Water supply – detailed precipitation and hydrologic analysis

1. Hydrometric stations – instrumentation and monitoring procedures:

There is only one established, federally operated hydrometric station in the area: on St. Mary's River at Stillwater, roughly 24 km west of Goldboro. Data from it cannot be easily applied to the Isaac's Harbour River watershed, as the St. Mary's River watershed is much larger than the Isaac's Harbour River watershed, topography is different, as is the bedrock type at the upper reaches of the St. Mary's watershed.

In an effort to properly assess the characteristics of the Isaacs Harbour River and the Gold Brook watersheds, four hydrometric stations were installed in the vicinity of the proposed Keltic plant site and operated from November 2001 through to May 2003. Three were installed on the Gold brook system: one (GB1) at a tributary to Gold Brook Lake from Oak Hill Lake, another (GB2) in Gold Brook a short distance below Gold Brook Lake, and the third (GB3) in Gold Brook just above Seal Harbour Lake. The fourth stream gaging station (ML1) was installed on the Issac's Harbour River just below Meadow Lake where the gas pipeline crosses the river.

The stations were established using Global Water model WL-14 data loggers and pressure transducers (0 to 4.5m, vented for automatic barometric compensation) placed as deep as possible at each stream location. For protection the transducers were placed inside schedule 40 PVC screens, except at GB1 where the transducer was jammed in a joint in a culvert under the road. The data loggers were placed inside PVC tubing with caps for protection. They were programmed to record stream water depth every 30 minutes.

Stream-flow was estimated using:

$$Q = VA$$

Stream profiles at stations GB2, GB3 and ML1 were obtained using total-station survey gear, and at GB1 the cross-section of the culvert was assumed to be circular with a diameter of 1.68 m. At the ML1, GB1 and GB2 stream locations, flow-velocity (measured using Global Water model FP101 Flow Probe), stream-depth and lake level (ML1 and GB2 only) were measured and recorded 45 times at high and low stream stages and before and after major precipitation events between November 2001 and April 2003.

In order to estimate a flow value for each of the 45 measurement days, the wet cross-sectional area of the channel was calculated for each of those days. At ML1, GB2 and GB3 the cross-sectional area was calculated by dividing the channel into a series of slivers defined by the location of each stream profile station. The height of water at each profile station was determined using measured depth and station elevation (see Figures 1, 4 and 7). The shape of each sliver was assumed to be trapezoidal and the area of each was calculated. The sum of the sliver-areas equals the total cross-sectional area of the channel.

At the time each velocity measurement was taken in the field, the channel was divided into equally spaced panels and average velocity was measured by sweeping the probe from top to bottom across each panel. At GB2 and GB3 the channel was divided into two panels and two average velocity readings were taken. At ML1 the channel was divided into four panels and four average velocity measurements were made. The cross-sectional area of each panel was then calculated based on the assumption that at the time of every manual depth measurement, the channel width was equally divided into the same number of panels.

Isaacs Harbour River (ML1)

The stream profile at station ML1 on the Isaacs Harbour River is shown in Figure 1 below.

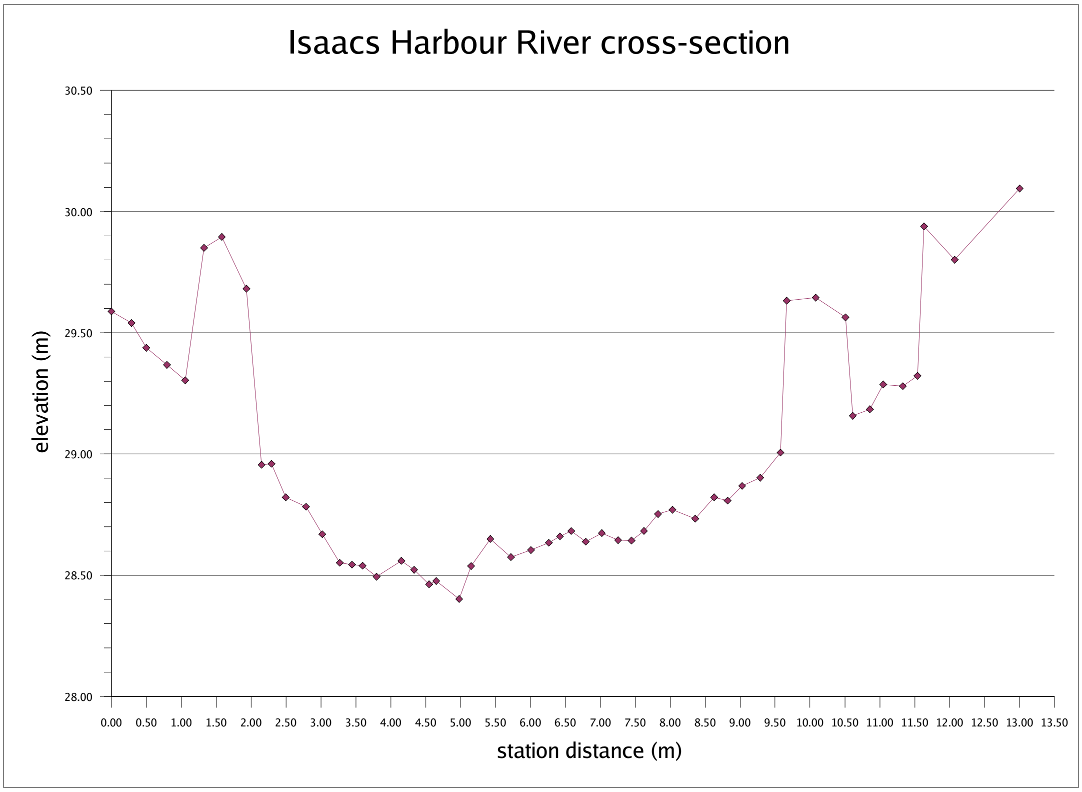


Figure 1. Cross-section of the Isaacs Harbour River at ML1.

A graph of flow (m^3/s) vs. depth (cm) was constructed in order to determine an appropriate flow-depth relationship (see Figure 2).

Two flow-depth relationships are necessary to describe the stream because of a “threshold condition” occurring at about 64 cm depth. For depth values less than or equal to 64 cm, the flow-depth relationship is best described with a power function and for those greater than 64 cm, the trend is linear. Several relationships were tested and the following were chosen because of the overall fit to both the upper and lower sections of the curve:

$$d \leq 64\,cm \qquad Q = 7.33\,x10^{-8}\,d^{4.1430}$$

$$d > 64\,cm \qquad Q = 0.153\,d - 7.562126$$

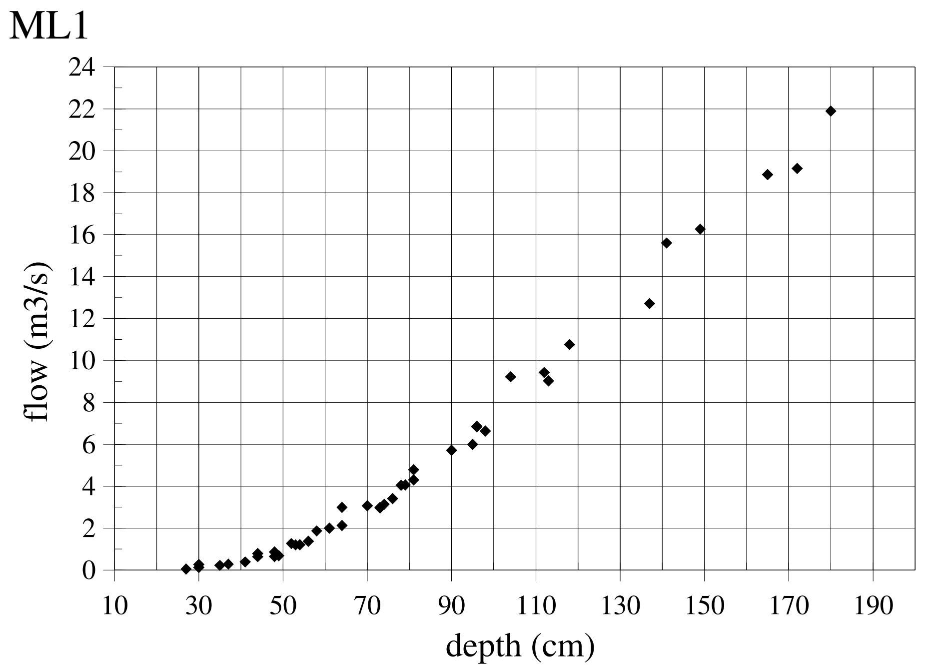


Figure 2. Isaacs Harbour River graph of measured flow (m^3/s) vs. depth.

Gold Brook Lake – GB1

At GB1, the cross-section of the culvert was assumed to be circular with a diameter of 1.68 m. A graph of flow (m^3/s) vs. depth (cm) was constructed in order to determine an appropriate flow-depth relationship (see Figure 3).

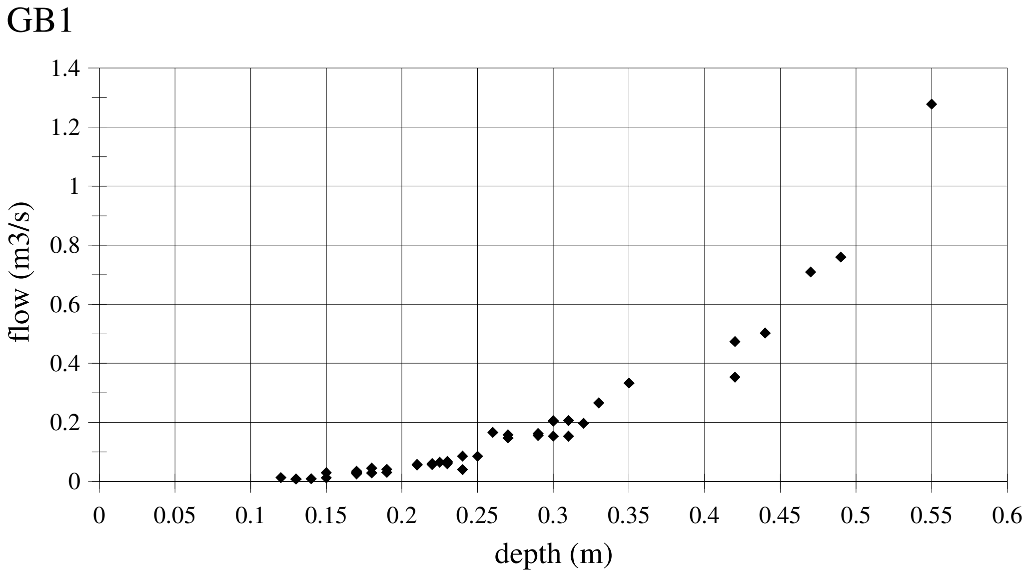


Figure 3. Gold Brook Lake (GB1) graph of measured flow (m^3/s) vs. depth.

Using Figure 3, the flow-depth relationship determined for GB1 was:

$$Q = 7.27\, d^{3.083}$$

Gold Brook Lake – GB2

The stream profile at station GB2 on Gold Brook a short distance downstream of Gold Brook Lake is shown in Figure 4 below.

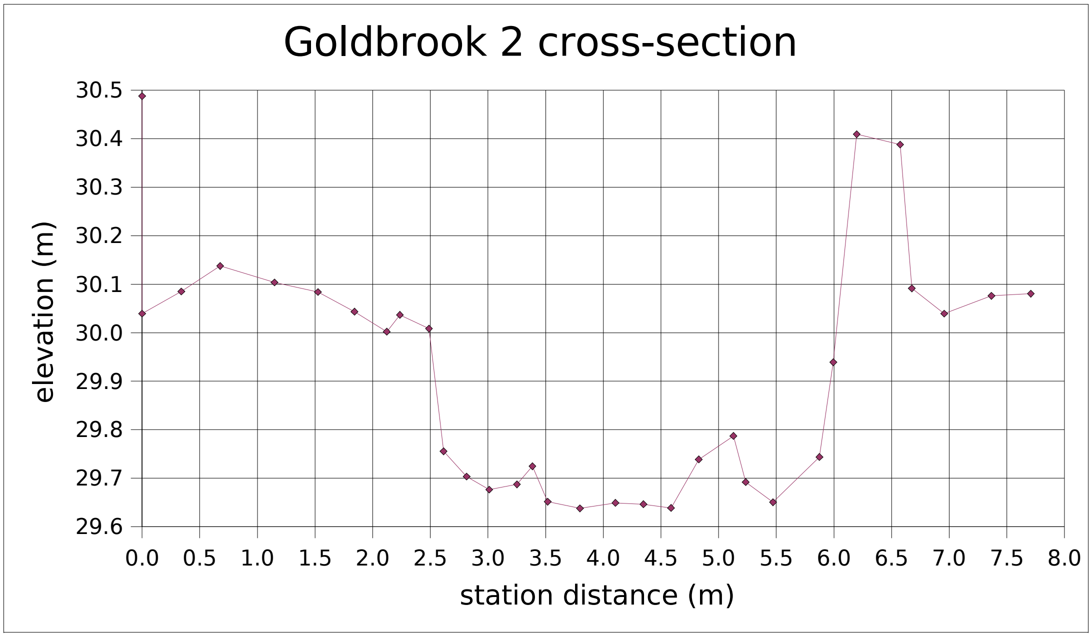


Figure 4. Cross-section of Gold Brook at GB2.

It became apparent at the time of data analysis (after data collection had already ended) that on several occasions during the data collection period (October 2001 to May 2003) the water level at GB2 had risen above the level of the banks. On these high-flow days, the channel was still separated into two panels for velocity measurements using the original channel dimensions. Since there is no way to estimate the vertical or horizontal extent of the water on the high-flow days, it was assumed that the channel behaved as a column of water whenever the channel depth was greater than the bank height of 36 cm. "Phantom elevation stations" were created at the actual channel edges between stations 9 and 10 and also between stations 26 and 27 (see Figure 5) and the stations beyond the channel edge were assumed to always be dry. This method underestimates the actual flow at GB2 on high-flow days, but keeps the actual dimensions of the channel without introducing additional errors by re-calculating the shape of the channel.

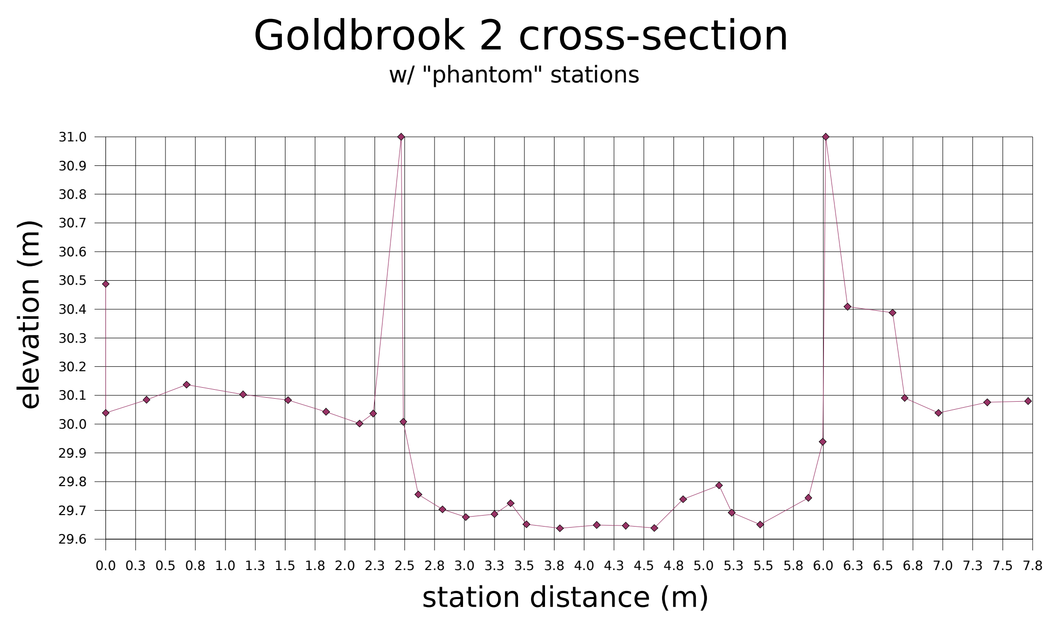


Figure 5. Cross-section of at GB2 showing “phantom elevation stations”.

A graph of flow (m^3/s) vs. depth (cm) was constructed in order to determine an appropriate flow-depth relationship (see Figure 6).

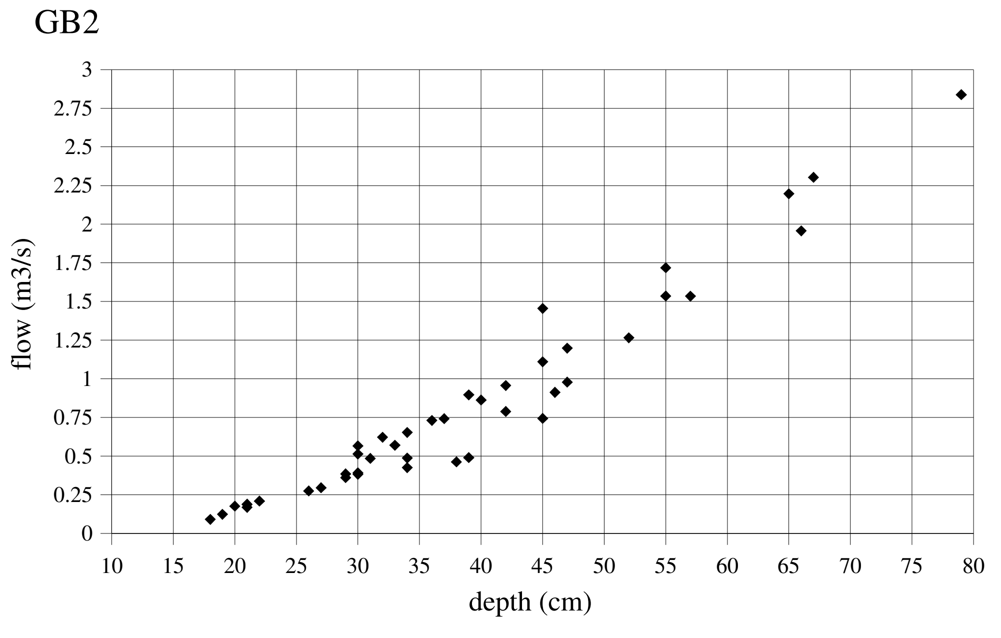


Figure 6. Gold Brook Lake (GB2) graph of measured flow (m^3/s) vs. depth.

Due to the assumption of vertical channel walls for stream depths greater than the bank height (36 cm), the bank height was chosen as the boundary depth. The depth-to-flow relationship is described using a power function relationship for depths less than or equal to 36 cm and a linear relationship for depths greater than 36 cm. This division is confirmed by studying the graphical relationship between depth and flow (see Figure 6). Several relationships were tested and the following were chosen because of the overall fit to both the upper and lower sections of the curve:

$$d \leq 36\,cm \qquad Q = 6.2\,x10^{-5}\,d^{2.580}$$

$$d > 36\,cm \qquad Q = 0.0520\,d - 1.229827$$

Gold Brook – GB3

The stream profile at station GB3 on Gold Brook is shown in Figure 7 below.

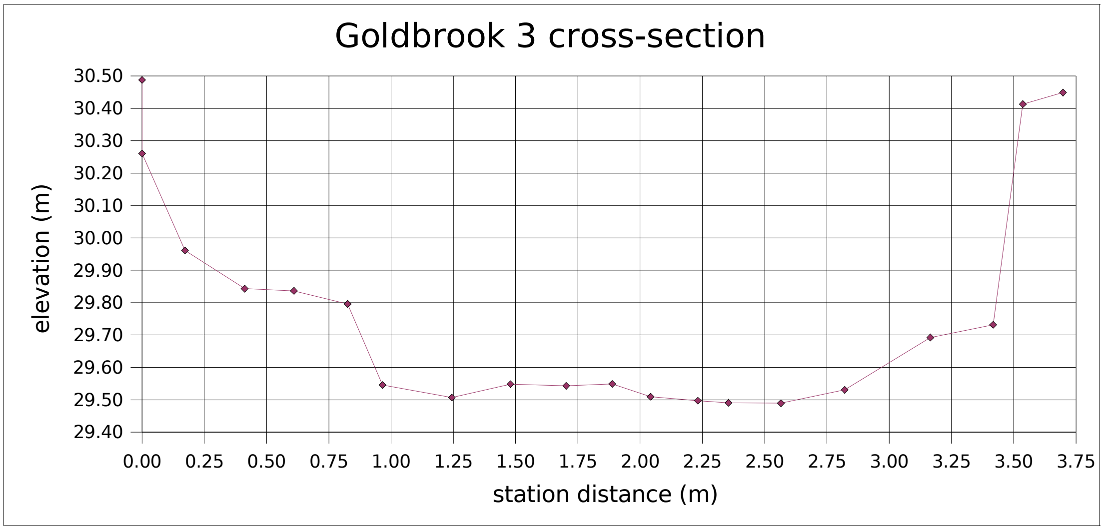


Figure 7. Cross-section of Gold Brook at GB3.

On several high-flow occasions, it was noted that the stream formed several channels upstream of the measurement site, which resulted in over-bank leakage at GB3. Therefore the depth and velocity measurements do not accurately represent the conditions at GB3, particularly on days when high-flows were present. Because of this and the damage incurred by the data logger placed at ML1 on 04 March 2002, the data logger at GB3 was removed on 09 March 2002 and placed at ML1 for the remainder of the data-collection period.

A graph of flow (m^3/s) vs. depth (cm) was constructed in order to determine an appropriate flow-depth relationship (see Figure 8)

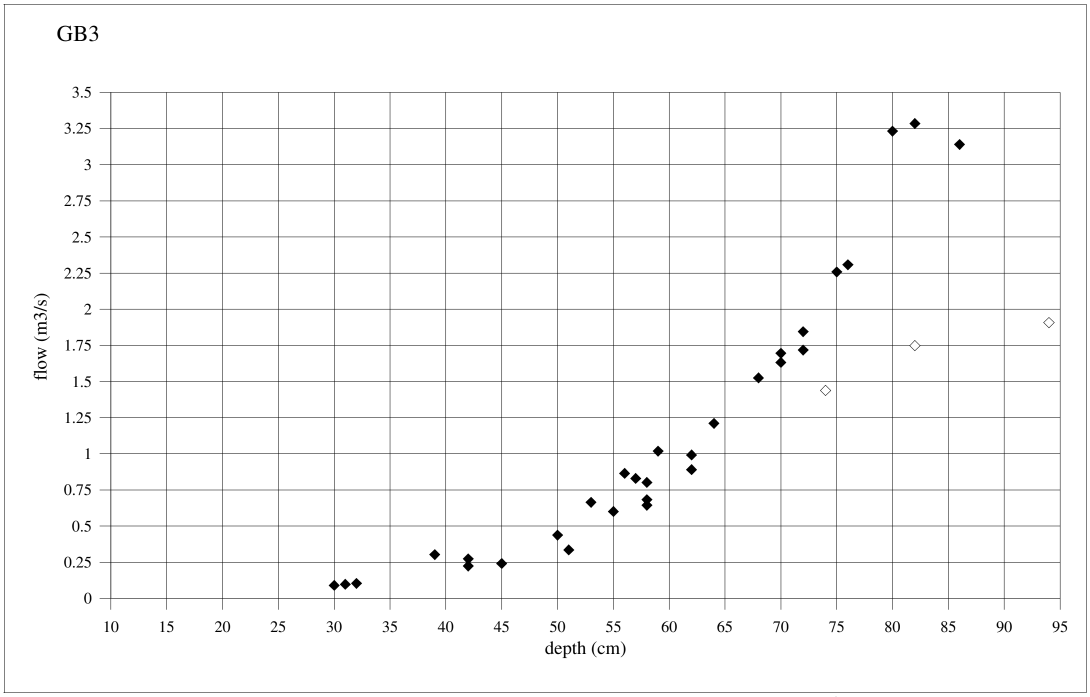


Figure 8. Gold Brook Lake (GB3) graph of measured flow (m^3/s) vs. depth (cm)

Three points which are considered outliers are shown as open circles in Figure 8. These points represent measurements made during high-depth conditions. The high-depth conditions should correspond to high-flow conditions, but that is not the case for these three points, likely due to over bank leakage which occurred on many occasions during high-flows. These three points were not used in the determination of the flow/depth relationship.

The following power function was determined to be the best relationship between depth and flow:

$$Q = 1.25\, x10^{-6}\, d^{3.315}$$

Gage-depth calibration

The manual flow and depth measurements were made at the same location (at the measured stream profile) every time, but these measurement could not be made directly at the pressure transducer location and so the depths recorded from both instruments could not be the same. Therefore, to apply proper flow/depth relationships to the depths recorded by the data logger at each site, the relationship between the data logger depth values and the manually-measured depth values was determined for each site. Also, the data logger clock did not account for time changes (daylight savings), and so an average of instantaneous pressure transducer depth measurements taken within one hour of the manual measurement was used as the equivalent value. In this way each manual measurement had an equivalent data logger measurement, and a linear relationship between the two could be determined.

At ML1 two data loggers were used to collect stream-depth data. The first was installed on 29 September 2001 and removed on 04 March 2002 when, because of rising stream levels, the data logger became submerged and stopped operating. The second data logger unit, which had originally been placed at GB3, was installed at ML1 on 13 March 2002 and remained in place until May 2003. Since the two data loggers at ML1 could not be placed at exactly the same location within the stream, two data logger–measured depth relationships were determined, as follows:

29 September 2001 to 04 March 2002 $d_c = 1.38\, d_d - 23.73$

13 March 2002 to 24 May 2003 $d_c = 1.19\, d_d - 0.67$

where d_c is corrected depth in cm, and d_d is data logger depth in cm. The data logger relationships for the GB1, GB2 and GB3 in the Gold Brook watershed were:

$$d_c = 1.07\, d_d + 10.01$$

$$d_c = 1.22\, d_d + 2.61$$

$$\text{and} \quad d_c = 0.98\, d_d + 19.73$$

At the time of installation, each data logger was calibrated, and so the relationships between measured depths and data logger depths should theoretically be 1:1. The equations above show that this is in fact the case as all relationships have a slope which is very close to 1. The y-intercepts represent the depth at which the data logger was installed at each site.

2. Hydrograph construction – measured stream flows

Stream-flow hydrographs were constructed for 01 October 2001 to 23 May 2003 for each of the four stream gaging stations (shorter period for GB3). The depth measurements collected by the data loggers at each site were collected at 30 minute intervals, then the appropriate data logger-measured depth relationship was applied, followed by the corresponding flow/depth relationship. The end result was an instantaneous flow value in m^3/s for each 30-minute interval. The hydrographs for each station were constructed by plotting the time of each depth measurement and the instantaneous flow values in m^3/s. The stream-flow data in Tables 1 to 6 was obtained from these hydrographs.

Table 1 Total 2002 Outflow (m^3) for ML1, GB1 and GB2

ML1	*GB1*	*GB2*
118,752,483	3,712,699	23,098,767

Table 2 Statistics of 2002 flow (in m^3/hour) for ML1, GB1 and GB2

Station	*mean*	*mode*	*minimum*	*25th percentile*	*median*	*75thpercentile*	*maximum*
ML1	13,895	11,033	156	3,262	10,286	20,176	79,755
GB1	424	196	37	187	279	490	10,445
GB2	2,637	1,139	216	1,177	2,136	3,258	10,850

Table 3 Monthly summary statistics of flow values for ML1 (m^3/hr)

Month	***mean***	***mode***	***minimum***	***median***	***maximum***
October 2001	2,038	295	233	1,285	12,075
November 2001	4,274	917	698	3,508	13,961
December 2001	11,445	10,189	1,597	10,078	34,043
January 2002	14,117	16,291	2,475	12,907	45,360
February 2002	16,550	3,679	2,651	18,455	54,126
March 2002	32,783	18,123	9,167	34,171	79,755
April 2002	27,282	20,736	8,401	23,348	64,959
May 2002	13,473	11,406	3,174	12,152	30,812
June 2002	1,353	552	156	1,027	4,582
July 2002	3,905	2,533	1,225	2,683	12,899
August 2002	5,297	1,027	705	1,601	34,357
September 2002	3,560	3,537	323	2,840	13,272
October 2002	11,588	5,575	2,461	9,540	36,783
November 2002	26,021	11,033	6,724	19,430	61,414
December 2002	16,572	7,868	5,443	15,511	37,529
January 2003	6,699	6,129	2,320	4,817	25,401
February 2003	20,274	5,575	4,817	17,004	56,562
March 2003	15,708	12,899	3,632	12,152	78,394
April 2003	20,746	5,575	3,352	10,846	65,705
May 2003	11,186	12,152	1,357	12,339	27,640

Table 4 Monthly statistics of flows for GB1 (in m^3/hour)

Month	***mean***	***mode***	***minimum***	***median***	***maximum***
October 2001	278	235	132	235	1,195
November 2001	383	302	246	315	913
December 2001	452	235	215	368	1,531
January 2002	528	235	215	441	2,238
February 2002	836	279	246	490	10,445
March 2002	638	279	37	382	5,887
April 2002	607	659	179	474	4,710
May 2002	362	215	187	302	790
June 2002	253	162	126	215	701
July 2002	261	196	106	225	618
August 2002	173	126	50	119	1,164
September 2002	179	50	43	126	723
October 2002	330	154	119	225	2,192
November 2002	640	279	162	382	4,867
December 2002	320	196	154	235	1,019
January 2003	239	179	95	162	1,226
February 2003	578	279	132	327	3,637
March 2003	560	196	89	246	6,839
April 2003	149	79	46	119	1,047
May 2003	111	65	22	106	279

Table 5 Monthly statistics of flows for GB2 (in m^3/hour)

Month	*mean*	*mode*	*minimum*	*median*	*maximum*
October 2001	704	283	260	604	1,745
November 2001	1,009	566	530	943	1,769
December 2001	1,752	2,164	656	1,672	4,113
January 2002	2,168	2,000	740	1,895	5,427
February 2002	2,345	994	784	2,404	6,610
March 2002	5,161	6,873	1,488	5,033	10,324
April 2002	4,119	2,667	1,139	3,456	10,225
May 2002	2,119	1,625	617	1,895	4,770
June 2002	948	1,065	441	960	2,601
July 2002	2,167	2,277	861	2,164	3,488
August 2002	1,642	579	316	994	6,150
September 2002	1,261	316	216	1,083	3,423
October 2002	2,625	2,000	1,139	2,306	5,657
November 2002	4,609	1,973	1,555	3,390	10,850
December 2002	2,464	1,158	1,065	2,404	4,836
January 2003	1,128	1,236	484	994	3,225
February 2003	3,251	960	799	2,601	9,272
March 2003	2,004	894	670	1,745	11,507
April 2003	4,981	2,930	1,870	3,439	11,934
May 2003	3,283	3,488	815	3,521	5,789

Table 6 Monthly statistics of flows for GB3 (in m^3/hour)

Month	*mean*	*mode*	*minimum*	*median*	*maximum*
October 2001	1,190	849	481	1,068	3,375
November 2001	1,331	810	771	1,192	2,735
December 2001	2,061	2,185	810	2,033	4,620
January 2002	2,589	2,970	870	2,690	5,385
February 2002	3,785	1,324	1,117	3,875	16,206
March 2002*	5,147	4,053	2,345	4,753	9,339

*indicates a month for which the full month of data is not available.

3. Water available to the watershed – precipitation analysis

Total annual flow for 2002 (full water year for which stream data is available) for the Isaacs Harbour River was 118,752,483±3,000,000 m^3. An estimate of total water available to the watershed for 2002, based on a 77,462,500 m^2 watershed and total annual precipitation of 1,379 mm (mean from three closest Environment Canada climate stations at Collegeville, Deming and Sherbrooke for

January to December 2002), is 106,820,787 m^3. This suggests that about 11 percent more water was present as stream discharge at ML1, than was available as total precipitation falling onto the Isaac's Harbour River watershed for the year 2002. It was clear from this that using simple means from the nearest climate stations would not produce reliable data for the Keltic water supply and so a study of the precipitation at the watershed was initiated in order to better understand the water balance in the area and, therefore, total quantity of water moving through the watershed system.

Data Acquisition

Climate data was obtained for all Environment Canada climate stations within 100 km Goldboro. This included historic data (daily monthly, annual summaries), available in digital format, plus paper copies of all raw field data for the three closest stations at Collegeville, Deming and Sherbrooke for the period October 2001 to May 2003. In addition, rain gages were placed immediately above the Isaac's Harbour River watershed at Salmon River to give an indication of precipitation amounts in the upper reaches of the watershed, and at Goldboro to give an indication of precipitation amounts the coastal region at the lower reaches of the watershed for the period October 2001 to May 2003. Figure 9 shows the locations of the study rain gages and Environment Canada climate stations.

The study gages used were RainWise® tipping-bucket type rain gages, calibrated to tip every 0.254mm (0.01 in) and equipped with HOBO® electronic data loggers programmed to record the time at each bucket tip. In order to compare the study rain-gage data to the Environment Canada climate station data (which is collected twice a day, usually at 8:00 and 18:00) the rain-gage data collected at Goldboro and Salmon River Lake was grouped to match “Environment Canada days”. The rain-gage data collected at Goldboro ad Salmon River was also grouped into actual 24 hour days to help study the stream-flow hydrographs in detail.

Over the 20 months during which rain-gage data was collected, continuous data from Goldboro is available for the periods 01 October 2001 to 16 October 2001, 09 November 2001 to 30 June 2002 and 19 October 2-02 to 28 May 2003. Continuous data from Salmon River Lake is available for the periods 09 November 2001 to 08 March 2002, 28 June 2002 to 19 October 2002, and 07 February 2003 to 28 May 2003. The gaps in the data are mainly due to human interference and/or equipment malfunction. Because of the larger gaps in the data available from the Salmon River station, the Goldboro data was used as a primary indicator of precipitation in the watershed and the Salmon River data was used when no Goldboro data existed.

Daily Environment Canada precipitation data (digital format) for Collegeville was available from 1916 to 2003, for Deming from 1956 to 2003 and for Sherbrooke from 1967 to 2003. These three station were chosen as indicators of precipitation amounts in the area, to establish historical precipitation trends and to confirm the reliability of data collected within the Isaac's Harbour River watershed at Goldboro and Salmon River Lake.

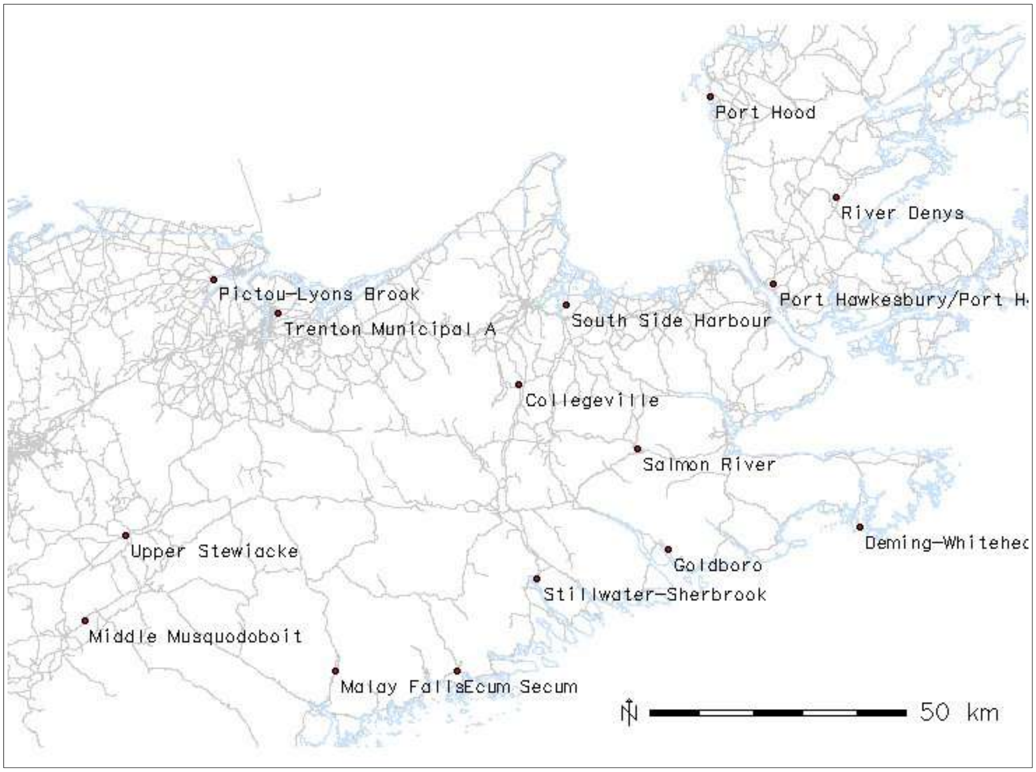


Figure 9. Locations of study rain gages and EC climate stations.

Data validation

For the period October 2001 to May 2003, the data collected at Goldboro was compared to daily precipitation data for Deming and Sherbrooke. These two were selected for the validation process because the coastal conditions at these two stations most resemble coastal conditions at Goldboro.

For each day data was available, the Goldboro data was examined in terms of quantity of rain recorded and the timing of the precipitation. If the precipitation at Goldboro was confirmed by either of these two Environment Canada climate stations, it was considered a valid reading. If not, the stream-flow hydrographs were examined for the same period and if the stream-flow response within a few days of the supposed precipitation seemed to confirm the occurrence of precipitation, then it was also considered valid precipitation. Precipitation falling as snow was generally found to melt shortly after each event and, therefore, tipping bucket readings generally matched the Environment Canada rainfall equivalent for each snowfall event. There was no doubt moisture loss due to sublimation before snow melted, but this would likely not account for any large errors.

Precipitation recorded on 28, 29 and 30 June 2002 was the only Goldboro data found to be erroneous. On 28 June 2002, the data from 09 March 2002 to 28 June 2002 was downloaded at 12:30. This data included 10.92 mm (0.43 in) recorded on 28 June 2002. After the download, between 28 June 2002 at 12:34 up until 30 June 2002 at 18:50, the rain gage at Goldboro recorded an additional 113.54 mm (4.47 in) of precipitation. This amount was not confirmed by any of the three nearby stations nor by the stream-flow response on the hydrographs. This suggested that someone may have tampered with the rain gage, possibly dumping water into it. The data was adjusted accordingly and the additional 113.54 mm (4.47 in) was not used in calculations.

The data collected at Salmon River was analyzed for the period during which no data from Goldboro was available (28 June 2002 to 19 October 2002) and was compared to Collegeville data since both stations are located inland. The Salmon River data appears to match Collegeville data in terms of timing of precipitation events, but not in terms of quantity recorded. The precipitation amounts recorded at Salmon River for the months of July, August and September (complete months during which data was collected) seem to be significantly lower than the amounts recorded at Collegeville. The total precipitation for September (4.57 mm (0.18 in) was so low that it was considered unusable.

Total monthly precipitation for Collegeville, Deming, Sherbrooke, Goldboro and Salmon River for the period October 2001 to May 2003 was calculated (see Table 7 and Figure 10). Table 7 and Figure 10 serve as a means of visually comparing the precipitation at the different stations during the period October 2001 and May 2003. They reinforce similarities in data observed between Goldboro and the Environment Canada stations, Deming and Sherbrooke in terms of climatic conditions and precipitation events, and that between Collegeville and Salmon River also.

Table 7 Total monthly precipitation (in mm)

Date	***Deming***	***Sherbrooke***	***Goldboro***	***Collegeville***	***Salmon River***
Oct-01	99	53	36	69	-
Nov-01	124	84	89	80	99
Dec-01	118	90	122	64	101
Jan-02	131	102	174	106	94
Feb-02	158	146	148	75	108
Mar-02	179	87	247	78	60
Apr-02	191	62	230	52	-
May-02	100	89	117	55	-
Jun-02	100	71	104	92	14
Jul-02	129	103	-	81	25
Aug-02	104	61	-	44	34
Sep-02	119	123	-	107	5
Oct-02	178	155	67*	127	77*
Nov-02	235	254*	305	150	-
Dec-02	98	101*	93	98	-
Jan-03	144	128	83	40	-
Feb-03	131	206	135	52	40*
Mar-03	88	92	110	131	142
Apr-03	206	127	197	104	102
May-03	96	98	105	79	65

* indicates a month for which the full month of data is not available.

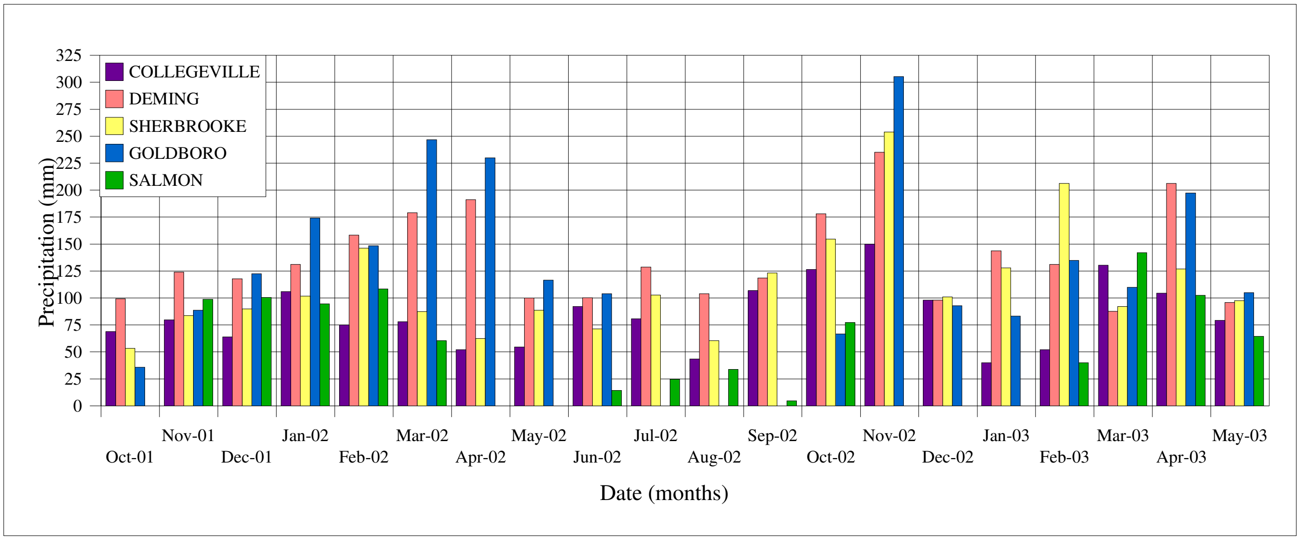


Figure 10. Total monthly precipitation (mm) for October 2001 to May 2003

Although there is a correlation between precipitation recorded in the watershed (at Goldboro and Salmon River Lake) and precipitation at nearby Environment Canada stations (Collegeville, Deming and Sherbrooke), due to the lack of data for Goldboro for July, August and September 2002, the unreliability of the Salmon River data for this same period, and the relatively short period available for comparison between stations (October 2001 to May 2003), a more detailed precipitation study and precipitation modeling using GIS were initiated to better understand the relationship between climatic conditions within the watershed and the surrounding Environment Canada stations.

Historic precipitation trends

To identify long-term precipitation trends in the study area, running decadal means were calculated using total monthly and annual precipitation for all Environment Canada climate stations within 100 km of Goldboro with a record of at least 20 years.

The precipitation record for the Deming station was extended from 1967 to 2003 to cover the period 1883 to 2003, by linking it to data from the Whitehead station (see Figure 9) at the same location, which has data available for 1883 to 1960. A period of overlap of 45 months between the years 1957 and 1960 exists, during which both stations recorded climate data. During this period, the two-station average was used and a record for Deming-Whitehead was created for 1883 to 2003.

The precipitation record for the Sherbrooke station was extended from 1956 to 2003, to cover the period from 1915 to 2003, by linking it to data from the Stillwater station at nearly the exact same location, which has data available from 1915 to 1960 and 1978 to 1979. In this case a period of overlap did not exist, so the record for both stations was simply combined and a record for Stillwater-Sherbrooke was created for 1915 to 2003.

Regardless of the amount of “data smoothing” provided by running decadal means, there were still years for which little or no data is available for many months (less than nine months of data), such as: at Collegeville between 1944 and 1948 and between 1961 and 1964; at Deming-Whitehead between 1883 and 1889, and between 1908 and 1926; and at Stillwater-Sherbrooke between 1961 and 1966 and between 1971 and 1980. Nevertheless, between 1926 and 1944 and from 1982 to 2002 there exists a near-complete record for these three stations – which indicates that there has been a general increase in total annual precipitation amounts over time. This increase is most obvious in the Deming-Whitehead and Collegeville areas. Overprinted on this long-term trend, mean total annual precipitation (values obtained from GIS at roughly the center of the Isaac's Harbour River watershed) increased from 1,475mm during the period 1982-1987, to 1,507mm during the period 1988-1994, decreasing to 1,341mm during the period 1995-2002. Total annual precipitation over the watershed averaged 1,554mm during the year 2002 (value obtained from GIS). The individual records for total annual precipitation for 2002 at Collegeville, Deming-Whitehead and Stillwater-Sherbrooke were 1,065mm, 1,722mm and 1,357mm, respectively. For these three stations, eleven, eleven and nine out of twelve months in 2002 recorded more precipitation than in 2001.

Three quasi-distinct periods were identified within the more recent data by which to characterize total annual precipitation amounts. These are from 1982 to 1987, 1988 to 1994 and 1995 to 2002. Also, by studying the seasonal total precipitation at Collegeville, Deming-Whitehead and Stillwater-Sherbrooke, "precipitation seasons" were defined, as follows:

Fall - September to November;
Winter - December to February;
Spring - March to May;
Summer - June to August.

Precipitation modeling

The 11 percent excess runoff versus precipitation observed at the start of this section suggested that simply using mean precipitation from the three nearest Environment Canada climate stations might not correctly represent the precipitation amounts actually falling onto the Isaac's Harbour watershed – it was thought that one or more climate station could be biasing the mean.

Nearly complete data from several other Environment Canada stations is available for the period 1982 to 2002, including at Ecum Secum, Malay Falls, Middle Musquodoboit, Pictou-Lyons Brook, Port Hastings, Port Hawkesbury, Port Hood, River Denys and Upper Stewiacke. Use of this data allowed an accurate simulation of precipitation over the Isaacs Harbour Watershed using GRASS-GIS, where rainfall data interpolation from the stations listed in Table 8 and (raster surface) modeling was done to tabulate the following:

Seasonal means (1982-2002)
Seasonal means (1982-1987)
Seasonal means (1988-1994)
Seasonal means (1995-2002)
Average annual total (1982-2002)
Average annual total (1982-1987)
Average annual total (1988-1994)
Average annual total (1995-2002)
Monthly totals (October 2001 to May 2003)
Seasonal totals (2002)
Annual total (2002)
Average monthly totals (1982-2002)

To illustrate how rainfall distribution has varied over time, Figures 11 to 14 show total mean annual precipitation for eastern Nova Scotia for the periods 1982-1987, 1988-1994, 1995-2002 and 1982 to 2002, respectively. Also, mean average total monthly precipitation for the period 1982 to 2002 (shown in Figures 15 to 26) and individual monthly totals for October 2001 through May 2003 were tabulated for the stations listed in Table 9. These data are used later to calculate the October 2001 to May 2003 and overall average (1982 to 2002) monthly and annual flow versus precipitation at Isaacs Harbour River, and thus, reservoir storage requirements.

Table 8 Period of record for stations used for historic (1982-2002) rain modeling

Station Name	***Period of Record***
Collegeville	1982-2002
Deming-Whitehead	1982-2002
Ecum Secum	1982-1985
Malay Falls	1988-2002
Middle Musquodoboit	1982-2002
Pictou-Lyons Brook	1985-2002
Port Hawkesbury/Port Hastings	1982-1995/2001-2002
Port Hood	1982/1985-1987/1990
River Denys	1982-1987
Stillwater-Sherbrooke	1982-2002
Upper Stewiacke	1982-2002

Table 9 Period of record for stations used for modeling October 2001 to May 2003

Station Name	***Period of record data available***
Collegeville	Oct-01 to May-03
Deming-Whitehead	Oct-01 to May-03
Goldboro	Oct-01 to May-03
Malay Falls	Oct-01 to Mar-03
Middle Musquodoboit	Oct-01 to Mar-03
Pictou-Lyons Brook	Oct-01 to Mar-03
Port Hawkesbury	Oct-01 to Mar-03
Salmon River	Oct-01 to May-03
South Side Harbour	Oct-01 to Feb-03
Stillwater-Sherbrook	Oct-01 to May-03
Trenton Municipal A	Oct-01 to Mar-03
Upper Stewiacke	Oct-01 to Mar-03

Figure 11 Precipitation distribution – mean annual total, period 1982-1987.

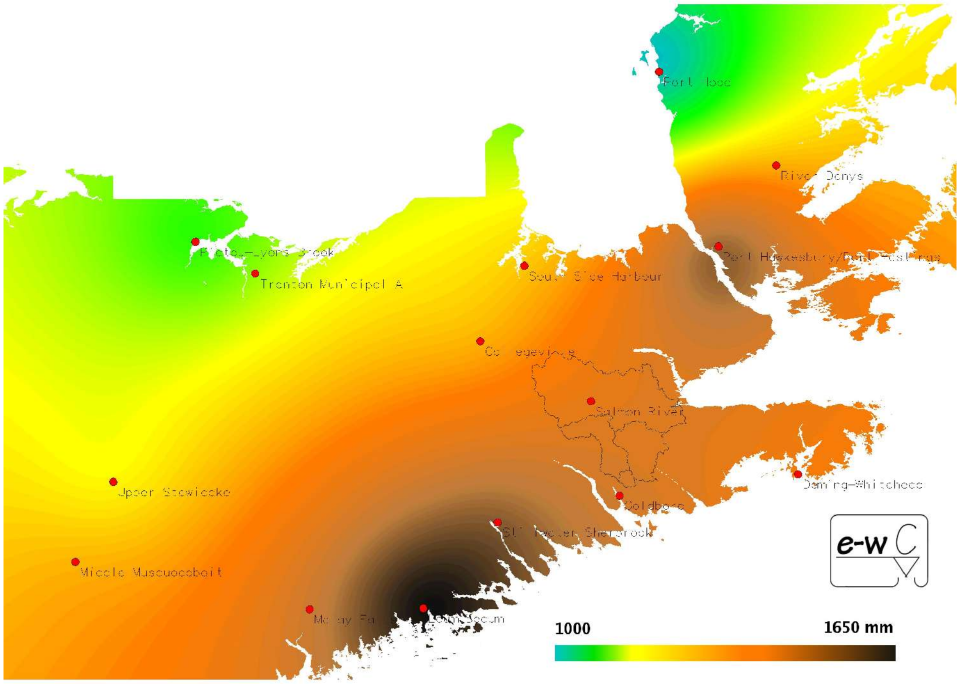


Figure 12 Precipitation distribution – mean annual total, period 1988-1994.

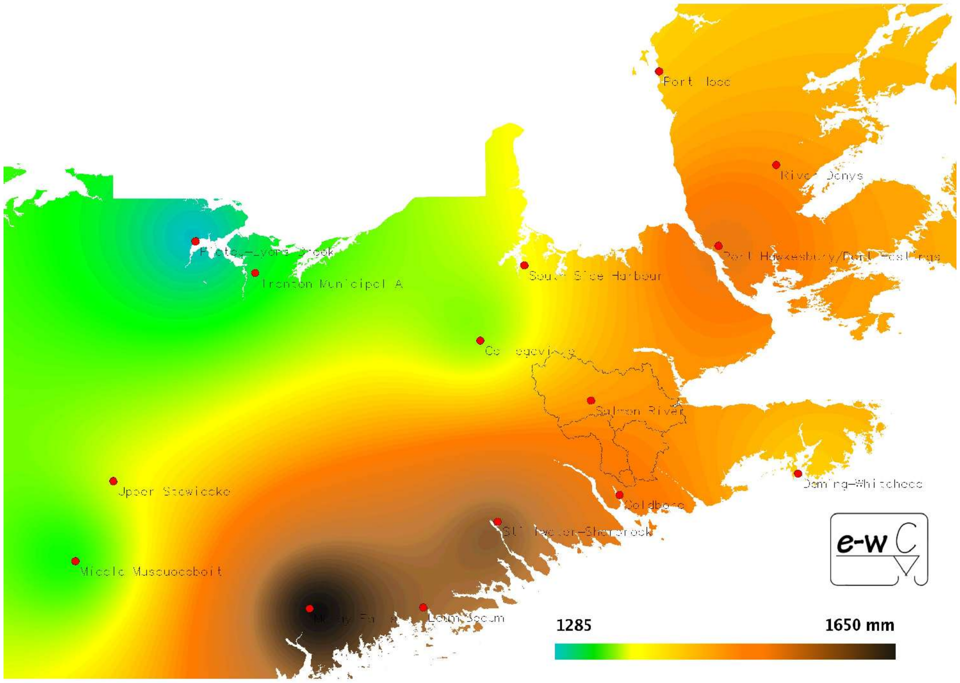


Figure 13 Precipitation distribution – mean annual total, period 1995-2002.

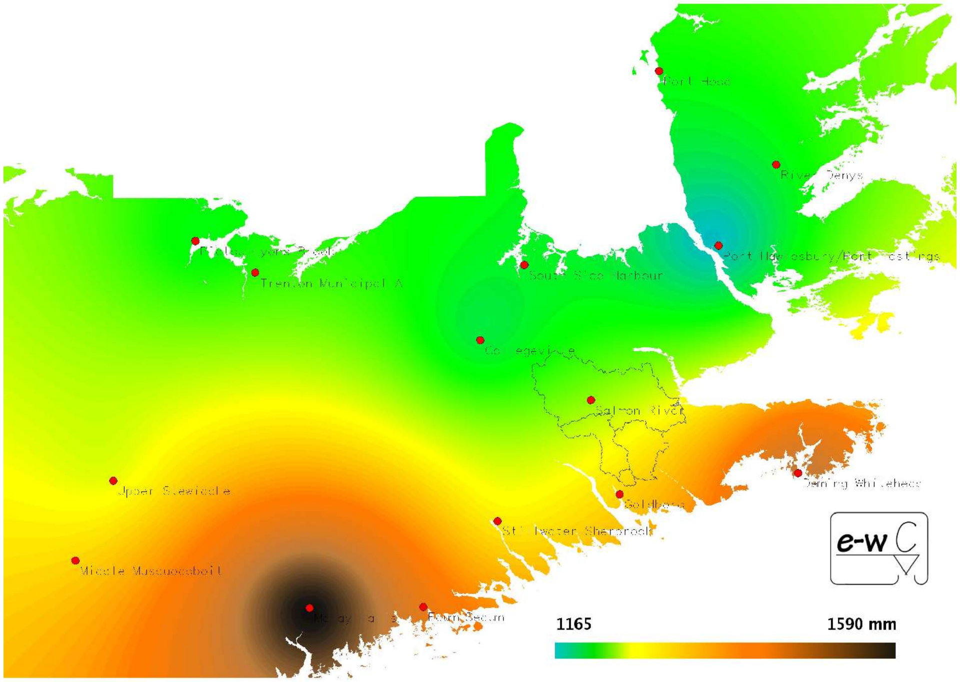


Figure 14 Precipitation distribution – mean annual total, period 1982-2002.

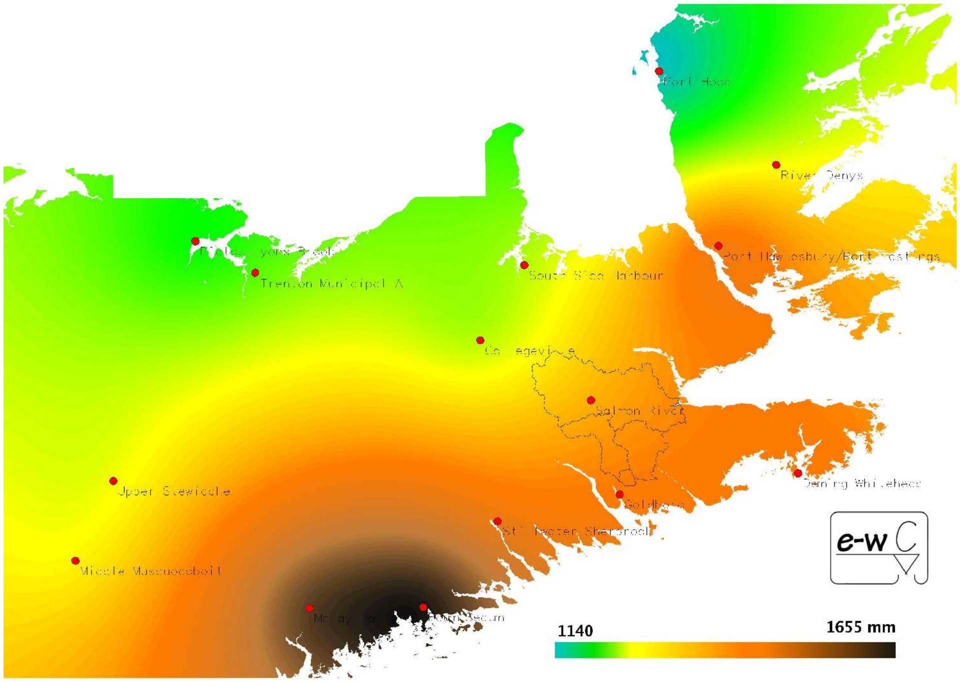


Figure 15 Precipitation distribution – mean January monthly total, 1982-2002.

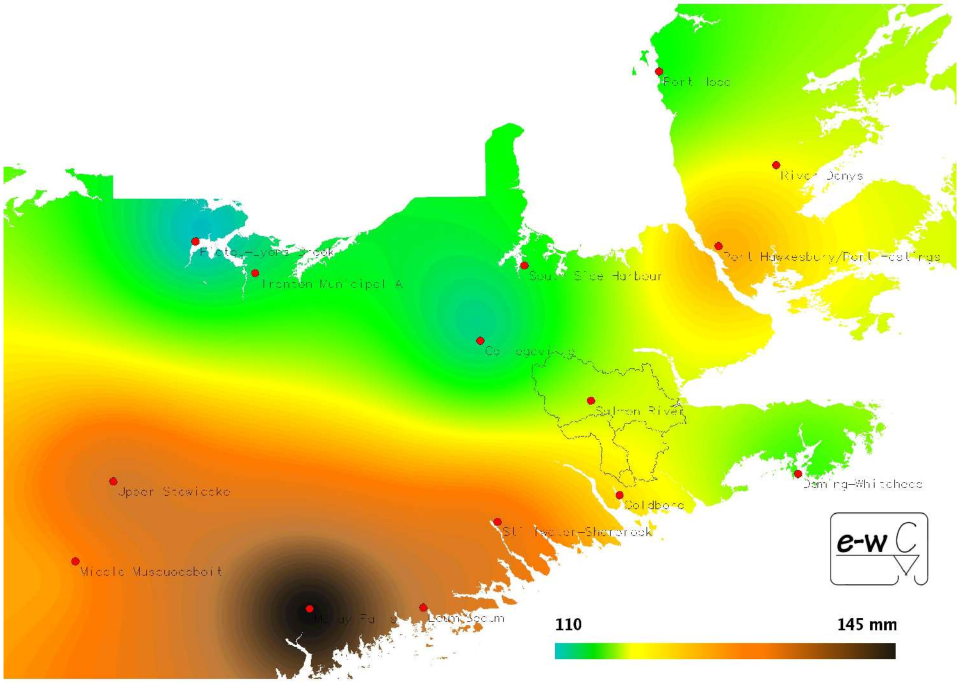


Figure 16 Precipitation distribution – mean February monthly total, 1982-2002.

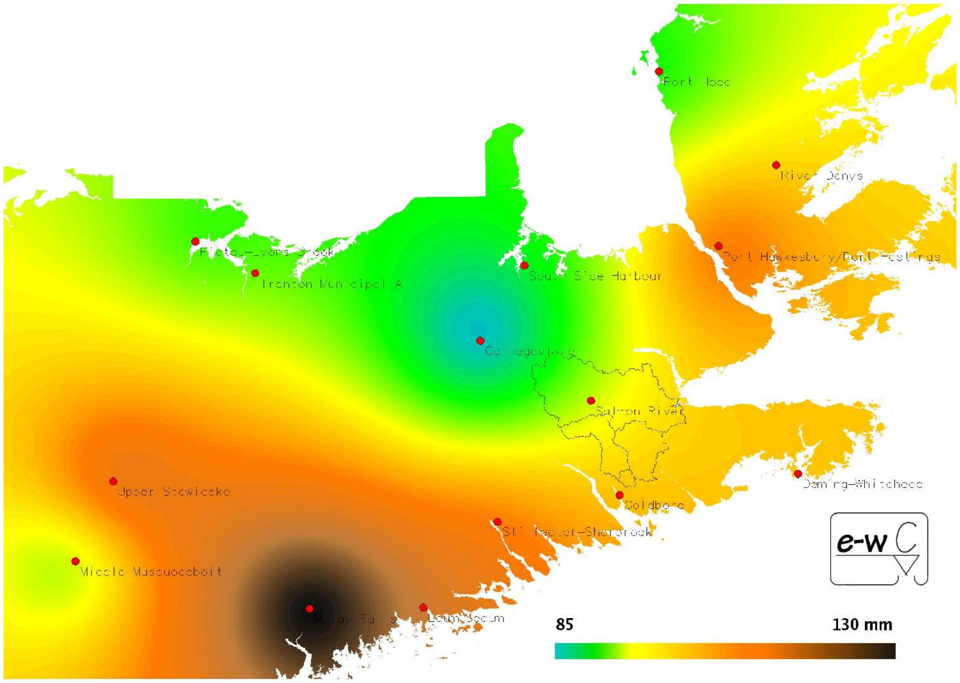


Figure 17 Precipitation distribution – mean March monthly total, 1982-2002.

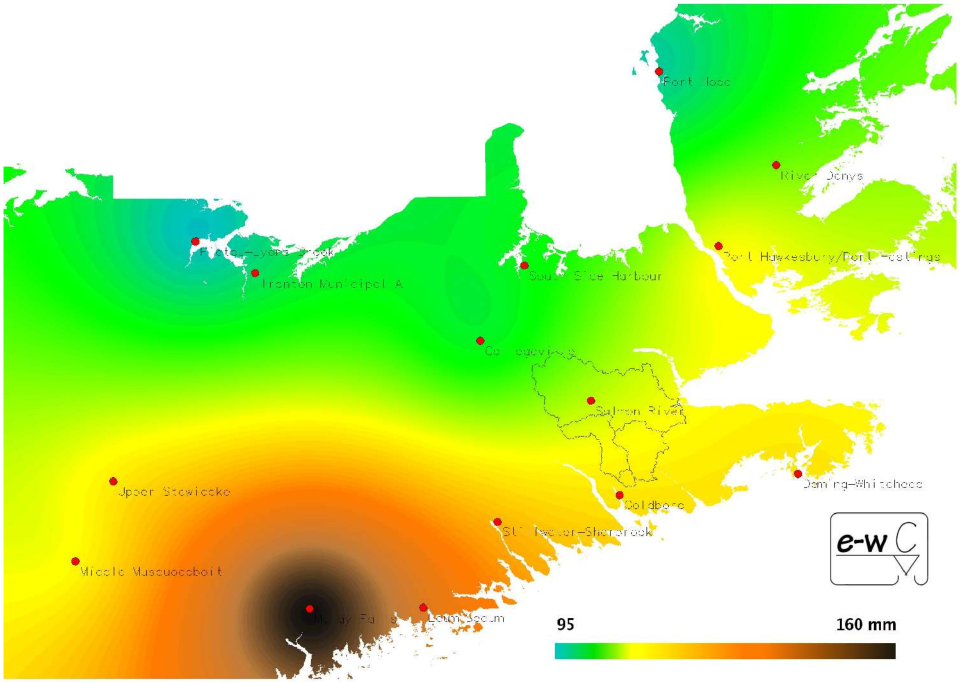


Figure 18 Precipitation distribution – mean April monthly total, 1982-2002.

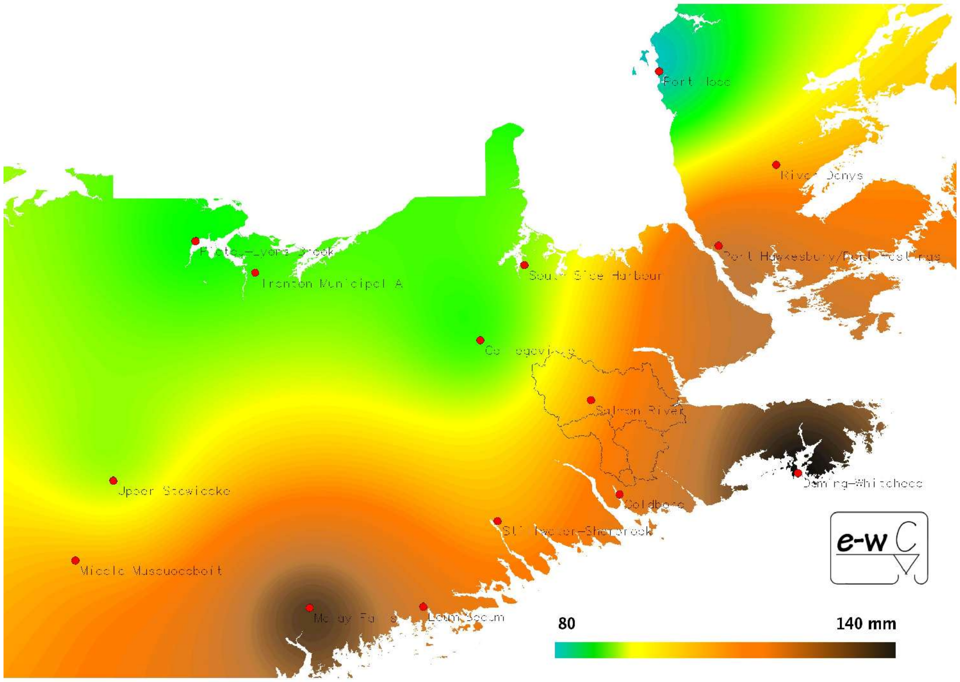


Figure 19 Precipitation distribution – mean May monthly total, 1982-2002.

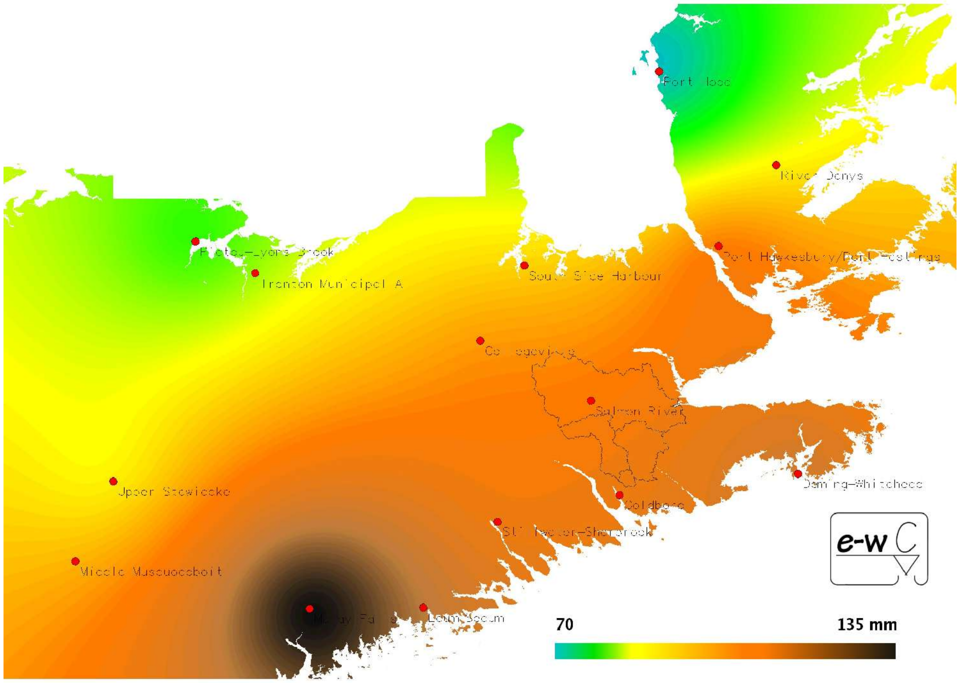


Figure 20 Precipitation distribution – mean June monthly total, 1982-2002.

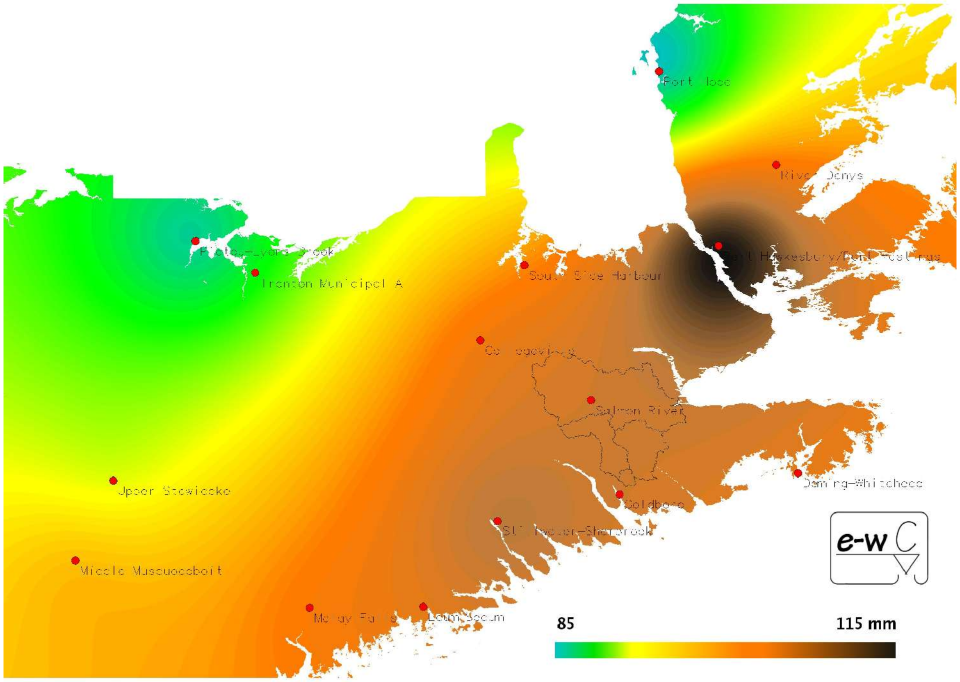


Figure 21 Precipitation distribution – mean July monthly total, 1982-2002.

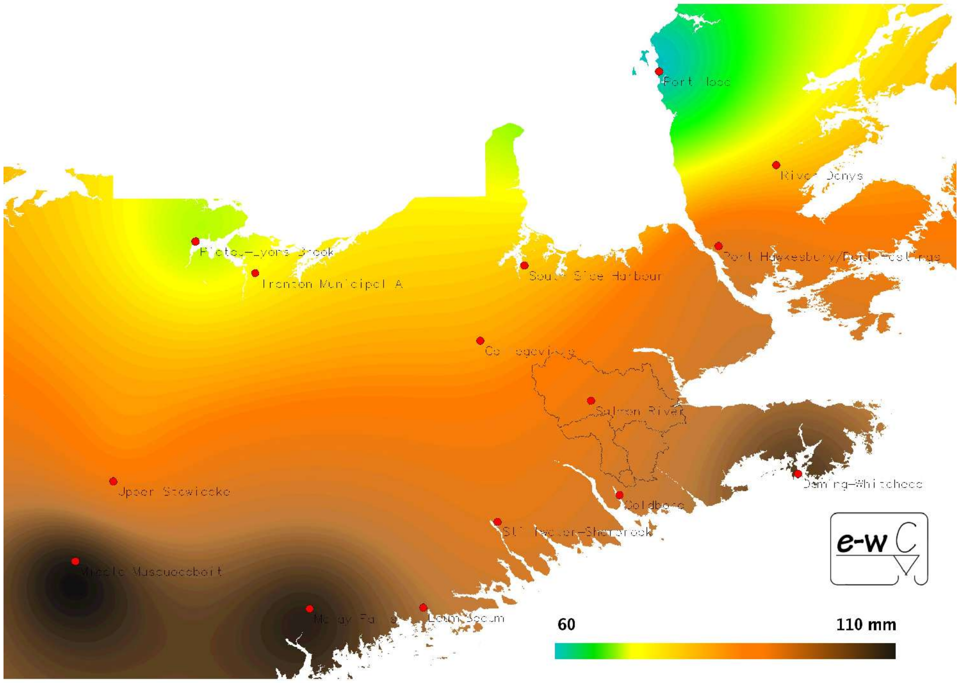


Figure 22 Precipitation distribution – mean August monthly total, 1982-2002.

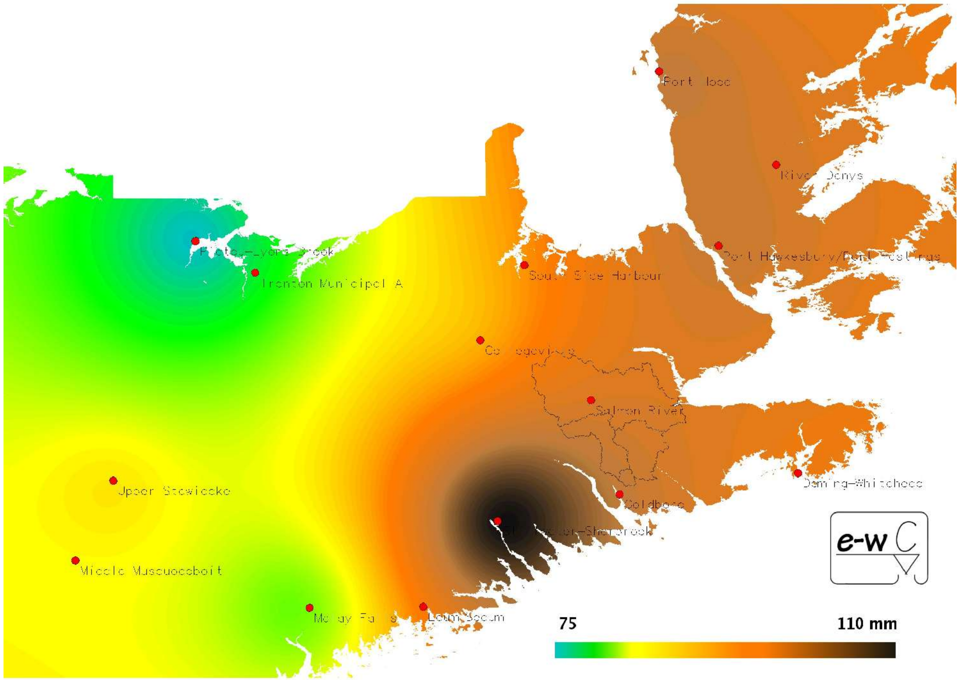


Figure 23 Precipitation distribution – mean September monthly total, 1982-2002.

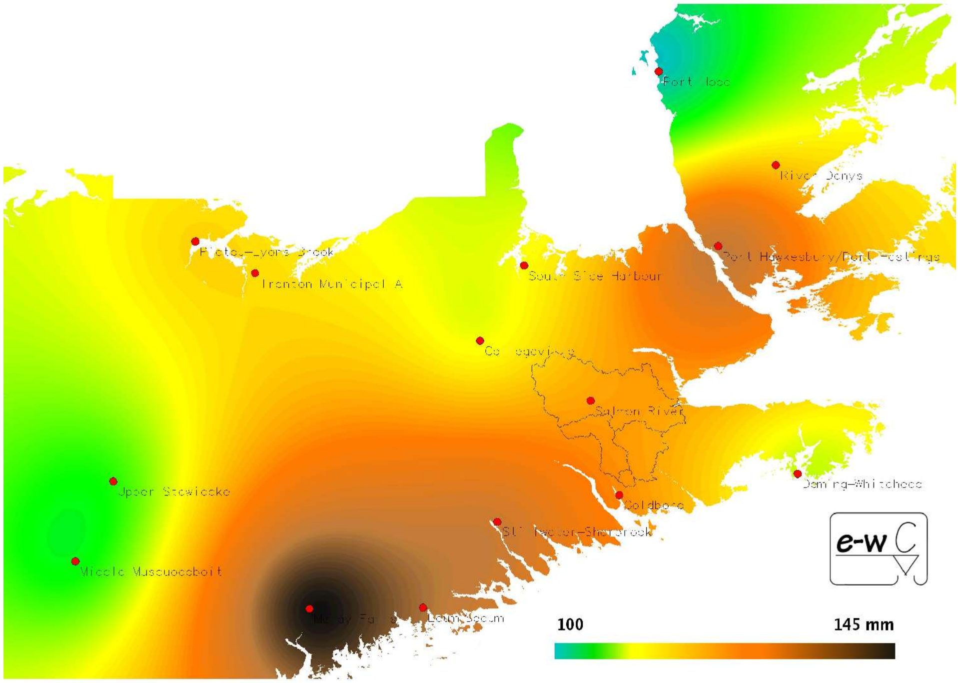


Figure 24 Precipitation distribution – mean October monthly total, 1982-2002.

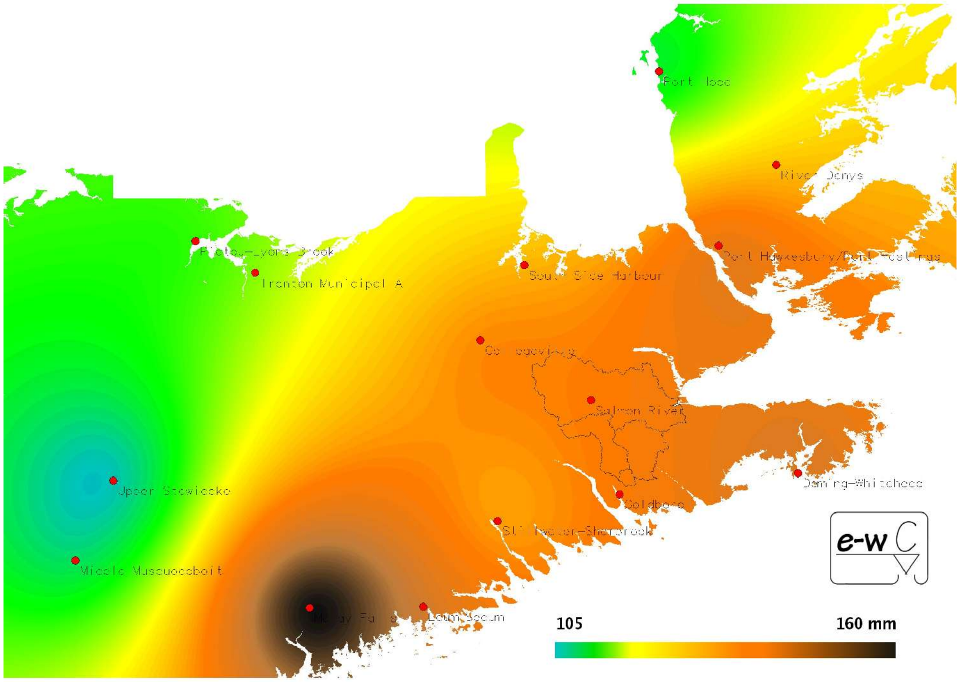


Figure 25 Precipitation distribution – mean November monthly total, 1982-2002.

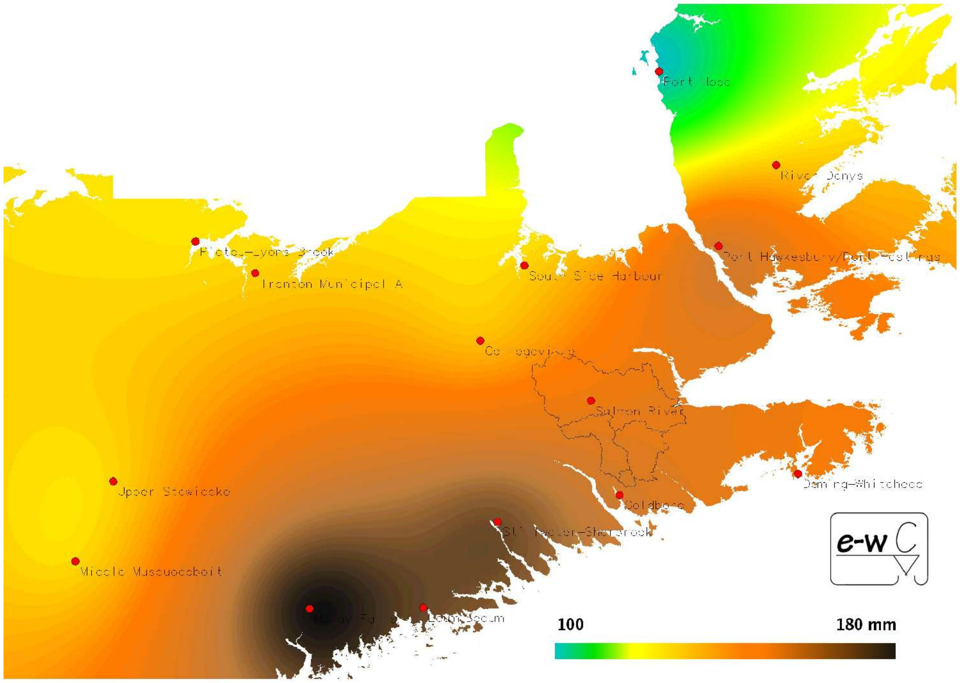
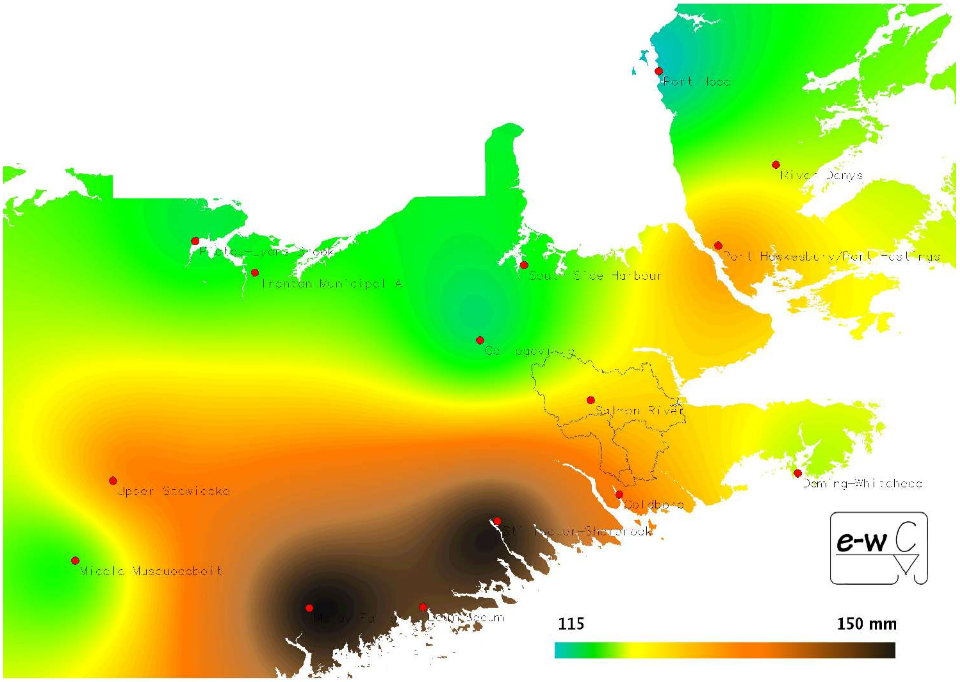


Figure 26 Precipitation distribution – mean December monthly total, 1982-2002.



Drought and flood frequency forecasting

Drought frequency analysis was performed on total summer (June, July plus August) precipitation values for the three nearest Environment Canada stations (Collegeville, Deming-Whitehead and Stillwater-Sherbrooke). For each station, the total summer precipitation was calculated for each year of record. The data was ranked in ascending order and the non-exceedance probability was calculated using:

$$P_{ne} = \frac{m}{(n+1)}$$

where P_{ne} = probability of non-exceedance, m = rank, and n = number of years of record.

The recurrence interval, (return period) was calculated using:

$$T = \frac{1}{P_{ne}}$$

where T = return period in years.

A semi-log graph of the recurrence interval (in years) and precipitation (in mm) was plotted for each climate station. Trend lines were drawn to estimate a range of values for the 50-year, 100-year, 200-year and 500-year summer droughts for each climate station which are presented in Table 10.

Table 10 Summer (June, July, August) drought estimates (in mm).

Station Name	***50-year***	***100-year***	***200-year***	***500-year***
Collegeville	110-115	85-95	65-77	25-55
Deming-Whitehead	100	70-75	37-50	0-15
Stillwater-Sherbrooke	120	85-92	53-70	15-28

Storm frequency analysis was performed on 24-hour, 48-hour and 72-hour precipitation values for the same three climate stations. For the 24-hour events, daily precipitation values were used. The calculations for the 48-hour and 72-hour events required the sum of the daily precipitation values for every two and three consecutive days respectively. For each station, the total event precipitation was calculated for each year of record. The data was then ranked in descending order and the exceedance probability was calculated using:

$$Pe = \frac{m}{(n+1)}$$

The recurrence interval, (return period) was then calculated in days and converted to equivalent years. A semi-log graph of the recurrence interval (in years) and precipitation (in mm) was plotted for each climate station for the 24-hour, the 48-hour and the 72-hour storm events. Trend lines were drawn in order to estimate a range of values for the 100-year, 200-year and 500-year storm events for each climate station and the results are presented in Tables 11, 12 and 13.

Table 11 100-year storm events (in mm)

Station Name	***24-hour event***	***48-hour event***	***72-hour event***
Collegeville	150-204	176-240	180-250
Deming-Whitehead	135	170	185-188
Stillwater-Sherbrooke	145-150	185-192	208-213

Table 12 200-year storm events (in mm)

Station Name	***24-hour event***	***48-hour event***	***72-hour event***
Collegeville	164-212	186-258	196-270
Deming-Whitehead	138-142	179-185	194-202
Stillwater-Sherbrooke	155-162	200-210	222-230

Table 13 500-year storm events (in mm)

Station Name	***24-hour event***	***48-hour event***	***72-hour event***
Collegeville	184-220	204-280	210-300
Deming-Whitehead	144-153	191-204	208-220
Stillwater-Sherbrooke	171-179	220-230	242-251

4. Detailed hydrographic analysis

The rainfall models noted above give a value of 120,400,662 m^3 as total amount of water available from precipitation falling onto the Isaac's Harbour River watershed during the year 2002. When compared to total discharge at ML1 of 118,752,483 m^3 for the same period, this suggests a value of C=0.99 as runoff coefficient for the Isaac's Harbour River watershed – a value that is considered much too large in light that there is perhaps 20 to 30 percent water loss from evapotranspiration and groundwater recharge (little of which would be expected to emanate as base flow at ML1).

One hypothesis to help explain the large value obtained for C involves groundwater contributions from the Salmon River watershed (situated at higher elevation and immediately north of the Isaac's Harbour River watershed); deemed possible in light of the presence of sandstone with relatively high porosity and permeability beneath the Salmon River watershed, and northwest trending faults present within the Isaac's Harbour River watershed and basement rock which are likely to be present under and in hydraulic connection with the Salmon River sandstone aquifer above. Groundwater computer modeling would help to confirm such a hypothesis. However, there is insufficient groundwater data to warrant doing groundwater modeling – the Isaac's Harbour River watershed and parts of the Salmon River watershed of concern are sparsely populated and thus contain too few wells to provide a proper groundwater database. Therefore, it was necessary to further evaluate the watershed by doing detailed analysis of the hydrographs in an effort to separate quick flow (surface rain event flows) from base flow (steadier groundwater contribution to streams).

Two stream-flow hydrographs were created showing stream-flow (m^3/s), instantaneous precipitation (mm) and total precipitation (mm). One hydrograph (at ML1, shown in Figure 27) was used to describe the Isaacs Harbour River Watershed and the other (combining GB1, GB2 and GB3 onto one chart) to characterize the Gold Brook sub-watershed for comparative purposes. The precipitation used was actual rain gage data collected at Goldboro. Base flow separation was performed manually by corresponding hydrograph response peaks to individual precipitation events, and drawing a straight line to represent the baseline condition beneath each peak. A detailed view from ML1 is presented in Figure 28 to help illustrate this.

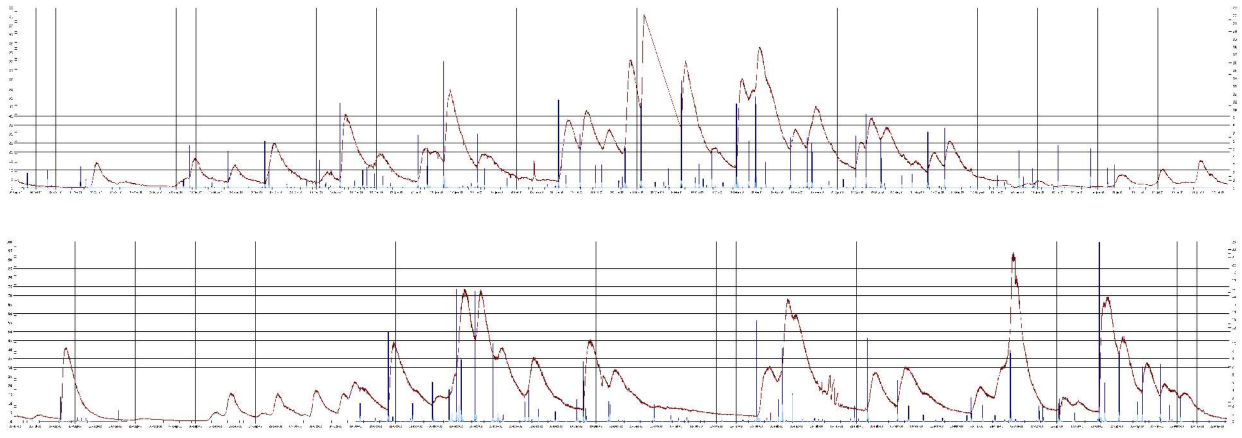


Figure 27 ML1 hydrograph with precipitation from Goldboro rain gage, Oct 2001 to May 2003.

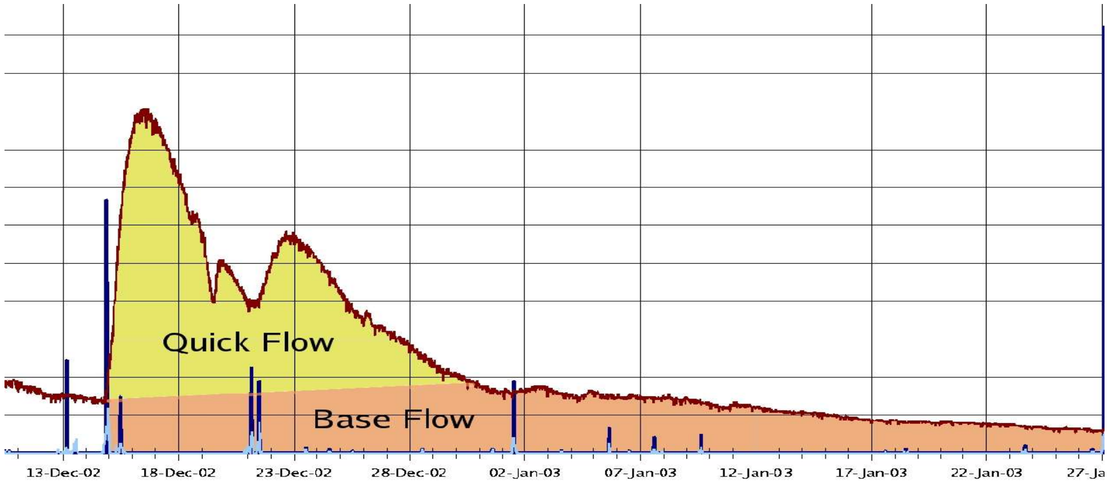


Figure 28. Detail from ML1 hydrograph showing separation into base flow and quick flow

The area beneath all base flow on the ML1 hydrograph was integrated to obtain total monthly base flow for the period October 2001 to May 2003. These values were subtracted from the total flow recorded for the same periods to obtain monthly values for quick flow.

Table 14 shows the average peak delays observed in the hydrographs following individual fall, winter, spring and summer precipitation events in the two watersheds under study. Monthly estimates of total flow, base flow and quick flow (in m^3/s) for October 2001 to May 2003 for Isaacs Harbour River (at ML1) and the Gold Brook sub-watershed system (at GB1, GB2 and GB3) are given in Tables 15, 16, 17 and 18, respectively. Table 15 also shows ratio of total flow to precipitation (TF/P), base flow to precipitation (BF/P) and quick flow to precipitation (QF/P), where the precipitation values (total precipitation falling onto the Isaac's Harbour River watershed) are those defined using GIS.

Table 14 Typical precipitation event to stream-flow peak delay (in hours).

Station Name	**Fall**	**Winter**	**Spring**	**Summer**
ML1	24 - 36	48	24 - 48	36
GB1	6 – 18	24 - 48	6 – 12	6
GB2	48	48 – 72	24 - 36	36 - 48
GB3	18 - 42	24 - 48	24	-

Table 15 Monthly summary for Isaacs Harbour River (ML1).

Month	***Precip. (m^3)***	***Total Flow (m^3)***	***Base Flow (m^3)***	***Quick Flow (m^3)***	***TF/P***	***BF/P***	***QF/P***
Oct-01	5,634,481	1,516,085	828,433	687,652	0.27	0.15	0.12
Nov-01	7,281,637	5,331,479	2,710,218	2,621,261	0.73	0.37	0.36
Dec-01	8,526,869	6,435,641	3,719,646	2,715,995	0.75	0.44	0.32
Jan-02	9,840,439	10,328,155	5,676,480	4,651,675	1.05	0.58	0.47
Feb-02	9,702,234	14,690,627	7,510,770	7,179,857	1.51	0.77	0.74
Mar-02	14,883,402	27,481,652	15,072,012	12,409,640	1.85	1.01	0.83
Apr-02	13,841,780	20,103,119	10,829,556	9,273,563	1.45	0.78	0.67
May-02	7,801,808	8,820,617	5,788,062	3,032,555	1.13	0.74	0.39
Jun-02	7,806,563	1,479,522	1,044,922	434,600	0.19	0.13	0.06
Jul-02	3,573,861	2,400,045	1,340,118	1,059,927	0.67	0.37	0.30
Aug-02	3,432,845	3,940,844	1,099,726	2,841,118	1.15	0.32	0.83
Sep-02	9,615,633	3,079,701	1,451,062	1,628,638	0.32	0.15	0.17
Oct-02	11,753,728	8,869,048	3,444,291	5,424,757	0.75	0.29	0.46
Nov-02	20,847,237	21,375,682	8,680,356	12,695,326	1.03	0.42	0.61
Dec-02	7,301,132	8,924,936	6,104,988	2,819,948	1.22	0.84	0.39
Jan-03	6,967,033	4,984,243	4,150,660	833,583	0.72	0.60	0.12
Feb-03	6,241,024	14,037,745	8,460,078	5,577,667	2.25	1.36	0.89
Mar-03	9,898,641	15,885,776	6,621,264	9,264,512	1.60	0.67	0.94
Apr-03	11,069,070	10,701,359	4,062,265	6,639,094	0.97	0.37	0.60
May-03	6,436,220	6,008,197	4,329,774	1,678,423	0.93	0.67	0.26

Tables 15 through 18 show that the values TF/P, BF/P and QF/P are clearly variable on a monthly and annual basis. Comparing the values for fall (October to December) 2001 to those for fall 2002, the following is apparent:

- the watersheds received substantially more precipitation (86% more in the Isaacs Harbour River Watershed) during the fall 2002 than during the fall 2001,
- the proportion of precipitation contributing to total flow within the watersheds is significantly higher during the fall 2002.

This is likely due to there having been considerably more precipitation recorded for the year 2002, than is shown for the GIS-modeled annual average for the period 1982-2002. Similarly, comparing the values for January to May 2002 (winter/spring 2002) to those for January to May 2003 (winter/spring 2003), it is noted that the watersheds received 38% more precipitation during the winter 2002 than during the winter 2003. Notwithstanding this variability, due to the absence of any other data, the values in columns 3 to 5 of Table 19 were calculated by simply multiplying those in column 1 (total monthly precipitation obtained from GIS) by the ratios in Table 15 (the mean of two months was used where data was available for more than one year).

Table 16 Monthly summary for GB1

Month	***Total Flow (m^3)***	***Base Flow (m^3)***	***Quick Flow (m^3)***
Oct-01	207,161	172,136	35,024
Nov-01	325,985	257,865	68,120
Dec-01	285,659	229,617	56,042
Jan-02	392,961	296,441	96,520
Feb-02	561,526	267,636	293,891
Mar-02	485,556	276,364	209,192
Apr-02	449,011	305,089	143,923
May-02	246,569	208,899	37,670
Jun-02	181,906	154,509	27,397
Jul-02	198,726	158,240	40,486
Aug-02	124,208	87,608	36,600
Sep-02	128,623	81,320	47,303
Oct-02	245,286	157,589	87,697
Nov-02	460,558	264,112	196,445
Dec-02	237,769	160,704	77,064
Jan-03	177,928	128,199	49,729
Feb-03	440,290	278,395	161,895
Mar-03	365,100	217,374	147,726
Apr-03	107,316	87,294	20,023
May-03	61,928	49,856	12,072

Table 17 Monthly summary for GB2.

Month	***Total Flow (m^3)***	***Base Flow (m^3)***	***Quick Flow (m^3)***
Oct-01	523,585	385,011	138,573
Nov-01	1,082,771	752,138	330,633
Dec-01	1,088,869	703,522	385,348
Jan-02	1,471,440	1,013,165	458,275
Feb-02	2,004,065	1,407,050	597,015
Mar-02	3,472,990	2,104,274	1,368,716
Apr-02	3,106,891	1,652,639	1,454,252
May-02	1,373,820	988,829	384,991
Jun-02	1,008,405	700,604	307,801
Jul-02	1,430,051	1,170,426	259,625
Aug-02	1,076,998	488,267	588,731
Sep-02	1,202,145	587,262	614,883
Oct-02	1,990,527	1,124,494	866,034
Nov-02	2,986,559	1,247,885	1,738,675
Dec-02	1,833,189	1,287,581	545,608
Jan-03	861,424	772,563	88,860
Feb-03	2,238,444	1,135,055	1,103,388
Mar-03	2,652,792	1,355,042	1,297,750
Apr-03	2,581,073	1,401,831	1,179,242
May-03	1,605,265	1,274,597	330,669

Table 18 Monthly summary for GB3.

Month	***Total Flow (m^3)***	***Base Flow (m^3)***	***Quick Flow (m^3)***
Oct-01	907,033	685,291	221,742
Nov-01	1,364,898	935,947	428,951
Dec-01	1,266,999	888,754	378,245
Jan-02	1,798,210	1,287,354	510,856
Feb-02	2,864,231	1,906,812	957,418

Table 19 Monthly average values for precipitation (GIS-modeled values) and calculated flow for the years 1982 to 2002 for the Isaacs Harbour River watershed at ML1.

Month	***Precipitation (m^3)***	***Total Flow (m^3)***	***Base Flow (m^3)***	***Quick Flow (m^3)***
January	9,736,045	8,869,995	5,692,556	3,177,439
February	8,076,487	14,553,131	8,090,463	6462668
March	9,359,327	16,378,389	8,192,806	8,185,584
April	9,033,673	11,170,939	5,400,371	5,770,567
May	8,612,891	8,970,270	6,120,498	2,849,773
June	8,328,281	1,578,400	1,114,755	463,645
July	7,418,206	4,981,735	2,781,661	2,200,073
August	7,950,241	9,126,733	2,546,892	6,579,841
September	9,667,652	3,096,361	1,458,912	1,637,449
October	10,867,227	6,490,466	2,670,353	3,820,113
November	12,009,330	11,402,344	4,863,087	6,539,257
December	10,371,420	10,065,137	6,437,667	3,627,469
Total annual	111,430,780	106,683,900	55,370,021	51,313,878

Hydrologic budget calculations

The hydrologic budget is usually calculated on the basis of the water year (October 1 to September 30) because surface water discharge and groundwater storage are generally at a minimum at the beginning and end of this period. However, this period may vary from place to place. At the study area, the water year for the period of 20 months (October 2001 to May 2003) over which stream and precipitation data were collected appears to have been 01 November to 31 October (see Table 15), whereas for the 1982 to 2002 period represented in Table 19, the end of the water year appears to be somewhere between the start to the middle of September.

When stated as an equation including all items that may be involved, the hydrologic budget is:

$$P_r + SurI + SubI + Imp = R + ET + U + Exp \pm \Delta Soil \pm \Delta Ss \pm \Delta Sg$$

where:
P_r = precipitation
SurI = surface inflow
SubI = subsurface inflow
Imp = imported water
R = stream flow (includes surface and groundwater runoff)
ET = evapotranspiration
U = subsurface flow
Exp = exported water
ΔSoil = change in soil moisture storage
ΔSs = changed in surface water storage
ΔSg = change in groundwater storage

Of the many factors that may introduce water into a basin, precipitation and perhaps subsurface inflow are the only contributions of water to the Isaacs Harbour River watershed. On the right side of the equation, runoff, evapotranspiration, and changes in groundwater and perhaps also changes in soil storage (especially for calculations done on a monthly or seasonal basis) are by far the most important. Subsurface outflow is present only in the vicinity of the gaging station. Elsewhere, groundwater would be expected to move toward the Isaacs Harbour River, toward Meadow Lake, or toward tributaries to the river or lake.

Change in soil moisture storage, however, may be an important factor in the water budget, particularly if the budget is calculated on a monthly or season basis. The soil is generally near or above field capacity in the late winter and early spring, and has the greatest soil moisture deficiency in the late summer. On an annual basis, however, the change in soil moisture storage should be small except between wet and dry years. The 2001 water year appears to have been unusually dry and there may be a error in the budget due to the lack of soil moisture data.

About 5.2 percent of the Isaacs Harbour River watershed is covered by surface water, almost all in the form of lakes in the upper reaches of the watershed. Records of uncontrolled lake levels are not available, but this does not introduce serious errors in the water budget because a relative change in lake levels of 0.3 to 0.5 m from one year to the next would amount to less than 2 percent of the total volume of water accounted for on the right side of the hydrologic budget equation.

By eliminating those items of the hydrologic budget which do not apply to the Isaacs Harbour River watershed or which are generally insignificant int eh calculations, the equation for the hydrologic budget reduces to the following form:

$$P_r + \mathrm{SubI} = R + ET \pm \Delta Sg$$

Average total annual runoff (R) for the period 1982 to 2002 is known from Table 19 to be 106,683,900 m^3. The change in groundwater storage is not known, but available data suggests that it may have varied from one year to the next over the 20 months of study records (see Table 15). However, without also having a record of groundwater levels for the area (there are no groundwater hydrographic stations nearby – the nearest one which is drilled into similar bedrock is located at Lawrencetown), it is not clear whether this change may represent an overall increase or a decrease in groundwater storage over this period of record.

Values for ET may vary from place to place and over time, but ET is generally expected to be in the range of 20 to 35 percent of total precipitation (a value of 25 percent is suggested for the study site due to its close proximity to the ocean), or perhaps around 27,857,700 m^3 annually (25 percent of precipitation) for the period 1982 to 2002.

Rearranging terms in the hydrologic budget equation so that the unknowns are on one side, we get:

$$P_r - R - ET = \pm \Delta Sg - \mathrm{SubI}$$

This suggests that SubI or ΔSg (or both combined) may be equal to approximately 41,193,000 m^3

for the year 2002 during which stream and precipitation measurements were taken, or on average, 23,110,800 m^3 per year (about 2,638 m^3/hr) for the period 1982 to 2002.

Notwithstanding any changes to surface water infiltration and/or groundwater flow regimes, one can expect increases in groundwater storage to equal decreases generally over the long term, suggesting a significant value for SubI for the Isaacs Harbour River watershed of around23,110,800 m^3 per year on average (27 percent of total annual runoff) based on period 1982 to 2002. As noted earlier, this subsurface inflow may originate from the Salmon River watershed to the north. Unfortunately, since the Salmon River is not gaged, similar calculations are not possible for the Salmon River watershed to determine whether it may be experiencing a SubI or ΔSg surplus or deficit to match the values estimated for the Isaacs Harbour River watershed.