An Analysis of the Massawippi Floods of 1982 and 1994

Norman K. Jones

Abstract: Flood events in the Massawippi drainage basin of southern Quebec are a common phenomenon, usually occurring in the spring months. They are often relatively benign events causing low levels of inconvenience to the local populace, however on occasion floods can bring large-scale damage and disruption. Two of the largest floods on record for this basin occurred in April 1982 and April 1994. This study examines the meteorological and hydrological conditions present during both months with the goal of identifying any comparable or contrasting features of the flood events. The Massawippi drainage basin is one of the largest sub-basins in the Saint-Francois River basin, covering approximately 1670 km^2. Its relatively large surface area, high frequency of streams, gentle slope and near-circular basin shape combine to create the geomorphological conditions suitable for frequent flood events. Abundant winter snowfalls, large spring precipitation events and river ice jams provide the necessary hydrometeorological conditions. In April 1982 a sudden, intense rainstorm created a flash flood type of situation. Rapidly rising river levels caused some of the worst infrastructure damages ever reported for the Massawippi basin. In contrast the April 1994 flood, which reached comparable river discharges, was created through a gradual rise of the basin's rivers by a series of rainstorms and the melting of a deep snowcover over a two-week period. Thus, these two events, although comparable in magnitude, contrasted significantly in their character. The 1982 event, because of the sudden development of its peak flow, allowed little time for flood preparations and thus caused much more damage than the 1994 event.

Résumé : Les épisodes d'inondations dans le bassin versant de la Massawippi dans le sud du Québec sont des phénomènes fréquents qui se produisent habituellement au printemps. Ceux-ci, sont souvent des événements relativement bénins qui causent un faible niveau d'inconvénient à la population locale et pourtant, de temps à autre, ces inondations peuvent être perturbantes et causer une destruction à grande échelle. Deux des plus importantes inondations jamais enregistrées dans ce bassin se sont produites en avril 1982 et avril 1984. Cette recherche, qui examine les conditions météorologiques et hydrologiques présentent lors des deux événements, a pour but d'identifier toutes les similitudes et dissemblances de ces deux inondations. Couvrant approximativement 1670 km^2, Le bassin versant de la Massawippi est l'un

Norman K. Jones[1]

[1] Department of Environmental Studies and Geography, Bishop's University, Lennoxville, QC J1M 1Z7

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des plus grand sous-bassin du bassin versant de la Rivière St-François. Sa relativement grande superficie, la fréquence élevée de ses cours d'eaux, la douce dénivellation de ses pentes et sa forme presque semi-circulaire se combinent pour créer des conditions géomorphologiques appropriées pour générer des inondations fréquentes. De nombreuses chutes de neige en hiver, des pluies printanières abondantes et la présence d'embâcles printaniers procurent les conditions hydrométéorologiques nécessaires. En avril 1982, un orage aussi violent que soudain créa une situation de crue subite des eaux. La montée rapide du niveau de l'eau de la rivière a occasionné parmi les pires dommages infra-structurels jamais enregistrés dans la bassin de la Massawwipi. A l'inverse, l'inondation d'avril 1994, laquelle a atteint des débits similaires, fut créée par une montée graduelle du niveau d'eau des rivières du bassin par une série d'orages et la fonte d'un épais manteau de neige sur une période de deux semaines. Donc, ces deux événements, même si comparables en magnitude, ont des caractéristiques diamétralement opposées. L'événement de 1982, dû au développement rapide de son débit maximum, n'a alloué que de peu de temps pour se préparer à l'inondation et a pour cette raison, causé beaucoup plus de dommage que l'inondation de 1994.

Introduction

Analyses of individual flood events are fairly common in the hydrological literature (Jowett, 1979; Riddell, 1984; Holmes, 1995; Munro, 1998; Todhunter, 2001). Riddell (1984) focuses on the relationship between storm rainfall and river flows and lake levels, as does Jowett (1979). Todhunter (2001) analyzes the flood hydroclimatology of the Grand Forks flood of April 1997, with a focus on the physical processes controlling spring snowmelt floods in northern North Dakota. The importance of the geomorphological characteristics of the river basin are incorporated into this study and the key role of river basin terrain in flood behaviour is stressed. In each case, efforts are made to understand the natural processes that control and promote flooding in the particular geomorphic and hydroclimatic environments.

The Massawippi River basin of southern Quebec is prone to frequent and, at times, damaging flood events. During the twentieth century rivers in the Massawippi basin overflowed their banks at several locations 95 times, in 66 of the 100 years (Jones, 2002). A detailed study of flooding during the 1964 to 1994 period found 23 flood events in 19 of the total 31 years (Jones, 1996). The Massawippi basin is not atypical of southern Quebec rivers in this respect. A recent study of the St. Francois River drainage basin, of which the Massawippi is a sub-basin, indicated that all rivers in the basin experience frequent flooding (Saint-Laurent *et al.*, 2001).

On April 17 and 18, 1982 the Massawippi drainage basin experienced the highest river discharges and, according to media sources, the most damaging flooding in the basin's history. The Lennoxville Scott Paper mill was damaged. Beaulieu farm, located just south of Lennoxville, lost 150 prize Holsteins valued at $500,000 and 100's of hectares of prime farmland was flooded and covered with debris. Nearby Wera farm lost 20 hectares of strawberry fields, had extensive property damage and lost a new laboratory facility. In Lennoxville 12 homes were evacuated and several small industries suffered major losses and damage to local roads was in the millions of dollars. A grand total of $15 million in damages overall was estimated by the Eastern Townships office of the Bureau de la Protection Civile du Quebec.

On April 16 and 17, 1994 near-record river discharges and severe flooding in the drainage basin once again occurred. The lowest part of the basin, an area just south of the basin outlet near the town of Lennoxville, again suffered the most damage but the damage was relatively low. Beaulieu farm lost only six Holsteins as most were successfully evacuated to higher ground. Wera farm suffered minimal damage. Over 600 students were evacuated from Bishop's University and minor property damage, mainly from basement flooding, occurred in the town. No official damage estimates were provided but the total was expected to be low.

Lennoxville has in place a flood warning and flood evacuation system based primarily on the monitoring of river levels. However, the town's existing flood warning system was especially ineffective during the 1982 flood event. Other locations throughout the drainage basin, including Coaticook, Stanstead and North Hatley, were also affected by the high river levels of both flood events (Jones, 2002).

This study compares and contrasts the 1982 and 1994 events in order to determine any factors or variables that can help us understand, and perhaps predict, future damaging flood events in this region. Why was damage so much higher during the 1982 event? The geomorphological characteristics of the basin are reviewed and the hydrological and meteorological conditions present during both events are analyzed and discussed.

Study Area

The Massawippi drainage basin, as a sub-basin of the St. Francois drainage basin in southern Quebec, covers an area of approximately 1,670 km^2 and is the second largest in the St. Francois River system. Thus this catchment has a high potential for capturing hydrological inputs, such as rainfall and snowmelt. In total the basin drainage network is composed of over 2,061 km of stream channels. The longest, that of the Coaticook River, exceeds 82 km from its origin at Norton Pond in northern Vermont, to its confluence with the Massawippi River just south of Lennoxville (Figure 1).

A regional slope to the north toward the St. Lawrence River valley has created a drainage pattern of four major sub-parallel streams: Massawippi, Coaticook, Moe and Ascot. However, most stream channels present in the basin, over 76%, are comparatively short often measuring less than 4 km. These first-order streams are the primary suppliers of water to the drainage network. The gradual, continuous land slope has contributed to the existence of not only numerous short streams and a low number of long streams, but also a landscape with very few lakes and a general absence of wetlands. Lake Massawippi, which has been enlarged somewhat by the dam near its north end, is the only relatively large lake present. Smaller water bodies, such as Lake Lyster, Norton Pond and Averill Lake, clustered in the extreme south of the basin, act as water collection areas and stream sources. A minor area of wetlands is present near Ayer's Cliff at the southern end of Lake Massawippi.

Most of the smaller streams in the Massawippi basin are of post-glacial age. Their valleys are poorly developed, cut in glacial sediments for the most part (Larocque *et al.,* 1985). Larger streams occupy preglacial valleys cut approximately 100 m into the general plateau level (Cooke, 1950). Examples of the larger type include the Coaticook, Moe and Ascot Rivers. In all cases the large valleys are graded with few falls or rapids and valley bottoms are moderately wide and flat with moderate meander development. Overall, the large streams in the basin follow the general slope

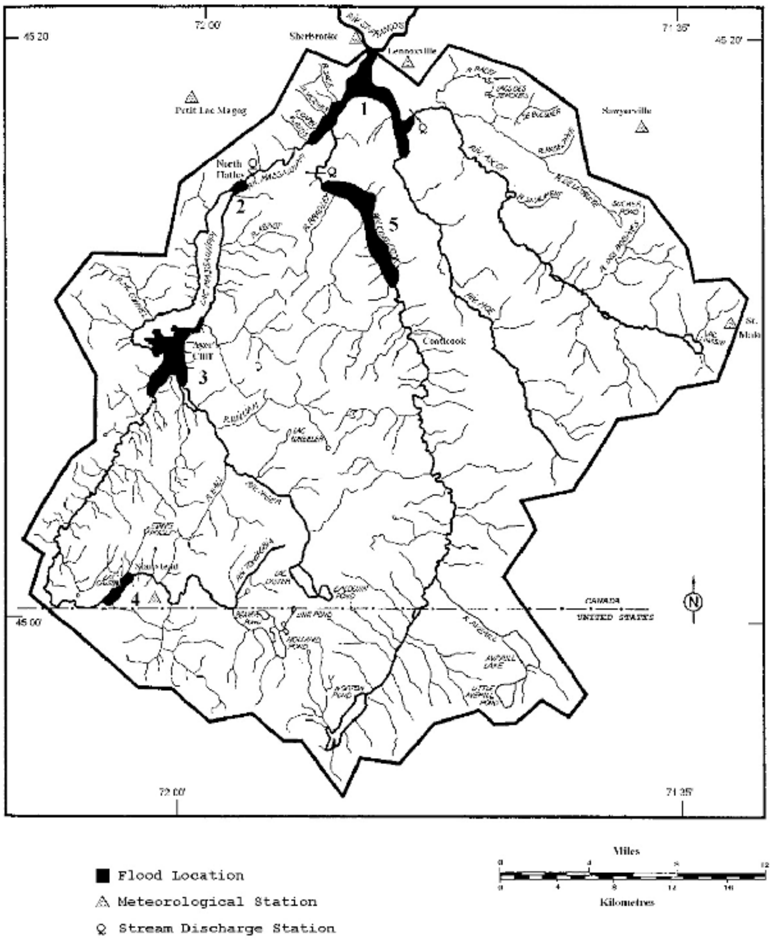

Figure 1. Study area locations.

of the land and are little influenced by the strike of the underlying bedrock. They are superimposed. However, a few anomalous characteristics do occur. Deep, narrow gorges are present at Coaticook, Dixville and Moe River villages. These are recent features where glacial sediment blocked wide channels forcing the streams to develop their present channels past the obstructions.

The study basin has an almost circular shape resulting in near simultaneous delivery of water from most tributaries to the outlet; the longest channel, the Coaticook River, is relatively short, due to this near-circular basin shape. In addition, the relative lack of lakes and wetlands aids this quick response to water input, except along the course of the Massawippi River where Lake Massawippi slows water delivery to the outlet. Jones (1996) estimated an average 24-hour delivery time for floodwaters reaching the basin outlet at Lennoxville following a major rainfall event. A slightly higher than average drainage density for this region, 1.23 km/km^2, and a moderate bifurcation ratio lead to a more dramatic flood peak and contribute to flood severity.

Precipitation

Floods in the Massawippi drainage basin result from heavy rains, snowmelt and river ice jams, usually occurring in March and April (Jones, 2002). In the case of the 1982 and 1994 flood events river ice-jams, which occasionally can exacerbate flooding in this region, were not present (Jones, 1996). Anthropogenic factors, such as floodplain development and bank constructions, often increase the flood hazard in the region (Saint-Laurent *et al.,* 2001). In the Massawippi basin only the dam on the Massawippi River at North Hatley causes some impedance to floodwaters and may increase the flood hazard at this locality. However, anthropogenic factors are of limited influence to the flood hazard here. Heavy rains and snowmelt are considered to be the principal factors in flood creation.

Rainfall and snowcover data are available for this region from Canadian and Quebec government sources. Meteorological data, collected at Lennoxville by Le Gouvernment du Quebec, Ministere de l'Environnment et de la Faune, are used in this study. Snowcover in the Massawippi area is measured at two types of stations: Open and Closed. At Open sites, such as the one at Lennoxville, snow accumulation is measured in an open area having a radius equal to at least two times the height of the nearest vertical obstacle (Pinard, 2003). The Lennoxville station is located within a federal government experimental farm operated by Environment Canada. Open sites are referred to by Environment Canada as 'Snow on the Ground' sites with snowcover being measured daily at 12 UTC (Pinard, 2003). Thus, at Open sites, a relatively continuous daily record is kept.

At the second type, Closed sites, data are taken from snow survey stations within forested areas. These stations collect snowcover data relatively discontinuously, usually three times per month. Also, snow density data are available for Closed sites, making calculations of water equivalent snow depths possible. Due to their protected collection environment, these Closed sites invariably record deeper snowcovers than nearby Open site stations. Data from Le Gouvernment du Quebec, Ministere de l'Environnment et de la Faune snow survey stations at St. Malo, Sawyerville, Stanstead and Petit Lac Magog are used in this study. See Figure 1 for locations of meteorological stations.

In the case of the 1982 flood event, significant rainfall at Lennoxville at the basin outlet initially occurred on April 13 when 6.8 mm of rain fell (Figure 2). The next three days were dry. On April 17, a day before the flood peak, the most severe rainfall took place: 30 mm (Figure 2). Small rain events occurred on April 20-21 (a total of 6.8 mm) and larger ones on April 23 (11 mm) and April 26 (8.3 mm). However by these dates the flood was ebbing. Total rainfall for the month was 81.2 mm, higher than the April average rainfall of 60.2 mm, calculated from 84 years of record. However the largest and most significant rainfall, 30 mm on April 17, is well below the largest recorded rainfall of 36.6 mm in 1950, and the 1 in 100 year event of 44 mm. The April 17 rainfall event has a calculated return period of about 15 years (Figure 3). This was calculated using monthly maximums of daily rainfall data.

Perhaps of more importance is the intensity of this day's rainfall; the 30 mm of rain fell over a relatively short 3-hour period for an intensity of 10 mm/hr. This degree of relatively high intensity rainfall would have had a dramatic effect on river levels in the basin, introducing a large amount of water to a partially frozen, water-saturated landscape.

Relatively thin snowcovers were recorded prior to the 1982 flood event. On March 31, 1982 6 cm of

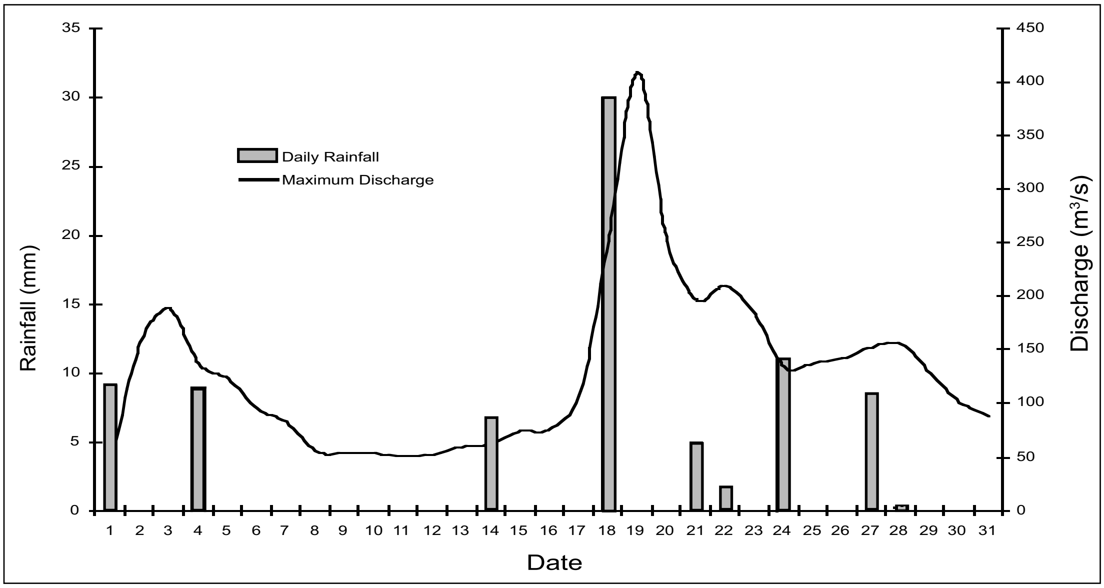

Figure 2. April 1982 discharge and rainfall.

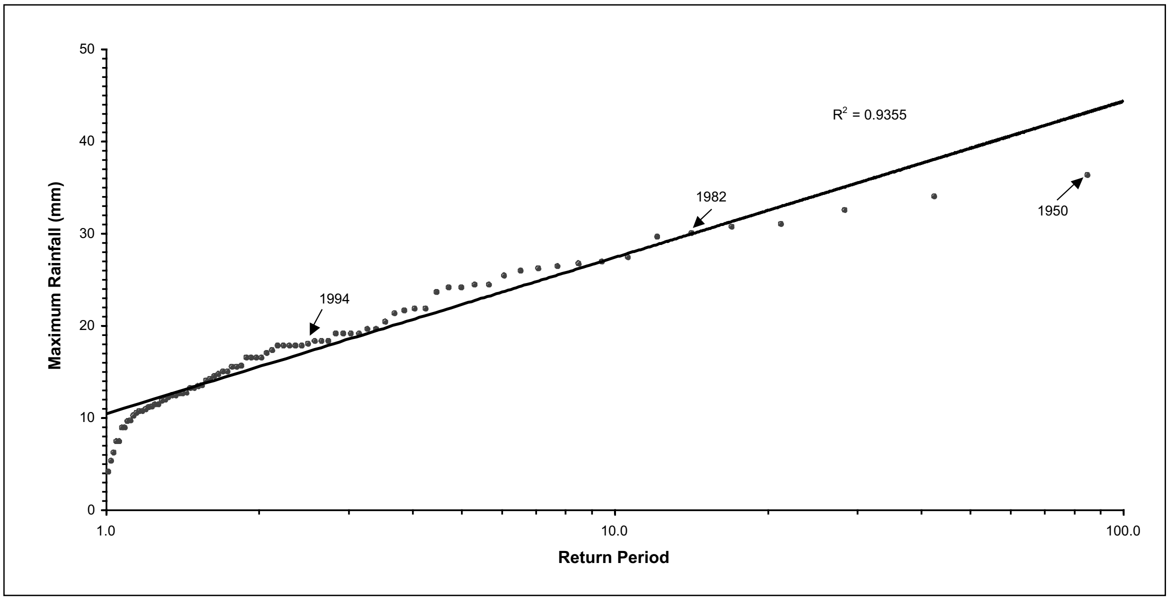

Figure 3. Maximum April precipitation at Lennoxville 1889, 1890, 1892, 1915–1925.

snowcover were measured at the Lennoxville Open site, compared to between 47.8 and 59.2 cm at nearby Closed sites; Sawyerville and St. Malo, located east and west of Lennoxville, respectively (Table 1). By April 13, five days before the flood peak, the snowcovers were reduced significantly. By April 26 the snowcover at all sites was recorded as zero (Figure 4; Table 1). Daily maximum temperatures remained below 10°C for most of early April 1982, dropping below 0°C on April 2, 5, 6 and 7, and rising above 15°C on only April 16 and 17. The Normal average April maximum temperature is 10.5°C (Environment Canada, 2002). The average maximum temperature for April 1982 was 8.5°C, two degrees less than Normal. In fact snowcover depths at Closed sites increased from early to mid April, as did the water equivalent snow depths at the St. Malo station (Table 1). From the available data it can be stated that most of the snow at the Open sites melted between April 13 and April 26. Closed sites may have provided some meltwater input, but a rather low input of water to local streams from snowmelt is to be expected during the flood event. Most of the decrease in 1982 snow depths, seen in Table 1, occurred after the flood peak had passed.

The situation in 1994 regarding precipitation is somewhat different. Five of the first ten days of April recorded rainfall, with April 6 receiving the largest amount, 20.4 mm (Figure 5). Another 8.4 mm fell on April 13 then, one day before the flood peak, 18 mm on April 16. The next six days are the driest period of the month, with only one minor event on April 20 and no large rain events until April 26 when 10.2 mm fell. By this time the flood event had passed. Total rainfall for April was 99.7 mm, 39.5 mm higher than the April average rainfall as calculated from 84 years of record. The largest rain event of April 6 is well below the maximum recorded April event of 36.6 mm in 1950, and has a return period of about 2.5 years, as does the April 16 event. In addition, the rainfall intensity for the latter date was relatively low: 18 mm over 4.7 hours for an intensity of 3.8 mm/hr.

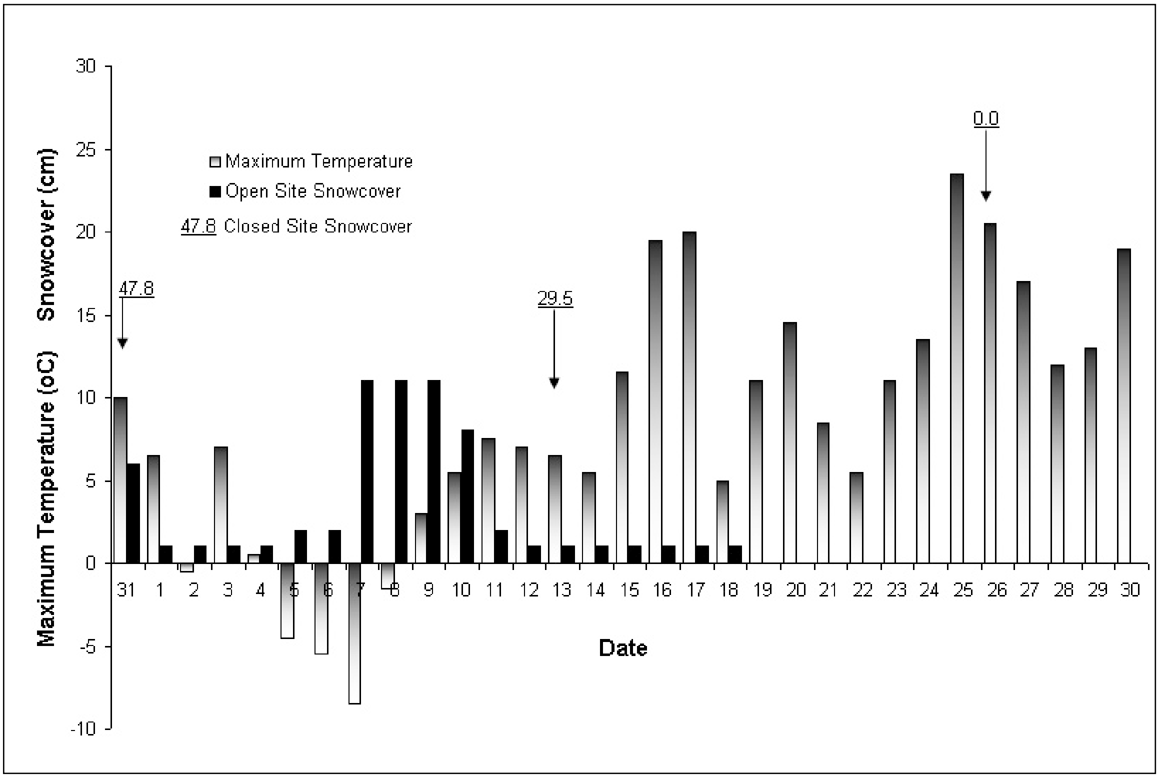

Figure 4. April 1982 temperature and snowcover.

Table 1. Snowcover at closed (forested) sites.

Meteorological Station	Date	Snowcover Depth (cm)	Snow Density (%)	Water Equivalent Snow Depth (cm)	Date	Snowcover Depth (cm)	Snow Density (%)	Water Equivalent Snow Depth (cm)
	1982				**1994**			
Sawyerville	31-Mar	59.2	35.6	21.1	30-Mar	73.2	29.5	21.6
	15-Apr	51.6	38.4	19.8	12-Apr	62.5	29.8	18.6
	26-Apr	0.0	0.0	0.0	26-Apr	19.0	33.7	6.4
St. Malo	31-Mar	55.1	38.3	21.1	30-Mar	77.0	29.4	22.6
	15-Apr	54.6	40.5	22.1	12-Apr	57.2	30.8	17.6
	27-Apr	2.5	44.0	1.1	26-Apr	4.2	38.1	1.6
Stanstead	30-Mar	53.6	35.6	19.1	30-Mar	86.9	28.3	24.6
	14-Apr	40.6	38.7	15.7	13-Apr	63.9	30.7	19.6
	26-Apr	0.0	0.0	0.0	26-Apr	14.0	38.6	5.4
Petit Lac Magog	31-Mar	47.8	36.2	17.3	31-Mar	73.3	29.1	21.3
	15-Apr	29.5	40.3	11.9	13-Apr	53.1	30.3	16.1
	26-Apr	0.0	0.0	0.0	27-Apr	6.1	32.8	2.0

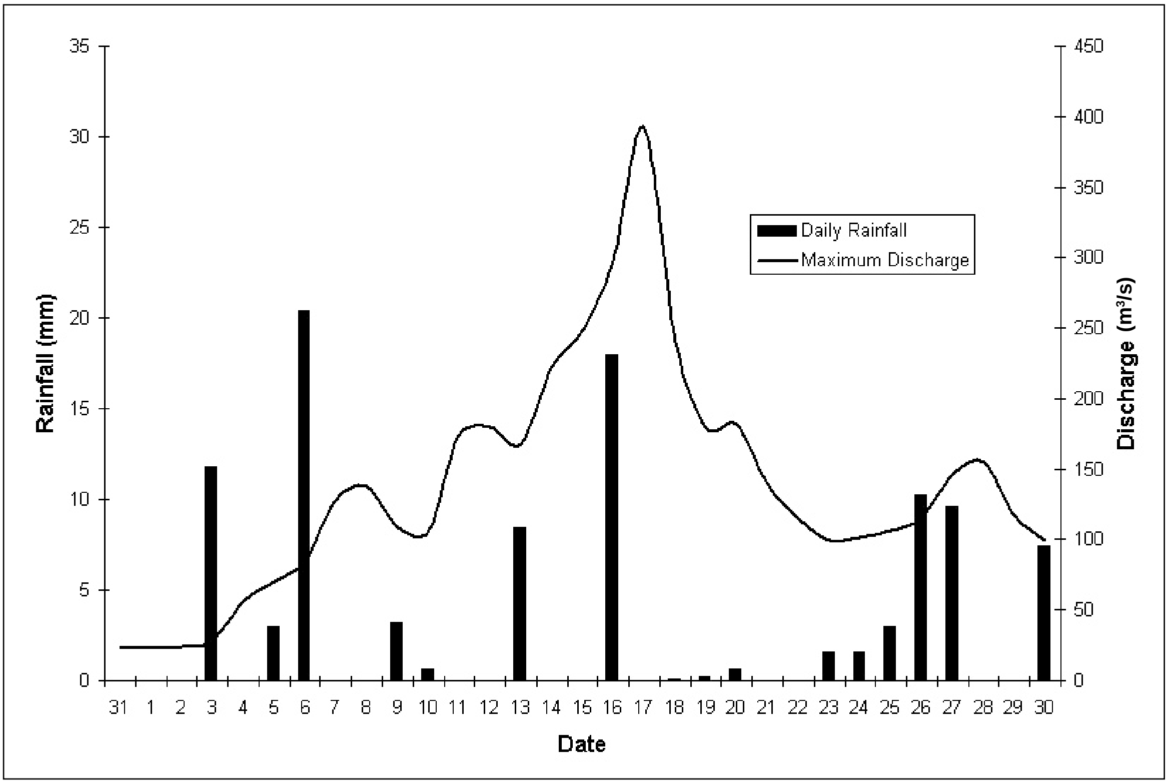

Figure 5. April 1994 discharge and rainfall.

Snowcovers, both at Open and Closed sites, were appreciably deeper in 1994 than in 1982. On March 31 the Lennoxville site recorded 25 cm of snow, while the protected forest sites recorded between 73.2 and 86.9 cm on March 30 or 31. Deep snow persisted in the region at Open sites until April 8 and at Closed sites until at least April 13 (Figure 6; Table 1). The daily maximum temperatures at Lennoxville remained above 0°C for every day of the month except one, April 7, with an overall mean maximum temperature of 9.5°C. The Normal maximum temperature for April is 10.5°C (Environment Canada, 2002) so the April 1994 temperatures were not unusual. However, the above-Normal temperatures recorded for the five days immediately preceding the flood peak likely produced significant snowmelt, contributing to the flood event. Open site snow depths dropped precipitously from April 8 to 13. Although it is impossible to track the exact rate of snowmelt at Closed sites, it is evident that the snow depths dropped on average 48.4 cm from April 13 to 26 at the four Closed sites in the region. As importantly, the decrease in water equivalent snow depths at Closed sites from the end of March to mid-April was consistently higher in 1994 than in 1982 (Table 1).

Flows

Total flow for the Massawippi River at Lennoxville was calculated using data from hydrological recording stations for the Massawippi, Coaticook and Ascot Rivers (see Figure 1). These data are available for the 1982 flood event from Le Gouvernement du Quebec, Ministere de l'Environnement et Faune (see Figure 1 for locations). For 1994, only the Massawippi and Coaticook stations were in operation, thus the Ascot River discharges were estimated using the Coaticook data. A correlation analysis performed from 1717 days when both stations were operating, using the Coaticook data as the independent variable, provided a Correlation Coefficient of 0.88. A strong correlation between the two river flows exists. Following the procedure suggested by Hirsch *et al.* (1993), a regression analysis of the two data sets provided an R-squared value of 0.77 and a regression equation: $y = 0.4758x - 0.1211$. This equation was used to fill in the missing Ascot River discharges from available Coaticook River data for the same dates.

There are no discharge records available for the Moe River. Thus, the needed discharge values were

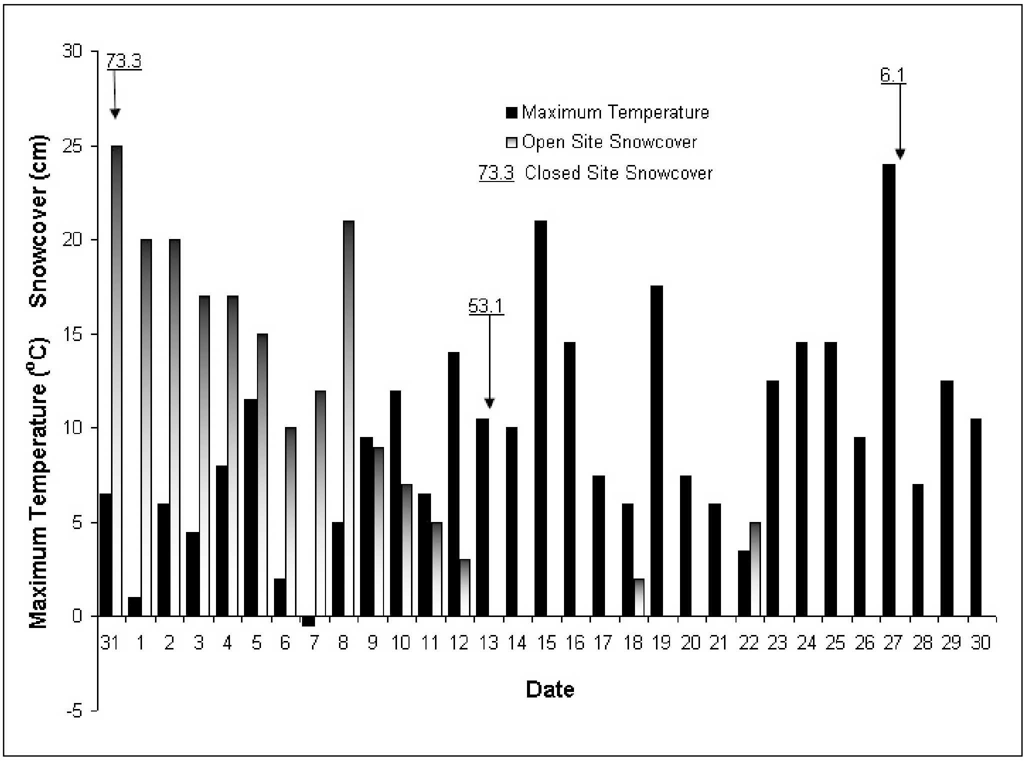

Figure 6. April 1994 temperature and snowcover.

estimated based on the basin area and contemporaneous flow data from the neighbouring Coaticook River (Patton, 1988).

The average April discharge for the Massawippi River basin at Lennoxville is approximately 86 m^3s^{-1}, as calculated from 44 years of available records. Peak discharges during flood events tend to exceed the average flow by 3.6 times for the same dates (Jones, 1996).

During the flood of April 1982 peak discharge reached 410 m^3s^{-1}, the highest peak discharge ever recorded for the Massawippi basin and over four times the average discharge for that date. Until April 16, river discharge had remained below average: 77 m^3s^{-1} on April 15, 107 m^3s^{-1} on April 16. Then on April 17, discharge more than doubled to 252 m^3s^{-1}, and finally on April 18 reached its peak of 410 m^3s^{-1}. The day following the flood peak the flow dropped back down to its April 17 level, dropped below 200 m^3s^{-1} on April 20, and, after a small rise on April 21, returned to near-average levels by April 23 (Figure 2).

The discharge curve for the month of April 1994 displays a quite different shape than the one from April 1982 (Figure 5). Peak discharge of 392 m^3s^{-1} was reached after a slow, quasi-steady climb. At the beginning of April, basin discharge was well below average at approximately 25 m^3s^{-1}, beginning its climb on April 4 following an April 3 rainstorm. From this date, except for small declines on the April 9, 10 and 13, discharge increased steadily to its peak on April 17. During the days immediately following the flood event, basin discharge declined quickly to near-average levels by April 23. Discharge then experienced a brief increase on April 27 and 28 following five days of relatively high temperatures and attendant snowmelt, and five consecutive days with rain; however, no flooding occurred in the basin during this late April period.

Discussion

The 1982 and 1994 flood events in the Massawippi basin represent the two largest events on record, yet they also represent two disparate types of flood events. According to Environment Canada (2002), a Normal April at Lennoxville would have 1.3 days with a maximum temperature <0°C, 28.7 days >0°C and 14.6 days >10°C. April 1994 must be considered fairly Normal, having one day with a maximum temperature <0°C, 29 days >0°C and 13 days >10°C. In contrast, April 1982 experienced five days with a maximum temperature <0°C, 25 days>0°C and 13 days >10°C. However, in 1982 only two of the days with maximum temperature >10°C occurred prior to the flood event. In 1994 a more even spread of warm days occurred. Thus, early April 1982, compared to early April 1994, was relatively colder and drier with a thinner snowcover in protected sites (Figures 4 and 6; Table1).

In April 1982, river flow went from a very benign discharge of 77 m^3s^{-1} on April 15 to a record level of 410 m^3s^{-1} two days later. At the time there existed little snowcover on open fields and low to moderate snowcovers within protected forest locations. The flood therefore was almost totally driven by the high intensity rainfall of April 17.

This event could in fact be termed a spring flash flood. The waters rose quickly after a sudden, intense rainstorm and dropped almost as quickly in the days following. A series of rain events on April 20, 21, 23 and 26 sustained higher-than-average river levels for the last part of the month, but did not produce a flood hazard. Below freezing point maximum temperatures during the first part of April would have kept the ground frozen. Thus, infiltration rates would have been low and most rain would have reached stream channels as surface runoff. Contributions to the flood event from melting snow would have been minimal.

The April 1994 flood event followed a quite different path. Unlike April 1982, relatively warm maximum temperatures during the first part of the month caused a complete melt of deep snowcovers in open field sites and significant melt in protected forest sites, although snowcovers remained relatively deep in protected sites throughout the month (Figure 6; Table 1). Also, pre-flood rainfall events were more frequent and of greater magnitude than in 1982. The combination of a large snowmelt and fairly frequent rainfall inputs in early April eventually produced the gradual climb toward the high river discharges and flood event of April 17. The large rainfall of April 16 was the final significant water input required to create flood conditions. A partially frozen ground surface and saturated soil conditions would have restricted soil infiltration causing rain and snowmelt water inputs to become direct runoff into stream channels.

In contrast to April 1982, this was not a flash flood but a gradual build-up of floodwaters beginning two weeks before, on April 3, when the first rain of April

1994 arrived. This flood could be properly described as a typical regional flood event. The post-flood decline of river levels can be related to the lack of significant rain from April 17 to 26 and the disappearance of most of the basin's snowcover.

Conclusions

Analyses of the April 1982 and April 1994 floods in the Massawippi basin have revealed important differences between the two events. The 1982 flood was of the flash flood type, driven almost exclusively by a high intensity rainfall on April 17; it must be considered an anomaly with respect to the usual types of flood events occurring in the basin. Snowmelt played little or no role in the flood event. In contrast, the April 1994 flood portrayed the character of a typical regional flood event. It occurred after a gradual build-up of river levels with water inputs from a series of rain events and the continuous melt of a deep snowcover.

In 1994 there was a one-day delay between the final large rainfall event and the flood peak. In terms of prediction and response, this delay offered the local populace time to prepare for the rising floodwaters. Throughout the Eastern Townships farmers had time to drive livestock and machinery to high ground. Evacuation of people from homes, schools and businesses proceeded quickly and effectively. In the case of the 1994 flood, a continuous monitoring of the relatively slowly rising river levels and the regional meteorological situation allowed sufficient time for flood warnings to be given and evacuation procedures to be completed.

In the case of the 1982 flash flood event, the monitoring of river levels and meteorological conditions was less useful; the available response time was very limited, thus flood warnings and evacuation procedures had less chance of success. Part of the problem can be related to the unusual speed at which the flood levels rose. For example, in the case of the 1982 Beaulieu farm loss little advance warning was provided: "Three years ago we had a flood, but the water didn't suddenly come in so fast and we had time to take all the cattle out." (The Sherbrooke Record, April 19, 1982). Precipitation levels exceeded expectations by three to four times, there was no notification of news media and little advance warning. The 150 lost cattle drowned while tied in their barn stalls.

The sudden occurrence of the April 1982 flood helps explain why local media reported the 1982 event as far more damaging to local infrastructure than the 1994 one, and why it is referred to anecdotally as the most significant in recent history. The 1982 flood, with its flash flood characteristics and high resulting damages, seems to be an anomaly in the history of flooding in the Massawippi basin. However, further detailed research on all large past floods would be necessary in order to verify this conclusion. Based on the results of this study, in future a more detailed monitoring and analysis of not only river levels and the current meteorological conditions but also of the regional synoptic situation during March and April may be necessary, in order for all potentially damaging Spring floods to be predicted successfully.

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