steering Committee. From a list of nearly fifty (50) hydrologic and water quality models, 28 models were selected for further assessment on their general characteristics, modeling capabilities and qualifying factors. A short list was carefully selected by applying a set of baseline, essential criteria that eliminated the majority of those models in the original list.

To choose a single model that would meet the needs of the largest number of users, members of the Steering Committee where asked to provide input by filling out a survey form which was designed to determine the anticipated use and desired benefits to be derived from application of the selected model.
In addition to the more general information collected by the survey, respondents were asked to rate a list of proposed selection criteria according to their perceived importance of each item for their intended application. This list was developed through consultation within the project team, input from the Steering Committee and review of criteria used in the selection process by other documented projects with similar objectives.

The information collected in this survey was analyzed and used to rank short listed model candidates.

4.0 Model Setup for Pilot Watersheds

Probably the most time consuming and technically demanding aspect of the nutrient budget and water quality pilot project involved the collection and processing of GIS data layers required as input to run the model. These procedures are summarized in the following sections.

4.1 Development of GIS Data Layers

All available data for the Nonquon River, Innisfil Creek and Black River pilot subwatersheds were collected from various sources. This data was subsequently used to develop the necessary GIS data layers required to run CANWET. Once GIS data layers, in raster grid or shape files, were generated, the data was converted into a format usable by the model with the corresponding database attribute fields. Greenland's scope of work was expanded to include much of the associated GIS layer development in order to keep within the project schedule.

Figures 4.1 through 4.3 on the next pages show sample GIS input images for the CANWET model of the Innisfil Creek Subwatershed. The basin shown to the right (west) is the Black River Subwatershed.

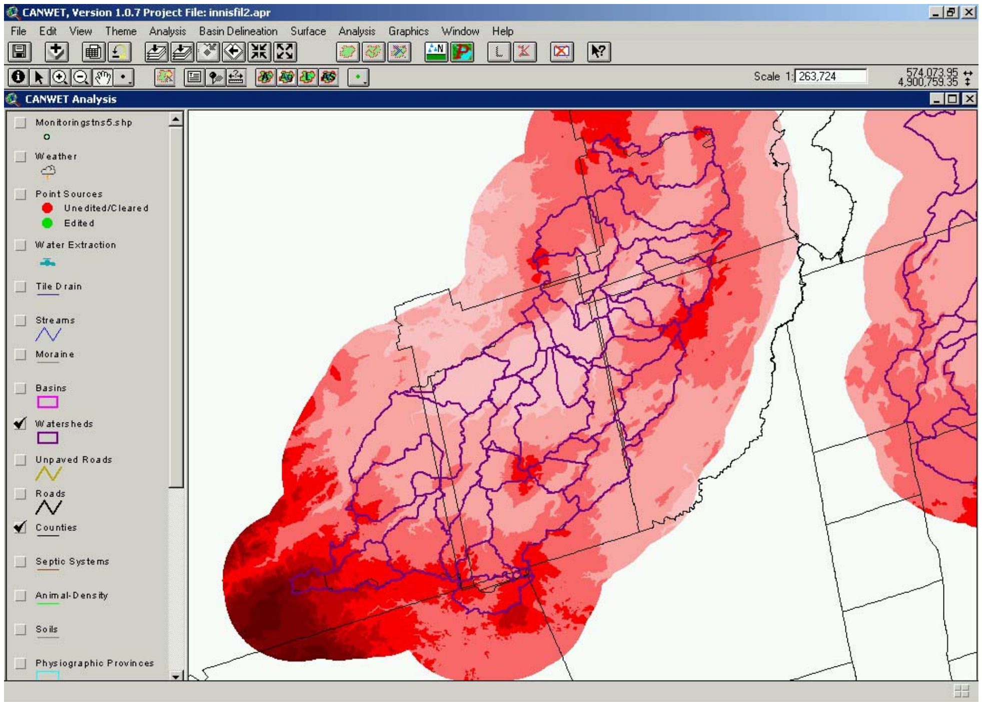

Figure 4.1: Innisfil Creek Sub-catchments and Digital Elevation Topography

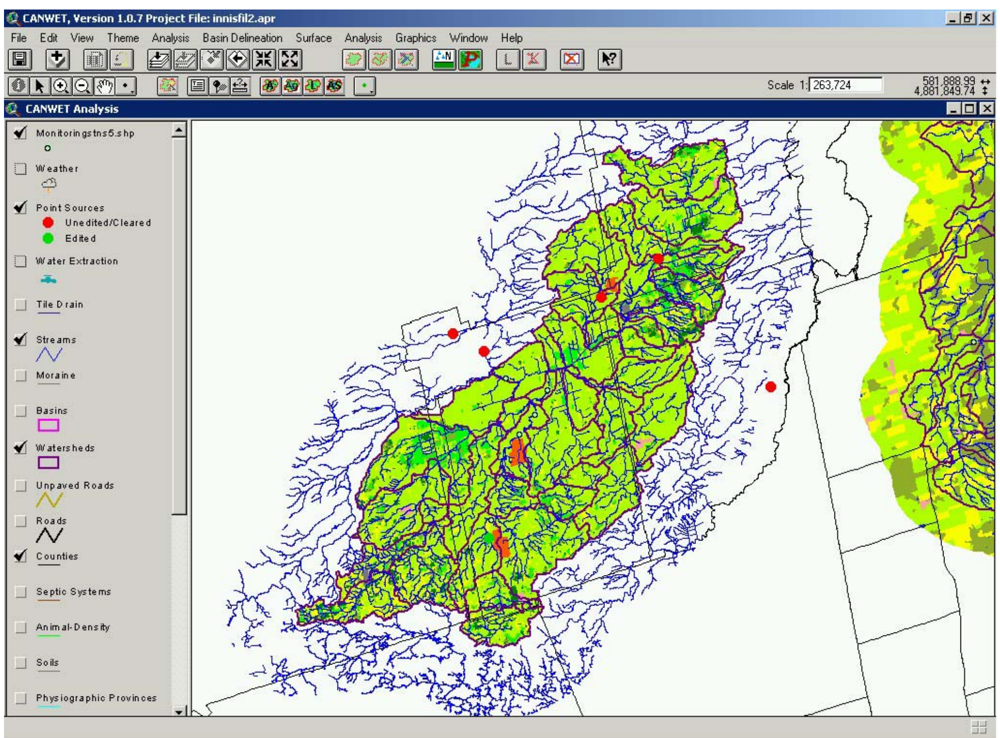

Figure 4.2: Land Use, Watercourses, Settlement Areas and Point Sources (i.e. Wastewater Treatment Plants)

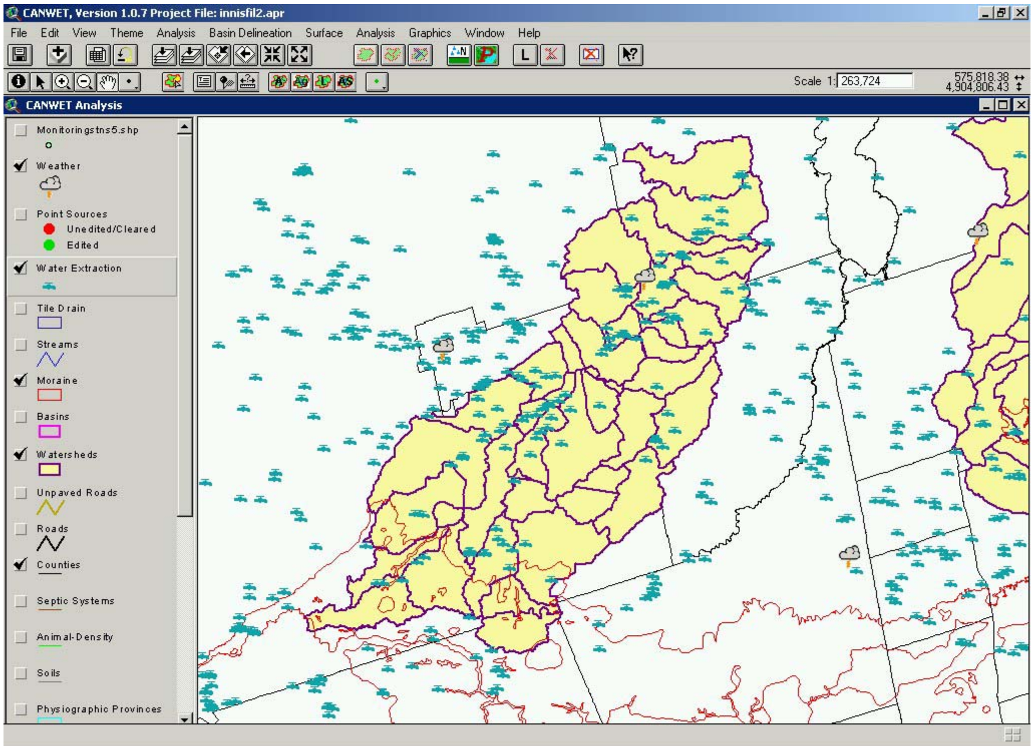

Figure 4.3: Location of Oak Ridges Moraine, Climate Stations and Permit To Take Water Users

It is important that the GIS data layers are continually updated as new information becomes available in order to maintain a reliable representation of the Innisfil Creek Subwatershed. Although every effort was made to provide complete data sets for each pilot basin, there are some known data gaps for which information was not available by the time the CANWET software was finalized for release. For example, some portions of the pilot study areas are missing tile drainage and Permit To Take Water coverage. We understand that projects proposed next year by the Province of Ontario for the same pilot basins would assist in compiling the remaining data layers.

4.2 Determination of Model Parameter Values

There are three (3) aspects to running CANWET.

In the first stage the model extracts spatial information from the GIS data layers and compiles spatially weighted parameter values associated with different land uses for a selected sub-catchment. Once these values have been estimated based on this compilation, the user has the option to modify these values if better information is available. Editing of these values takes place within the transport and nutrient input files. The software provides an interface for viewing and working with the nutrient and transport input files. Within these windows the user also provides information on parameters that cannot be derived from the GIS. Default values for these parameters are provided.

5.0 CANWET Model Features and New Components

The adaptation of AVGWLF to CANWET for use in Canada has involved a variety of updates and modifications to customize the model to account for features of the Southern Ontario landscape that impact water balance and nutrient and sediment transport. The model has also been adjusted to work in metric units. This will better accommodate users in Canada and facilitate the use of Environment Canada meteorological data in metric units.

A hybrid water balance was implemented by Greenland that accounts for water taking from both surface and groundwater sources. Inclusion of water extractions in the water balance routine required a shape file or geo-referenced database indicating the locations of all water permits and associated monthly water extractions within each catchment. Where enough information was available, a flag in the database classifies each point according to the period of the year during which water is drawn from either surface or groundwater sources. As some discrepancies remain in the level of information available for records in this data set, this consideration is only applicable for complete water taking records.

A point source routine to account for water added to streams via wastewater discharge was implemented in CANWET. This component accounts for monthly variation in concentration and flow from each point source location.

CANWET was also developed to consider infiltration and depression storage characteristics associated with hummocky terrain in the Oak Ridges Moraine headwaters. GIS data from the Ontario Ministry of Natural Resources (MNR) was obtained and added to the data layers. This spatial information determines the locations were the hummocky terrain algorithm is applied in the water balance.

To account for the common use of subsurface tile drainage networks in Southern Ontario agricultural practices, CANWET was outfitted with a routine to account for this drainage infrastructure. A polygon or shape file is required to identify regions were agricultural drainage systems are in use. This data was derived from the OMAFRA Artificial Drainage Systems Maps. During the pilot project, however, the required shape file was only available for the Nonquon River basin as a part of a subwatershed study completed by Greenland. Data was not available for the Innisfil Creek and Black River Subwatersheds.

The Best Management Practice (BMP) assessment tool in CANWET (Version 1.0) is based on the Pollution Reduction Impact Comparison Tool (PRedICT) module in AVGWLF. Enhancements to the urban land BMP Scenario Editor of the PREDICT component were also undertaken by Greenland during the pilot project. These enhancements include wet pond (storm water detention) and other source control BMPs by incorporating available research for Ontario conditions on treatment efficiencies and BMP application costs. Where specific information for Ontario conditions was not available, values from the State of Pennsylvania were assumed.

Water balance output in the CANWET model was also enhanced to provide pie chart visualization of various contributing factors to the overall water balance.

Model documentation was developed specifically for the CANWET model with the pilot watershed study areas. This report by Greenland is available under separate cover.

The CN* approach was adopted for use in CANWET. Runoff curve numbers are empirically derived values used in hydrologic simulation studies that reflect the relative amounts of surface runoff and infiltration occurring at a given location (U.S. Soil Conservation Service, 1986). Values are assigned on the basis of different combinations of soil and land use/cover type. The CN* values, used for Canadian conditions, are converted from standard CN values using tables. Procedures for determining these values are described in the Visual OTTHYMO v2.0 Reference Manual by Greenland International Consulting and Schaeffer & Associates Ltd (2002).

6.0 Calibration of CANWET for the Innisfil Creek and Black River Basins

6.1 General

For initial development purposes, CANWET was used to estimate water balance, sediment loads and nutrient loads for two subwatersheds within the pilot study area. These subwatersheds included the portion of the Black River basin up to the Baldwin in-stream monitoring station, and a portion of the Beeton Creek sub-catchment, located in the uppermost reaches of the Innisfil Creek Subwatershed. Refer to **Figure 6. 1**.

Available in-stream flow and water quality data were used to derive “observed” flows and loads for both drainage areas against which model-simulated results could be compared. In each case, the simulations were performed for the same period in which historical water quality sample data were compiled. Model input files were created using the GIS-based CANWET modeling application that automatically assigns parameter values using the GIS data layers and default values as discussed in preceding sections.

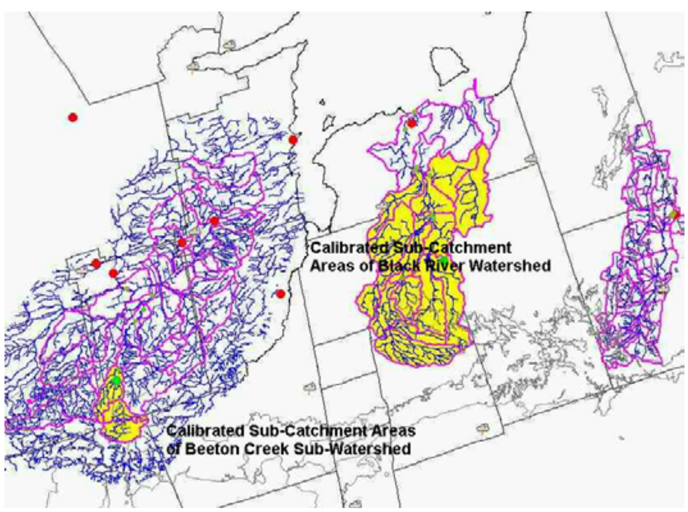

Figure 6.1: Calibrated CANWET Sub-catchments for the Innisfil Creek/Black River Subwatersheds

In recognition of the fact that various CANWET routines were based on original default values and algorithms developed in the State of Pennsylvania (Evans et al., 2002), effort was expended during this calibration exercise to "fine tune" selected default values and algorithms used to better reflect conditions in Ontario. The primary parameters and routines adjusted during this calibration activity included those that affected stream flow, nutrient and sediment loads due to upland erosion, sediment loads from stream bank erosion, and background concentration of nitrogen and phosphorus in groundwater. During the calibration process, an attempt was made to adjust these parameter values (or algorithms used to estimate these values) in a way that would achieve an overall "best fit" between the simulated and observed nutrient loads in the pilot watersheds. The objective was to provide a calibrated model with default parameters and algorithms applicable to all regions of the pilot study watersheds.

In the case of stream flow, adjustments were made to initial evapotranspiration (ET) estimates made by the model to allow for less stream flow during winter months when a good portion of the water in streams and rivers in Ontario is typically frozen. It was also found that the default value for groundwater recession used in the Pennsylvania version of the model that served as the basis for CANWET did not function as well in Canada. In this case, the default value of 0.1 was changed to 0.04 (the range is typically from 0.01 to 1.0).

With respect to upland erosion, calculations in CANWET are based on use of the Universal Soil Loss Equation (USLE), which uses, among other things, estimates of cropping ("C") factors for various land use/cover types. For the calibration exercise, the default C factors in CANWET were adjusted to better align with those reported in various studies for southern Ontario (e.g., Rousseau, 1987).

In CANWET, streambank erosion is estimated using an empirical routine that considers assorted watershed characteristics that affect this type of erosion (e.g., watershed slope, amount of impervious area, inherent soil erodibility, and grazing animal density). Algorithmically, calculations are made via a regression equation tested in Pennsylvania (Evans et al., 2003). Due to higher-than-expected sediment loads first simulated by the "original" version of CANWET, adjustments were made to this equation to provide less sediment from streambank erosion.

Similar to streambank erosion, empirical equations are also used in CANWET to estimate groundwater nitrogen and phosphorus concentrations based on the distribution of land use/cover within a given watershed. Based on an assessment of base flow water quality data in both calibrated sub-catchment areas, these equations were adjusted to provide estimates of both nutrient concentrations lower than those calculated by the uncalibrated version of the model.

Upon making the adjustments described above, the CANWET model was then run in both calibration sub-catchments. The simulated results in both cases were then compared with observed loads derived from existing stream flow and water quality data. The derivation of these observed loads is described below, and an evaluation of the results is provided in a later section.

6.2 Calculation of Historical Nutrient Loads

For the lower portion of the Black River watershed and the Beeton Creek sub-catchments, historical water quality and flow data were compiled for the periods of 1989-1994 and 1997-2000, respectively. These water quality and stream flow data were then used to derive sediment, total nitrogen and total phosphorus loads for each watershed, which could be compared against CANWET simulated loads. The water quality monitoring data were obtained from the Ontario Ministry of the Environment Provincial Water Quality Monitoring Network database and from a field monitoring study carried out by the LSRCA during the summer of 2004 on the Black River system.

To derive continuous, observed sediment and nutrient loads, relatively standard mass balance techniques were used. First, the in-stream sediment and nutrient concentration data and corresponding flow rate data were used to develop load (mass) versus flow relationships for each sub-catchment area for the events for which water quality data were available. Daily stream flow data for the areas and period of interest were then obtained from the Environment Canada HYDAT database, and daily sediment and nutrient loads for each relevant time period were subsequently computed for each watershed using the appropriate load versus flow relationship (i.e., "rating curves") equations. Loads computed in this fashion were used as the "observed" loads against which model-simulated loads were compared. Typical relationships between nitrogen load and daily flow is linear while phosphorus and sediment loads have polynomial relationships to flow. Establishing this relationship is useful because flow data is typically available on a continuous, daily basis whereas nutrient and sediment concentrations are available at a much lower frequency (i.e. monthly sampling events often less frequent in winter). Derived monthly flow and loading rates were calculated in units consistent with those outputs by the CANWET model.

6.3 Discussion and Analysis of Results

CANWET calculates water balance and loads on a daily basis, but provides output on a monthly and annual basis. For the purposes of evaluating the utility of the GIS-based modeling approach for simulating different time periods, statistical analyses were performed using monthly, seasonal and year-to-year modeling results. Plots of observed versus simulated monthly nutrient loads, observed versus simulated seasonal loads, and observed versus simulated yearly loads can be produced after running the model.

To assess the correlation, or "goodness-of-fit", between observed and predicted values, the Nash-Sutcliffe statistical measure recommended by ASCE (1993) for hydrological studies was used. With the Nash-Sutcliffe measure, an R^2 coefficient was calculated using the equation

$$R^2 = 1 - \frac{\sum (Q_o - Q_p)^2}{\sum (Q_o - Q_a)^2}$$

Where: Q_o is the observed value
Q_p is the predicted value
Q_a is the average of the observed values.

Coefficient (R^2) values equal to 1 indicate a perfect fit between observed and predicted data, and R^2 values equal to 0 indicate that the model is predicting no better than using the average of the observed data. (Note: throughout the remainder of this text, the term "N-S" will be used in place of "R^2" to differentiate the Nash-Sutcliffe coefficient from more traditional regression and correlation coefficients). The N-S coefficients for monthly, seasonal and yearly sediment, nitrogen and phosphorus loads calculated for the two test areas are shown in Table 6.1.

From Table 6.1, it can be seen that model accuracy varied by sub-catchment area, constituent and time period, with the Black River test site generally exhibiting better model results. As evidenced by the large number of positive values for the Black River, the CANWET approach was usually much more accurate than just using the mean monthly, mean seasonal or mean annual observed load for this watershed. The results for the annual loads were not as good, although the annual simulated results were actually fairly close to observed results. The lower N-S values in this case can be attributed primarily to the lack of variability in flows and loads in this particular watershed. The results for the Beeton Creek test site were not as good as those for the Black River, although the monthly predictions were fairly reasonable on average. In general, the flows and nutrient loads were under-estimated, and the sediment loads were over-estimated for this headwater basin of the Innisfil Creek Subwatershed. The under-estimation of flows and nutrient loads is likely related to the default manner in which ET values are estimated within the model, which does not account for watershed size in predicting stream flow.

The final model default parameters and algorithms were calibrated for the two (2) sub-catchment areas. As a result some accuracy was sacrificed from both areas used in the calibration process due to the dissimilarity between topographic and land use characteristics found in the two catchment areas.

Table 6.1: Summary of calculated Nash-Sutcliffe coefficients

Parameter	Calculated Nash-Sutcliffe Coefficients	
	Black River	Beeton Creek
Stream Flow (monthly)	0.58	0.01
Stream Flow (seasonal)	0.56	0.07
Stream Flow (annual)	< 0	< 0
Sediment (monthly)	0.31	< 0
Sediment (seasonal)	0.35	< 0
Sediment (annual)	0.12	< 0
Nitrogen (monthly)	0.62	0.30
Nitrogen (seasonal)	0.53	0.14
Nitrogen (annual)	< 0	< 0
Phosphorus (monthly)	0.57	0.41
Phosphorus (seasonal)	0.68	0.42
Phosphorus (annual)	0.84	< 0

6.4 Potential Sources of Modelling Errors

As described earlier, the under-estimation of stream flow for the Beeton Creek test area is likely due to the fact that default algorithms for ET calculations in CANWET do not vary for watersheds of different sizes. The default algorithms appeared to work reasonably well in the Black River basin given the fact that simulated stream flow compared favorably with observed stream flow in this instance. However, it is probably reasonable to assume that very small sub-watersheds located in more steeply sloping areas in the uppermost reaches of larger basins (such as Beeton Creek) contribute larger percentages of rainfall as stream flow than relatively larger watersheds which allow for increased travel times with respect to water flow, and therefore more time for ET. In the case of Beeton Creek, a better estimation of stream flow volumes would have resulted in concurrently higher (and better) estimates of nitrogen and phosphorus loads as well.

It should also be noted that the portion of the Beeton Creek catchment used in the calibration exercise lies almost completely within the Oak Ridges Moraine. The algorithm used in CANWET to account for hydrology in hummock terrain assumes high infiltration rates and therefore considerably lower rates of surface and subsurface runoff than comparable source areas outside the moraine features. Using a more refined characterization of the hummocky terrain features would better depict areas of depression storage.

With respect to the over-estimation of sediment loads in the Beeton Creek test area, this problem is likely related to the use of excessively high default values for the “C” factor used in the USLE equation for the “cropland” category in CANWET. In CANWET, only two agricultural categories are allowed (“Hay/Pasture” and “Cropland”), which have default “C” values of 0.05 and 0.14, respectively. The default value of 0.14 worked well in the Black River where much of the land depicted by the “cropland” category is in row crops such as corn. However, much of the agricultural land designated as “cropland” in the Beeton Creek area is actually in sod production, which would have lower “C” values than 0.14 (probably closer to 0.05). This discrepancy suggests the need to allow for more agricultural land categories in CANWET that would be assigned more appropriate “C” factors than now being utilized. Crops such as sod could be re-categorized into the “Hay/Pasture” category as one possible solution. However, this does not address the fact that such areas tend to have much higher dissolved nutrient loads than hay/pasture land. Having more categories would provide more flexibility in assigning model parameter values that more accurately reflect the unique characteristics of varying crop types with respect to their pollution potential.

7.0 Summary of Model Application Results

<u>7.1 General</u>

Application of CANWET has been completed for the Innisfil Creek, Nonquon River and Black River watersheds. The findings documented herein provide an overview of nutrient and sediment loading conditions for specific sub-catchment areas. For the Innisfil Creek and Black River watersheds, the results presented are based on availability of flow and monitoring data for comparison purposes. The model was calibrated for pilot basins based on suitable monitoring data for the Innisfil Creek and Black River watersheds.

The results presented in Table 7.1 are loading rates for the period of available data record for the calibrated test areas (Beeton Creek and Black Rover). These are presented for comparison purposes with observed loading rates and flows and typical documented research findings compiled from published studies in Southern Ontario. Figures are also included under separate cover as part of an appendix to the Innisfil Creek Subwatershed Study report by the NVCA.

The CANWET model from the pilot project was calibrated based on two (2) test areas using data from Environment Canada’s HYDAT database of stream gauging data, the Provincial Water

Quality Monitoring Network water quality database and recent data collected by the Conservation Authorities.

Table 7.1: Calibrated Model Output for Test Areas vs. Published Loading Rates

	Calibrated and Observed Annual Flows and Loading			
	Stream Flow (cm)	**Nitrogen (kg/ha)**	**Phosphorus (kg/ha)**	**Sediment (kg/ha)**
Black River at Baldwin (CANWET Results)	28.6	3.2	0.119	90.2
Black River at Baldwin (Observed)	25.1	2.6	0.117	121.3
Beeton Creek near Tottenham (CANWET Results)	22.0	10.4	0.43	377
Beeton Creek (Observed)	45.1	16.8	0.60	153
Typical Loadings from Literature		3 to 26 [a]	0.1 to 2.0 [b]	100 to 1000 [c]

a - Tan et al. (2002), Neilson et al. (1982), and Spaling (1995)
b - Miller et al. (1982), Gaynor (1995), and Wall et al. (1996)
c - Wall et al. (1982)

7.2 Model Application to the Pilot Project Basins

The CANWET model was successfully applied to the Black River, Innisfil Creek and Nonquon River Subwatersheds. The work completed includes verification of the data received from the Conservation Authorities and creation of required data files. Nutrient and sediment load modeling was undertaken for each of the pilot basins. The model provides average annual nutrient and sediment loading rates, distribution of annual loadings according to source area land use and temporal loading based on the continuous dataset applied. Water balance results are also available.

8.0 Recommendations and Future CANWET Model Development

Near the completion of the pilot project, Greenland initiated discussions with the LSRCA to partner with the University of Guelph and Penn State University to begin development on a further enhanced version of CANWET that will incorporate functionality beyond the scope of the pilot project and address issues and potential applications that have been gaining attention since the pilot project.

Based on the discussion above, it is recommended that at least two refinements be made to future versions of CANWET in order to better simulate flows and loads in Ontario. The first would involve improvements to algorithms used to estimate ET. Specifically, the current algorithms should be modified to vary ET calculations based on watershed size. The second would increase the number of agricultural land categories in CANWET to more accurately represent conditions in southern Ontario.

In addition to the refinements noted above, a number of other enhancements to CANWET should be considered. The following list, in no particular order, is based on discussions with many individuals and groups in Ontario. It is likely that many (and possibly all) of the listed enhancements to CANWET would result in a watershed modeling application that more accurately portrays conditions in the region.

- Revise estimation of runoff P from agricultural areas as a function of estimated soil P concentration;
- Provide an “in-stream” assimilative capacity modeling capability within CANWET (as well as coupling the water balance component with a groundwater system model);
- Add algorithms to account for nutrient and sediment loss/retention in lakes and wetlands; and/or,
- Add loss/attenuation rates for septic system nitrogen loads as a function of watershed size.

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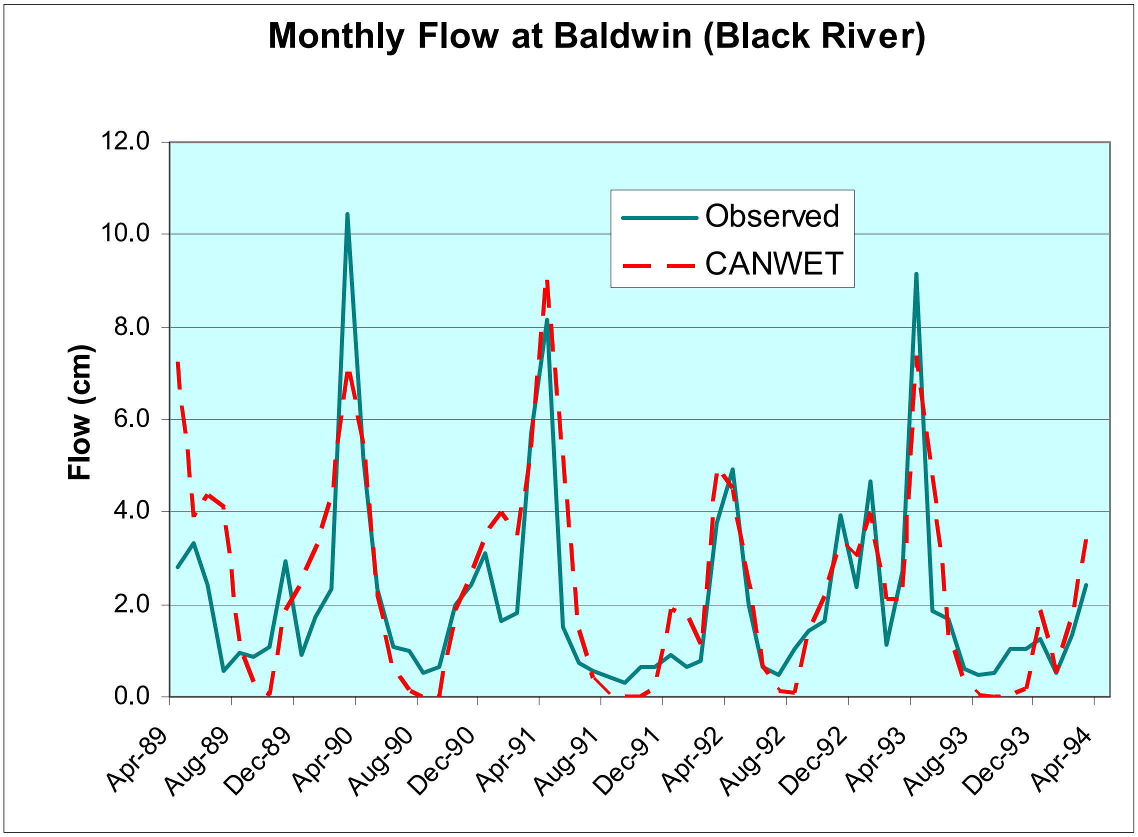
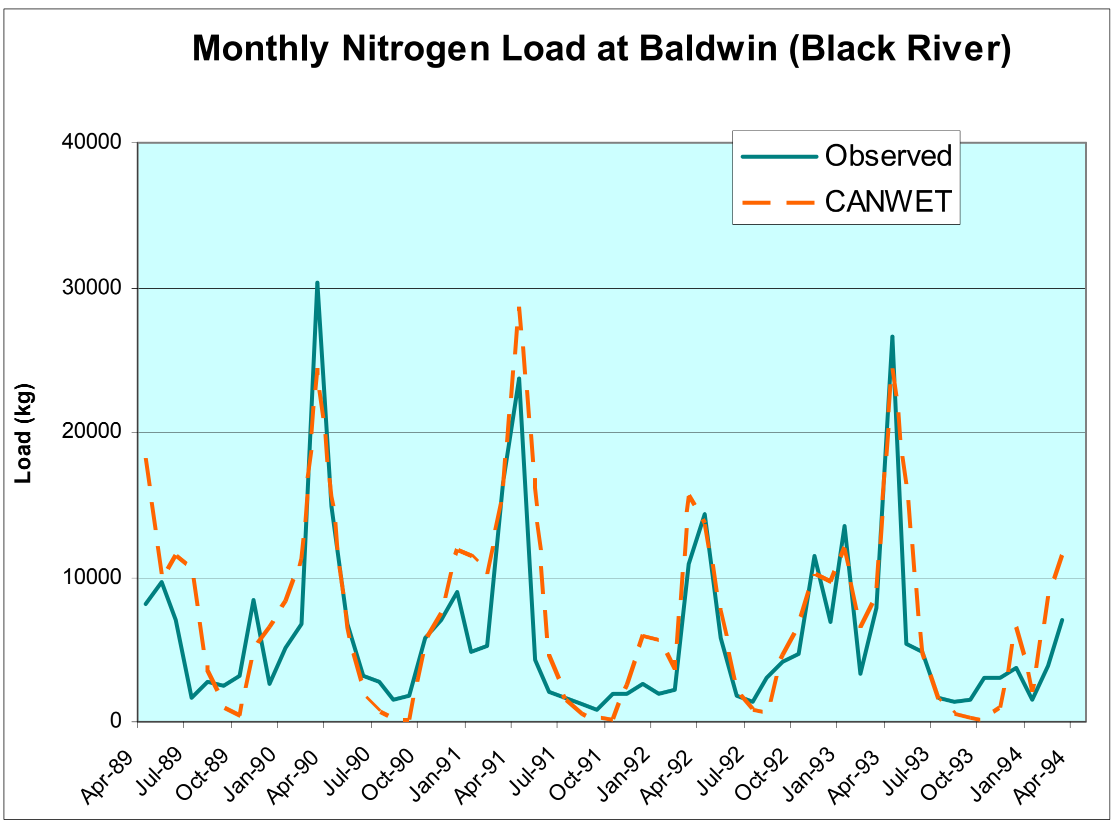
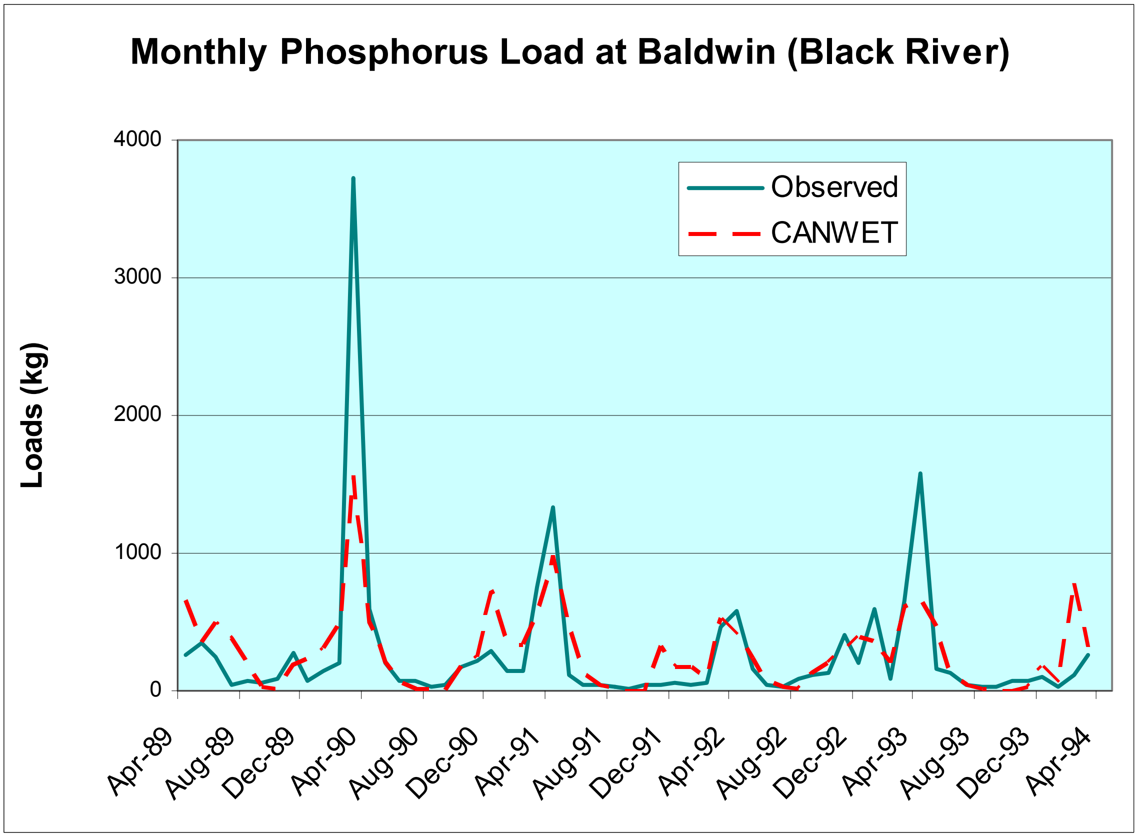
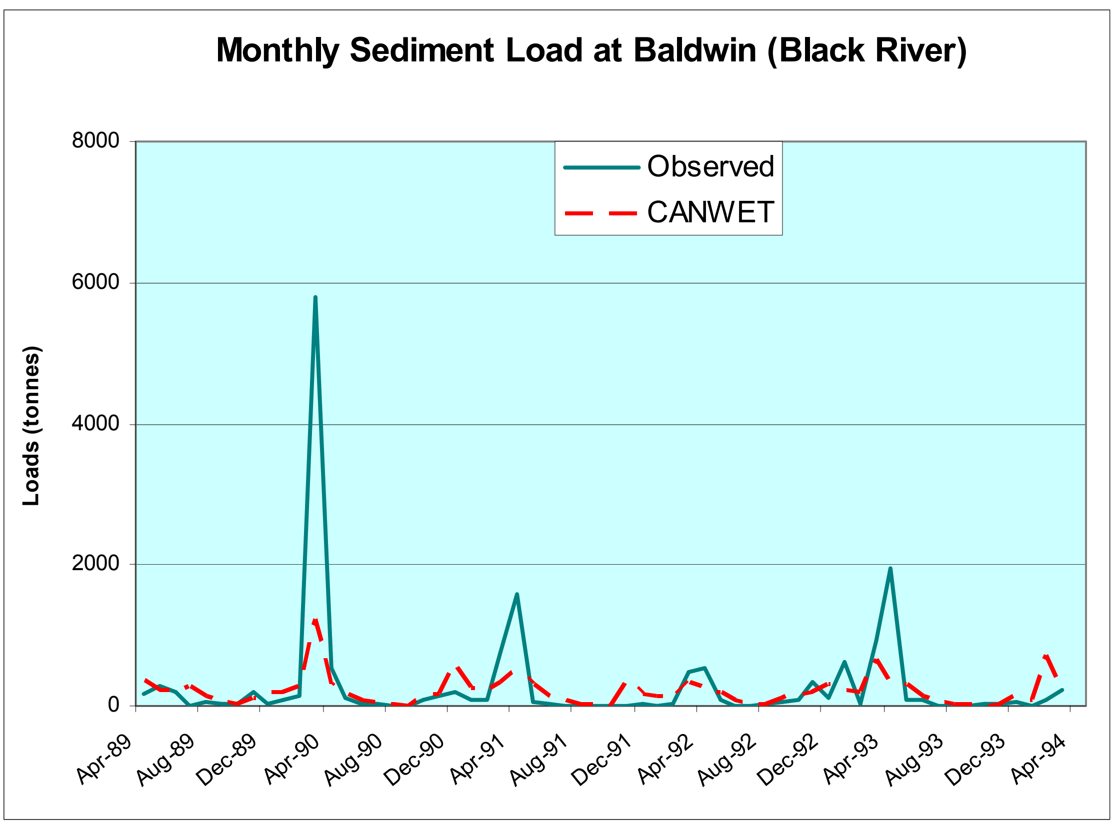
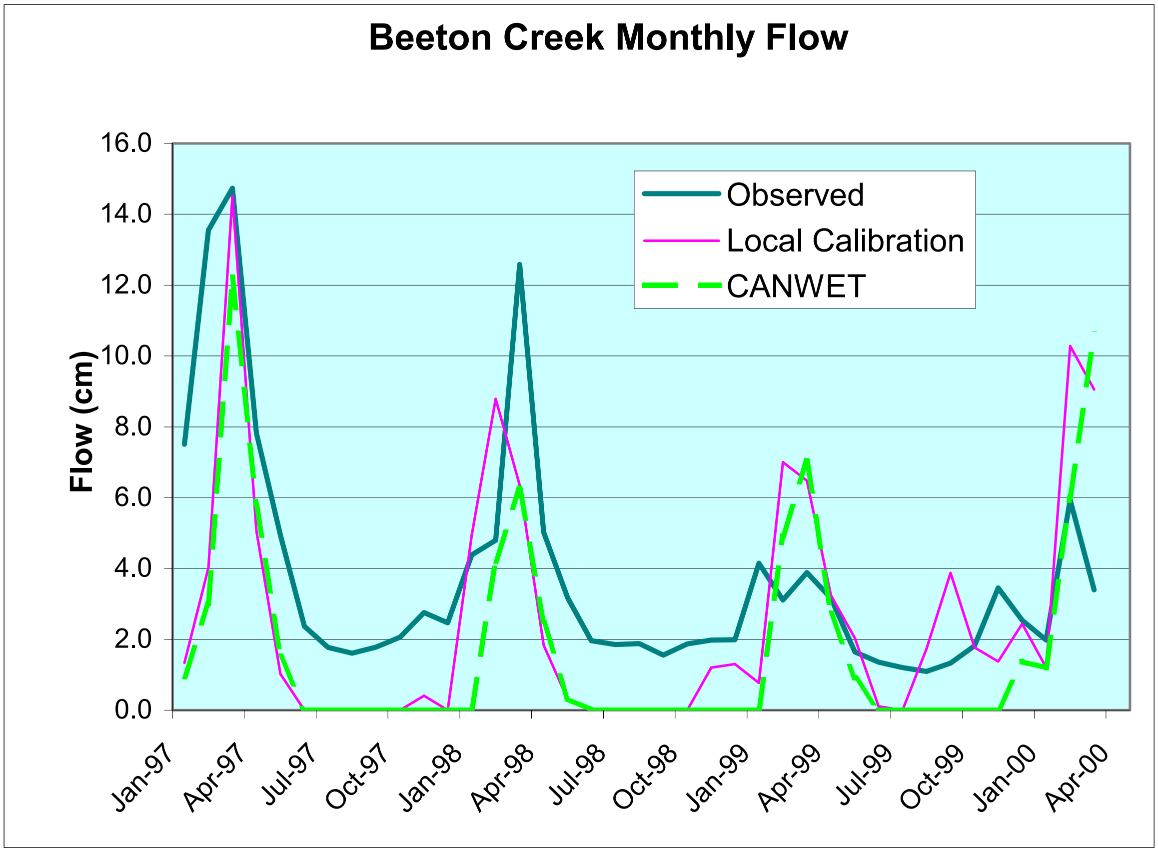
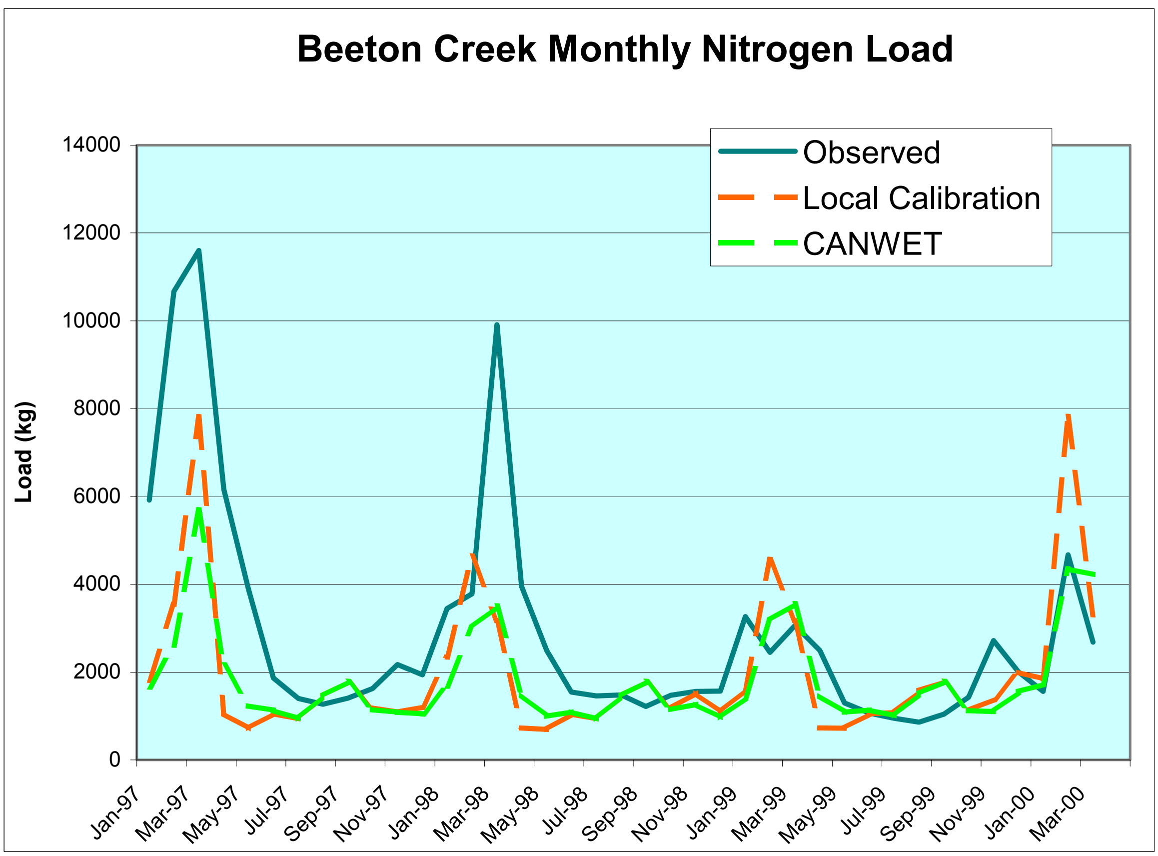

Monthly Flow at Baldwin (Black River)
Flow (cm)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Observed
CANWET
Apr-89
Aug-89
Dec-89
Apr-90
Aug-90
Dec-90
Apr-91
Aug-91
Dec-91
Apr-92
Aug-92
Dec-92
Apr-93
Aug-93
Dec-93
Apr-94

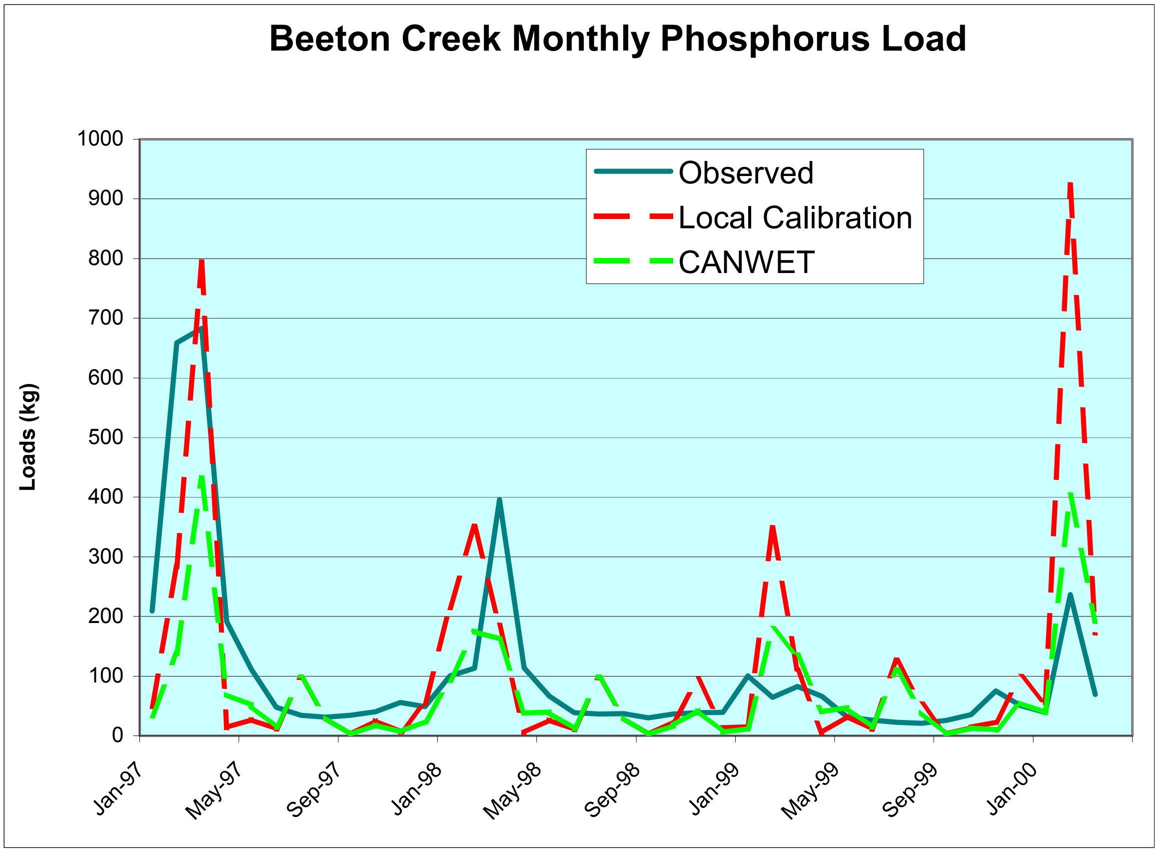

Monthly Nitrogen Load at Baldwin (Black River)
Load (kg)
40000
30000
20000
10000
0
Observed
CANWET
Apr-89
Jul-89
Oct-89
Jan-90
Apr-90
Jul-90
Oct-90
Jan-91
Apr-91
Jul-91
Oct-91
Jan-92
Apr-92
Jul-92
Oct-92
Jan-93
Apr-93
Jul-93
Oct-93
Jan-94
Apr-94

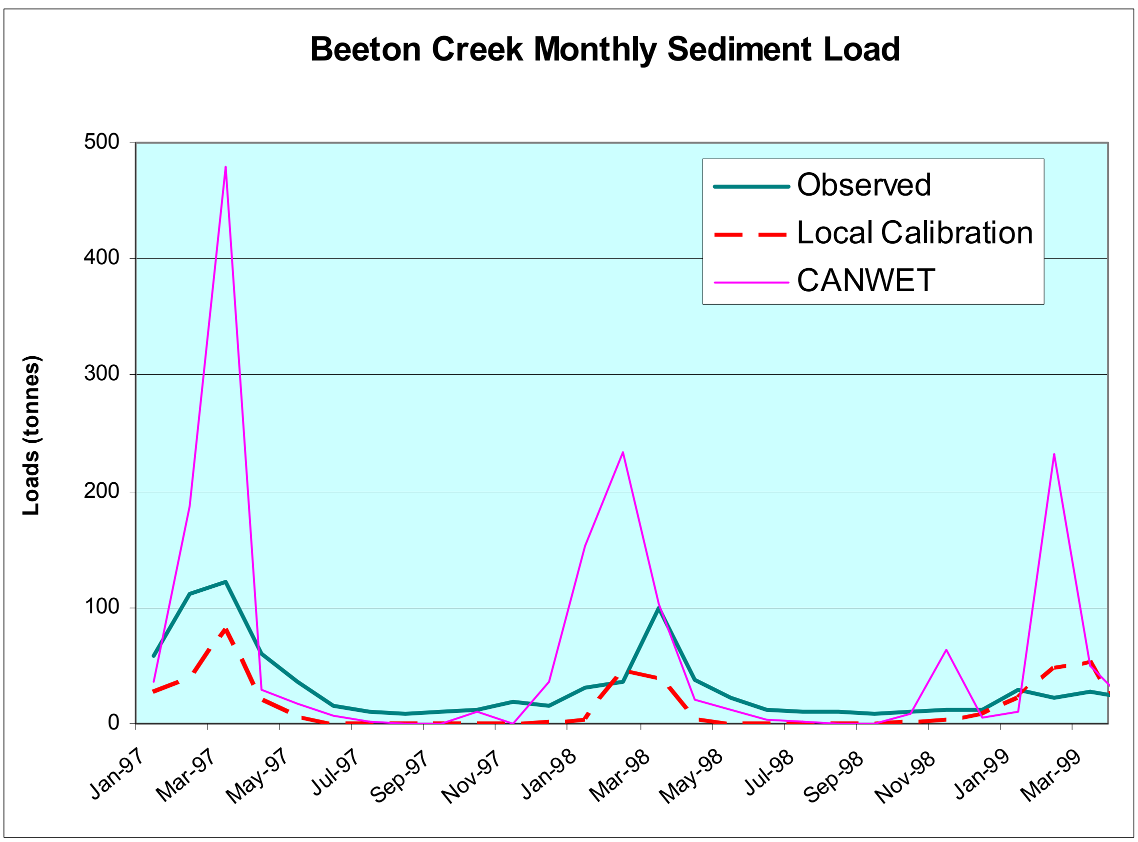

Monthly Phosphorus Load at Baldwin (Black River)
Loads (kg)
4000
3000
2000
1000
0
Observed
CANWET
Apr-89
Aug-89
Dec-89
Apr-90
Aug-90
Dec-90
Apr-91
Aug-91
Dec-91
Apr-92
Aug-92
Dec-92
Apr-93
Aug-93
Dec-93
Apr-94


Monthly Sediment Load at Baldwin (Black River)
Loads (tonnes)
8000
6000
4000
2000
0
Observed
CANWET
Apr-89
Aug-89
Dec-89
Apr-90
Aug-90
Dec-90
Apr-91
Aug-91
Dec-91
Apr-92
Aug-92
Dec-92
Apr-93
Aug-93
Dec-93
Apr-94


Beeton Creek Monthly Flow
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Flow (cm)
Observed
Local Calibration
CANWET
Jan-97
Apr-97
Jul-97
Oct-97
Jan-98
Apr-98
Jul-98
Oct-98
Jan-99
Apr-99
Jul-99
Oct-99
Jan-00
Apr-00


Beeton Creek Monthly Nitrogen Load
14000
12000
10000
8000
6000
4000
2000
0
Load (kg)
Observed
Local Calibration
CANWET
Jan-97
Mar-97
May-97
Jul-97
Sep-97
Nov-97
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98
Jan-99
Mar-99
May-99
Jul-99
Sep-99
Nov-99
Jan-00
Mar-00


Beeton Creek Monthly Phosphorus Load
Loads (kg)
1000
900
800
700
600
500
400
300
200
100
0
Observed
Local Calibration
CANWET
Jan-97
May-97
Sep-97
Jan-98
May-98
Sep-98
Jan-99
May-99
Sep-99
Jan-00


Beeton Creek Monthly Sediment Load
Loads (tonnes)
500
400
300
200
100
0
Observed
Local Calibration
CANWET
Jan-97
Mar-97
May-97
Jul-97
Sep-97
Nov-97
Jan-98
Mar-98
May-98
Jul-98
Sep-98
Nov-98
Jan-99
Mar-99