January 1999 Storms Dumped Snow on Southern Ontario, Yet Limited Streamflow Resulted

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ABSTRACT

On January 2nd 1999, a large storm event resulted in near-record snowfalls in numerous regions of southern Ontario and Quebec, Canada, and brought the city of Toronto to a standstill. This large snowfall was followed by several smaller, yet significant, winter storms. By January 15th, approximately 100 cm of snow had fallen in many parts of southern Ontario, including the Grand River basin. This accumulation of snow was one of the greatest in the Grand River basin in a number of years. At the time, local authorities expressed concern for snowmelt flooding. A statistical analysis of the 1999 snowpack depth and snow water equivalent (SWE) showed that the Gumbel Extreme Value best fit the distribution of data, and revealed that the snow depths were the largest on record with some return frequencies longer than 200 years. However, the amount of water in the snowpack was not substantial, with the return period for SWE, being small (2 to 10 years). Above freezing temperatures occurred in mid-January partially melting the pack and produced some streamflow. Prior to this partial melt, the spring snowmelt was expected to cause major flooding along the Grand River and its tributaries. No flooding occurred, and the spring peak streamflow was among the lowest on record.

Key words: snowfall, depth, SWE, streamflow, return intervals

INTRODUCTION

Hydrologists know the difference snow depth and snow water equivalent, however, the general public does not. Snow depth (SD) is an easily identified measure—it is the amount of snow on the ground given as a measure of length, and can be a blessing for some, such as outdoor enthusiasts, while a curse for others, such as commuters (Murphy, 1995; Chisholm, 1995; Mergen, 1997). Once explained, snow water equivalent (SWE) is easily understood as the amount of water is the snowpack when melted, yet *insitu* assessment is not intuitive (eg. Chisholm, 1995).

From January 2nd to 15th of 1999 a series of five snowstorms dumped record snowfalls across much of southern Ontario. These storms were called Toronto's Snowstorm of the Century (Environment Canada, 2000) and shut down numerous communities, including most of the city of Toronto. Snow removal budgets were quickly exhausted for Toronto and surrounding areas (Environment Canada, 1999). After the frustrations of the snowfalls had subsided, the vast snow accumulations then presented the potential for large snowmelt induced flooding. On the 16th, temperature increased to warmer than freezing and persisted for a week, enabling accumulated

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snow ice to began to melt. The mayor of Toronto stated that removal of snow in residential was important to reduce the potential for flooding (Moloney, 1999). North of Toronto, Tom Hogenbirk, an engineer with the Lake Simcoe Conservation Authority, warned that the warmer temperatures were melting ice in some areas, increasing water flows and causing flooding (Toronto Star, 1999). To the west of Toronto in the Grand River Valley, Jim Reid, a spokesman for the Grand River Conservation Authority, stated that the forecasted warmer temperatures and rain could contribute to flooding (Kirk, 1999). Two years earlier snowmelt flooding in the Red River Valley had caused \$815 million in damages in Canada (Office of Critical Infrastructure Protection and Emergency Preparedness, 1999) and the potential for flooding from the January 1999 southern Ontario snowstorms became a definite possibility.

This paper intends to discuss the snowpack and subsequent snowmelt streamflow that resulted from a series of large snowstorms across southern Ontario during the first two weeks of January, 1999. While the city of Toronto experienced larger snowfalls than the Upper Grand River basin, this study will focus on the later area due to historical flooding events and the limited urbanization (compared to Toronto), and thus only localized snow removal and redistribution. Statistical analysis will determine the return frequency of SD, SWE and streamflow (Q) for the Upper Grand River Basin. A regression between Q-SD and Q-SWE will further illustrate the relationship between snowpack properties and the resultant streamflow for the winter of 1999 across serval sub-basins of the Upper Grand.

FLOODING AND BLIZZARDS IN CANADA

Eleven of the seventeen major flood events in Canada since 1923, that caused 51% of the total \$6.5 billion dollars in estimated damage, were caused by snowmelt (Office of Critical Infrastructure Protection and Emergency Preparedness, 1999). The non-snowmelt flooding was either induced by tropical storms and hurricanes, such as the Hurricane Hazel flood in southern Ontario in October of 1954 that caused \$1.03 billion in damages, or by the development of severe anomalous storms, such as the Saguenay River flood in July of 1996 that caused \$1.5 billion in damages. In Canada, snowmelt flooding does not cause more damage, since a majority of the population lives in areas where snowfall contributes only 10–30% of the annual precipitation (Fassnacht, 2000).

STATISTICAL ANALYSIS OF FLOODING AND SNOW

A variety of probability distributions and methods have been used for flood frequency analysis, as summarized in by agency Technical Reports (eg. National Research Council, 1988; World Meteorological Organization, 1989; National Research Council Canada, 1989). Common continuous distributions used in flood frequency analysis include Log–Normal, Pearson Type III, Log–Pearson Type III, and Gumbel Extreme Value Type I. The Log–Normal distribution considers that parameters do not have negative values and the logarithms of the values are normally distributed. The Pearson Type III distribution employs the mean, standard deviation with a frequency factor that is a function of the recurrence interval and skewness. To reduce the skewness of the Pearson Type III distribution, the Log–Pearson Type III distributions uses the logarithms of the precipitation or discharge data to determine the mean and standard deviation and utilizes the same set of frequency factor as the Pearson Type III distribution. The Gumbel distribution uses a variate computed solely on the desired return period.

There has been a lesser focus in the application of frequency analysis to snow data. McKay and Thompson (1968) applied normal and extreme value distributions to snow density estimates to estimate return periods for SWE from snow depth measurements. No assessment of the fit of the distributions was undertaken. Thom (1966) stated that the cumulative nature of snowpack and a lack of sample data discounted the use of Fisher–Tippett Type I Extreme Value and Fréchet distributions to fit annual maximum SWE, but the Log–Normal and Gumbel distributions were used successfully. Thom (1966) noted that the binary nature of snow-cover, i.e., it is present or not, created a problem in applying a distribution to snow data with values of zero and focused efforts on fitted mixed distributions to account for zero values of maximum SWE. Tobiasson and Redfield (1976) used the chi-square goodness-of-fit test to demonstrate that the log–normal distribution fit annual depth maxima best, better than the Gumbel and Log–Pearson Type III distributions, whereas Nkemdirim and Benoit (1975) used the Gumbel distribution to estimate return periods for annual maximum one-day snowfalls.

CLIMATOLOGY AND HYDROLOGY OF THE STUDY SITE

Climatology

Across the Upper Grand River Basin in southern Ontario, snow constitutes 20–30% of the annual precipitation (Fassnacht, 2000). The precipitation in the area is caused by the meeting of frontal systems. The Jet Stream often runs near the area, as well in the winter Arctic systems meet warmer Maritime systems. In the summer localized convectional thunderstorms can be frequent, and such storms are observed on occasion in the winter. Winter storms can be lake effect, and snowfall is heaviest in the northern area. The two important factors in determining the amount of snowmelt runoff in a particular watershed are the snowcover distribution over the watershed and SWE.

Hydrology

Streamflow in the Upper Grand River of southern Ontario, Canada was gauged at five hydrometric stations by Water Survey of Canada (Figure 1 and Table 1). The peak annual flows in the Grand River are usually caused by spring snowmelt, which typically occurs in late March or early April, although the largest flows are from extreme rainfall events. The gauging station at Galt (02GA003) is of hydrological importance, as several large storm events have caused extensive overbank flooding in the Galt area. In particular, the impact of Hurricane Hazel, which yielded up to 7 inches of precipitation in some parts of the Grand River Valley, caused the maximum daily observed streamflow of 1140 m^3/s on the 16th of October, 1954. Extensive flooding in May of 1974, with at peak flow at Galt of 855 m^3/s, resulted from a combination of snowmelt and large rainfall events (Wert, 1998), and prompted the construction of dykes and leeves throughout the Galt area in order to prevent future flooding. Streamflow at Galt is regulated by several reservoirs. The streamflow on the Speed River below Guelph is also regulated, however the remaining three hydrometric stations in basin are not regulated (Table 1).

Snow depth and snow water equivalent (SWE) are measured at eight snowcourse sampling stations in the Upper Grand River Basin (Figure 1 and Table 2). The snowcourses are sampled approximately bi-weekly (eg. January 1, January 15) by the Grand River Conservation Authority (GRCA). The data are archived by the Streamflow Forecasting Centre of the Ontario Ministry of Natural Resources.

THE ONTARIO SNOWSTORMS OF JANUARY 1999

On January 2nd, 1999, a low pressure storm system originated in the Gulf of Mexico and traveled north, through the midwest United States. This storm resulted in near-record snowfalls in numerous areas including southern Ontario and Quebec, where up to 40 cm of snow fell. This large snowfall was followed by several smaller, yet significant winter storms. These storms, which occurred from January 2nd to 15th, 1999, were considered the number 1 weather story in Canada in 1999 (Environment Canada, 1999) and were called Toronto's Snowstorm of the Century (Environment Canada, 2000). Environment Canada’s (1999) description of the storms events was as follows:

> *By the first day of winter in 1998 (December 21), Toronto had recorded only 4 cm of snow—the second lowest amount in 155 years of weather record-keeping in the city. But just 12 days later, a series of storms stalked the downtown core dumping nearly a year's amount of snow in less than two weeks. The worst storm hit on January 2, when much of*

> *southern Ontario—from Windsor to Kingston—was buried in snow between 20 and 40 cm, affecting more than five million people. In total, at least eleven people died and thousands of passengers at the Toronto airports were stranded on one of the busiest days of the year. Four additional storms ensured the snowiest 2-week period since 1846. In all, the downtown station recorded the greatest January snowfall total with 118.4 cm and the greatest snow on the ground at any one time, with 65 cm.*

As recorded at the University of Toronto weather station, operating since 1840, January 1999 had the second largest monthly cumulative snowfall on record with 118.4 cm, exceeded only in March 1870 with 158.5 cm (Gough, 2000). The mean annual snowfall is 139.2 cm with 36.4 cm falling on average in January (Gough, 2000) at this Toronto station.

The major snowfalls of the first two weeks of January 1999 were followed by several periods of above-zero temperatures resulting in significant snowmelt. These periods of relatively mild weather (5°C maximums for several days) are unusual in winter in the northern parts of the Grand River Basin, where warmer temperatures are not typically experienced until late March or early April. As a result, much of the snowpack melted periodically throughout the winter rather than in the major spring snowmelt that usually occurs in the basin.

Table 1. Description of the five hydrometric stations operating within the Upper Grand River Basin. Also included are the mean annual flow and the period of record used in the analysis.

gauge number	location	total drainage area (km^2)	latitude (N)	longitude (W)	mean annual flow (mm/y)	period of record
02GA003	Grand River at Galt	3520	43°21'10"	80°19'01"	325	1961–99
02GA014	Grand River at Marsville	694	43°51'43"	80°16'22"	372	1965–99
02GA029	Eramosa River above Guelph	236	43°32'52"	80°10'59"	341	1961–99
02GA015	Speed River below Guelph	593	43°31'30"	80°15'44"	310	1961–99
02GA023	Canagagique Creek near Elmira	118	43°34'46"	80°30'30"	353	1962–99

Table 2. Description of the eight snowcourse locations in and around the Upper Grand River Basin.

snowcourse number	snowcourse name	elevation (masl)	latitude (N)	longitude (W)	period of record
2001	Cambridge	290	43°23'	80°16'	1972–99
2002	Cananagigue	404	43°38'	80°32'	1966–99
2004	Corbetton	518	44°10'	80°18'	1961–99
2005	Damascus	480	43°54'	80°29'	1972–99
2006	Jessopville	495	44°04'	80°19'	1961–99
2009	Rockwood	404	43°40'	80°13'	1972–99
2010	Spring Creek	414	43°42'	80°47'	1961–99
2012	Waldemar	454	43°54'	80°17'	1961–99

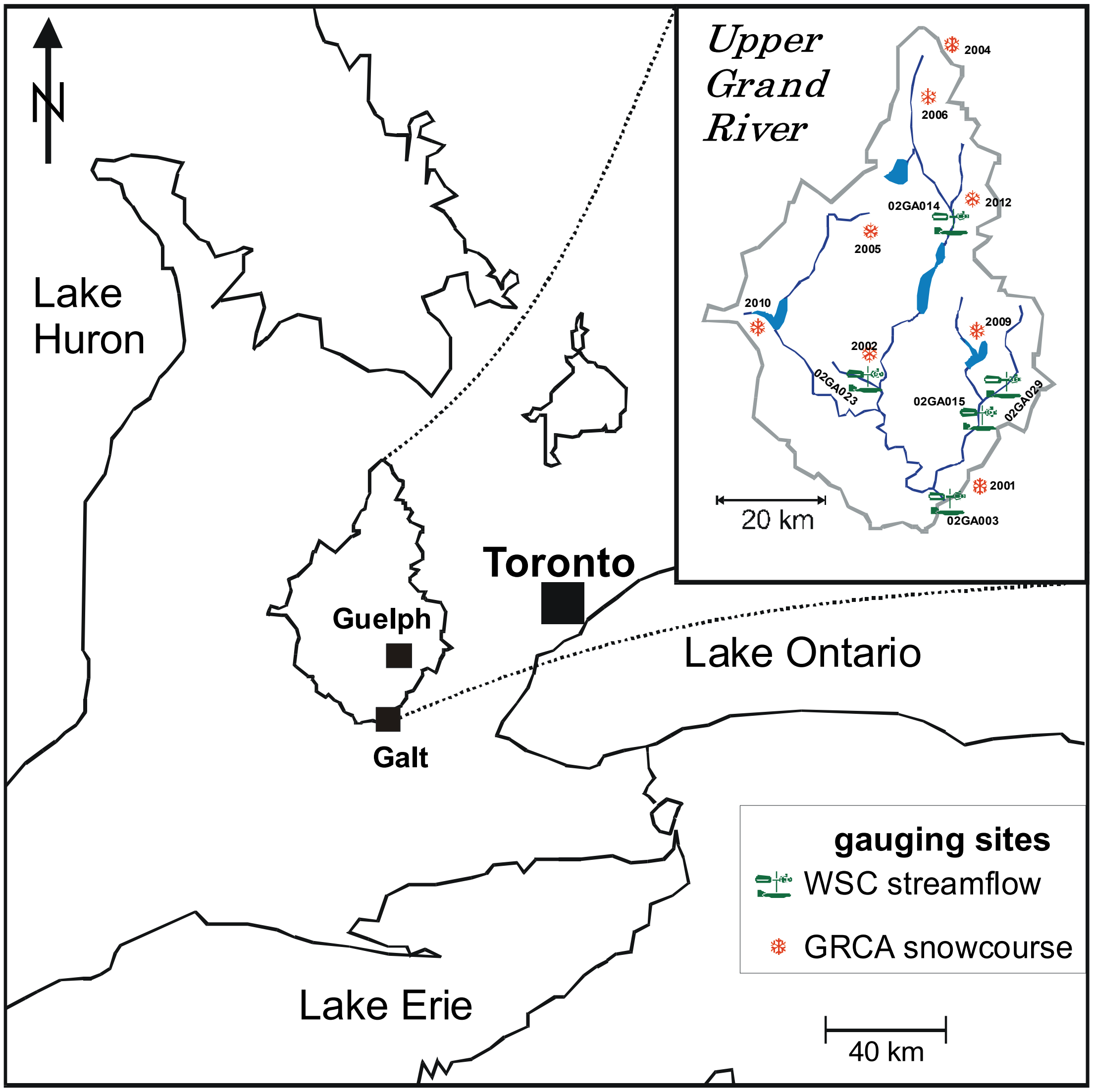

Figure 1. Location of the eight hydrometric stations (G1–G8) within the Upper Grand River Basin and the eight snowcourse sites (2001–2012).

METHODS

Statistical Analysis

Snow depth and SWE data were used in the analysis. Environment Canada (1999) stated that the January 2nd and the four additional storms resulted in the snowiest 2-week period in 153 years of record. Therefore, the 2-week increase and annual maximum values of both SD and SWE were computed for each of the years of snowcourse data on record between 1961–99. These values were determined since two factors that initiated this study were the amount of snow on the ground in mid-January of 1999, and the rapid rate of accumulation. Statistical analysis was used to determine the return frequency of short-term change (2-week increase) and annual maximum SD and SWE. Since SD changes more rapidly than SWE due to metamorphosis, the 4-week increase in SWE was computed to represent longer accumulation periods.

A statistical distribution was selected for the snow and streamflow data for each station based on goodness-of-fit. While all the observation stations were located in the same basin, the fitted distributions were not necessarily the same.

Regression Analysis

To examine how the 1999 peak daily snowmelt streamflow relates to basin average maximum SD and SWE, a linear regression was computed between Q-SD and Q-SWE. The correlation coefficient, the slope and the y-intercept of the lines were computed. The regression equations were used to determine the residual between the computed and observed streamflow based on SD and SWE. The residual was used to illustrate the extent that the 1999 streamflow peaks were outliers.

RESULTS

The Gumbel Extreme Value Type I and the Log–Normal statistical distributions suited the snowcourse SD and SWE data most appropriately, based on a goodness-of-fit test (Tables 3a-b, 4a-c). For the maximum SD, the Log-Normal distribution fit six stations; the Gumbel distribution fit 2001 and 2006 best (Table 3a). The Gumbel distribution fit all other stations and snowpack values (2-week SD increase, maximum SWE, 2-week SWE increase, 4-week SWE increase listed in Tables 3b, 4a, 4b, 4c), except the following: the 2-week increase SD at 2002, the maximum SWE at 2012, and the 4-week SWE increases at 2009 and 2012.

Table 3a. Upper Grand River Basin snowcourse annual maximum snow depth data. Note: [1] the Gumbel Extreme Value distribution is denoted by G EVI, while [2] the Log-Normal distribution is denoted by LN.

station number	average maximum SD (mm)	standard deviation	skew coefficient	1999 maximum	statistical distribution	return period (years)
2001	240	126	0.722	447	G EVI[1]	12.7
2002	354	128	0.352	419	LN[2]	3.7
2004	469	111	–0.051	599	LN	6.7
2005	444	137	0.104	542	LN	4.6
2006	535	175	0.606	732	G EVI	6.8
2009	307	128	0.496	396	LN	4.5
2010	386	122	0.284	455	LN	3.9
2012	420	124	0.218	497	LN	4.1

Table 3b. Upper Grand River Basin snowcourse 2-week snow depth increase data.

station number	average 2-week SD (mm)	standard deviation	skew coefficient	1999 2-week increase	statistical distribution	return period (years)
2001	112	73.5	0.982	236	G EVI	12.7
2002	122	62	0.351	224	LN	8.3
2004	175	94.8	1.55	503	G EVI	244
2005	173	81.3	1.1	384	G EVI	55.1
2006	205	110	1.41	570	G EVI	163
2009	133	73.4	0.942	274	G EVI	18.3
2010	148	68.7	0.845	323	G EVI	45.7
2012	153	62.9	1.11	325	G EVI	62.8

Table 4a. Upper Grand River Basin snowcourse annual maximum SWE data.

station number	average maximum SWE (mm)	standard deviation	skew coefficient	1999 maximum	statistical distribution	return period (years)
2001	53.4	32.8	0.821	62.9	G EVI	2.9
2002	108	61.6	0.77	60.3	G EVI	1.3
2004	134	59.9	1.05	105	G EVI	1.6
2005	131	55.9	0.618	88.3	G EVI	1.4
2006	174	83.8	0.895	135	G EVI	1.7
2009	98.9	62.1	0.868	53.8	G EVI	1.3
2010	117	57.9	1.06	78.7	G EVI	1.4
2012	111	47.2	0.376	86.4	LN	1.5

Table 4b. Upper Grand River Basin snowcourse 2-week SWE increase data.

station number	average 2-week SWE (mm)	standard deviation	skew coefficient	1999 2-week increase	statistical distribution	return period (years)
2001	27.1	18	0.667	33.0	G EVI	3
2002	42.8	23.6	0.68	32.9	G EVI	1.6
2004	49.9	26.5	1.47	86.4	G EVI	9.8
2005	49.5	29.7	1.12	46.5	G EVI	2.1
2006	64.8	29.7	0.538	86.4	G EVI	4.5
2009	44	27.5	1.01	39.4	G EVI	1.9
2010	44.6	21.4	0.8	41.9	G EVI	2
2012	42.2	14.1	0.736	43.2	G EVI	2.4

Table 4c. Upper Grand River Basin snowcourse 4-week SWE increase data.

station number	average 4-week SWE (mm)	standard deviation	skew coefficient	1999 4-week increase	statistical distribution	return period (years)
2001	37.7	24.3	0.714	62.9	G EVI	5.9
2002	60.1	35.5	0.582	60.3	G EVI	2.2
2004	62.2	28.8	0.672	105	G EVI	10.2
2005	62.1	31.4	0.997	88.3	G EVI	4.9
2006	90.5	42.5	0.588	86.4	G EVI	2
2009	50.9	33.8	0.435	52.1	LN	2.8
2010	60.7	31.3	0.71	78.7	G EVI	3.7
2012	55.1	23.5	0.327	66.0	LN	3.4

The 2-week snow depth increases were one-half to three-quarters of the maximum observed depth for 1999 and the same trend was observed for the SWE data (Table 3a and 3b). The 4-week SWE increase was either equal to the maximum observed SWE in 1999 or approached it (Table 3a and 3c). The 1999 maximum snow depth was 20–80 % greater than average, but the maximum SWE was 20–45 % less than average for most stations, except in the southern portions of the basin that receive less snow each year. The average peak snowpack densities were 30–50% lower than average in 1999.

The 2-week depth increases were the most significant of all increases and annual maxima; return periods ranged from 8.3 to 244 years (Table 3b). The return period of the maximum depth ranged from 3.7 to 13 years (Table 3a). The return periods for the maximum SWE were small (<3 years), with the 2- and 4-week SWE increases at snowcourse station 2004 being the only one greater than 6 years (9.8 and 10.8 years, respectively).

The Log–Normal distribution fit the annual daily maximum streamflows best for all gauges except 02GA015 that was fit best with the Gumbel distribution. The return periods for the 1999 annual daily maximum streamflows were insignificant (Table 5), with only the northernmost gauge (02GA014) having a return period more than a fraction greater than one year. This is the only gauge where the streamflow was not the lowest annual daily maximum on record (Table 5).

Table 5. Annual daily maximum streamflow statistics for the five streamflow gauges on the Upper Grand River from 1961–1999, the daily peak flow and return period for 1999, and the best fit distribution for the peak flows.

station	average flow	standard deviation	skew coefficient	highest flow	lowest flow	1999 flow	statistical distribution	return period
02GA003	384	162	0.198	733	73	73	LN	1.001
02GA014	164	56.6	0.472	306	46.6	108	LN	1.18
02GA015	49.8	24	0.792	107	10.7	10.7	G EVI	1.01
02GA023	21	8.55	0.259	45.3	2.03	2.03	LN	1.00003
02GA029	22.2	9.51	0.269	40.8	5.36	5.36	LN	1.003

Typically the peak snowmelt streamflows occur in late March; the 1999 peaks occurred in mid-February, six weeks earlier than average. The annual maximum streamflow generated from snowmelt, measured at the outflow of the basin can be correlated to basin average maximum SWE, as illustrated in Figure 2a-b. The four large streamflow outliers were in increasing order 1980, 1991, 1997 and 1985, while the two low streamflow outliers were 1984 and 1978. Considering all data, the correlation was 0.57, and without the seven outliers including 1999, the correlation was 0.87. The 1999 daily maximum streamflow is substantially less than what would be predicted from a regression fit in Figure 2a ($Q_{\text{modelled - all data}} = 323$ m^3/s, $Q_{\text{modelled - no outliers}} = 313$ m^3/s, while $Q_{\text{observed}} = 73$m^3/s). The relationship between annual daily maximum streamflow and sub-basin average maximum SWE for the Eramosa River (Figure 2b), shows 1984 and 1978 as the low streamflow outliers, and the 1999 streamflow would be substantially underpredicted from regression. For the gauge at Marsville (02GA014), the 1999 streamflow was not the lowest recorded and although it was less than average, as regressed from the SWE, it was not an large outlier.

The basin average maximum snow depth for the outflow gauge (02GA003) and 2 sub-basins (02GA014, 02GA029) were plotted against the annual daily maximum streamflow (Figure 3) to show the variability. For 02GA003, 1994 was a low flow outlier, and for 02GA029, 1984 was a low flow outlier. Aside from these two outliers, the 1999 snowpack yielded the lowest streamflow with respect to snow depth.

DISCUSSION

The January 1999 storms dumped a substantial amount of snow across southern Ontario. The depth of snow associated with the storms was an extreme snowfall event throughout the city of Toronto (Environment Canada, 1999) and in most portions of the Upper Grand River Basin, west of Toronto. The snow depth increased over half a metre in a 2-week period across the most northerly portions of the basin (Table 3b). The return periods for such a snowfall event is 100 years or more for the four northern snowcourse stations, and a return interval of 90 years for the most westerly site (Table 3b). The quantity of water that fell during this period was much less significant; the 2-week increase in SWE was less than 5 cm for all sites except in the northern area. These areas experience more snow, typically from lake effect storms coming off Lake Huron.

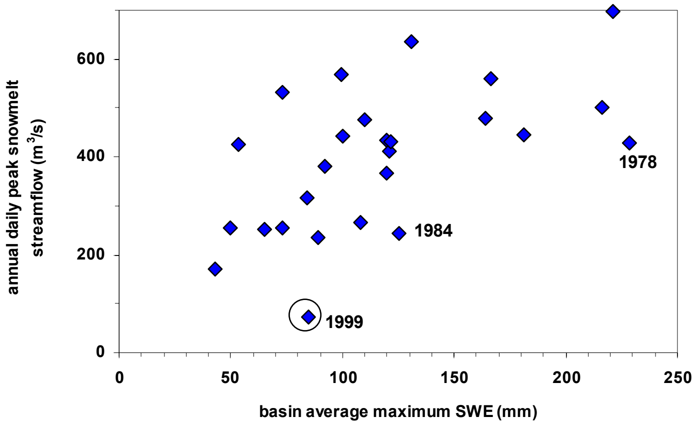

Figure 2a. Relationship between the annual daily peak streamflow from snowmelt at gauge 02GA003 versus the average maximum SWE across the Upper Grand River Basin.

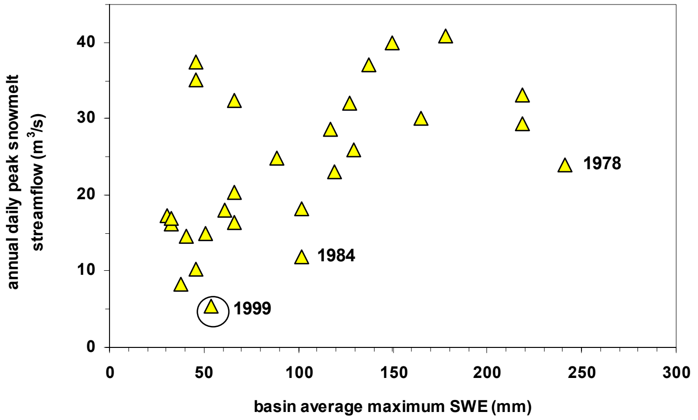

Figure 2b. Relationship between the annual daily peak streamflow from snowmelt at gauge 02GA029 versus the average maximum SWE across the Upper Grand River Basin.

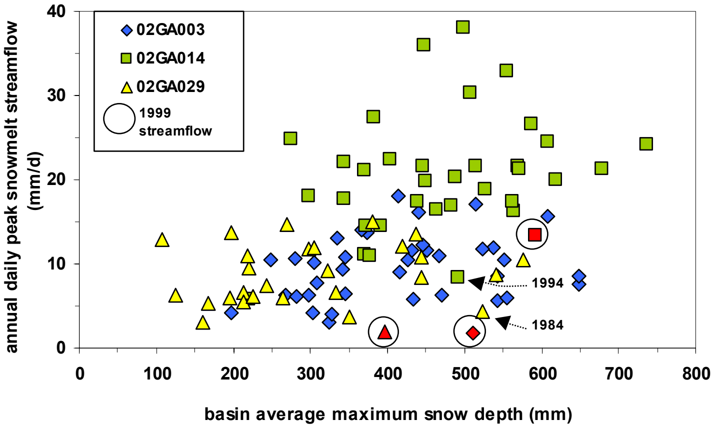

Figure 3. Relationship between the annual daily peak streamflow from snowmelt at three gauges across the Upper Grand River Basin versus the average maximum snow depth.

The return periods for the 2-week depth increases confirms that the snowfall in early January of 1999 was an unusually large event in terms of short-term snowfall. However, as the maximum depth return period values indicate, higher observed snow depths have not been uncommon in the past 40 years throughout the Grand River basin. Deeper snow depths most likely occurred later in the winter after a season of snowfall events. The 1999 largest snow depth and SWE increases occurred early in the winter season. In a more typical winter season, the maximum values would have occurred later in the season and would have yielded higher estimated return periods.

Following the major snowfalls in early January 1999, there were several periods of warmer than freezing temperatures. These periods of relatively mild weather are unusual in winter in the northern parts of the Grand River Basin. As a result, much of the snowpack melted periodically throughout the winter rather than the major spring snowmelt that usually occurs in the basin. The remainder of the winter was drier than usual enabling more snow to be sublimated than on average; typically only 30–40 mm of snow sublimates in southern Ontario. Prior to the partial melt, the spring snowmelt was expected to cause major flooding along the Grand River and its tributaries.

The peak streamflows generated from the snowpack in 1999 were insignificant (Table 5). As there was not a lot of SWE associated with the January 1999 snowfall events, and the winter was preceded by several dry years, yielding deep infiltration that does not contribute to streamflow. The streamflow on the Upper Grand River at Galt (02GA003) is regulated by Conestogo Lake, Guelph Lake and Lake Belwood, thus reservoir filling reduces flows. The second largest daily streamflow at 02GA003 in 1999 was 48.2 m^3/s on January 24th from snowmelt shortly after the series of storms, while the largest single day streamflow occurred on February 13th. Typically both the largest and second largest single day snowmelt streamflows occur on consecutive days, thus the 1999 snowmelt runoff volumes were not as sustained as usual. The water was not available in the snowpack to generate significant snowmelt streamflow in 1999.

Four different probability distributions have been used for the snow data, and five for the streamflow data. The return periods for the streamflow data are insignificant, and thus the distribution used to fit the data is not important. For the snow data, the most important result is the variation in the return periods. All datasets have positive skews in the range of 0.35–1.5, averaging approximately 0.8, except for the annual maximum depth where the skew ranges 0–0.7, with a mean of 0.35.

The maximum 2-week SWE increase return periods did not correspond to those for the maximum 2-week depth increases. Although the maximum 4-week SWE increases have slightly longer return periods than the 2-week values, they are still much lower than the maximum 2-week depth increases.

Snow depth typically represents public perception of the amount of snow present, but SWE is the snowpack property of most use to hydrologists. However, the SWE accumulated in the 1999 snowpack generated less streamflow than expected. This occurred primarily because the maximum SWE occurred earlier in the season, as a result of several large storms, instead of later from numerous smaller storms throughout the winter. The average peak snowpack densities were 30–50% lower than average in 1999, illustrating that a substantial snow depth accumulation would not necessarily yield a significant water content. As well, the basin had endured a series of dry years. Large streamflow were initially expected from the large snowfall events. These streamflows did not occur.

CONCLUSIONS

The January 1999 snowfall events were statistically significant in terms of accumulation snow depths, and this was indicative of the dehabilitating effect that the storms had on the city of Toronto, Ontario, Canada and surrounding regions. However the accumulation of water in the snowpack from the series of storms was not substantial compared to the annual accumulation of SWE. The January snowfalls were followed by a partial melt of the snowpack, and subsequent accumulation was less than the partial melt. In 1999, snowmelt generated peak streamflows were the lowest on record for four of the five streamflow gauging stations in the basin, and the runoff peaks were observed six weeks earlier than usual. The extremity of snowfall events and the state of the snowpack is often taken as an indicator of snowmelt streamflow, however, caution should be taken approximating streamflows only from large snowfall events.

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