RECONSTRUCTION OF FLOOD EVENTS AND LINKS WITH CLIMATIC FACTORS: A CASE STUDY OF THE SAINT-FRANÇOIS BASIN

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Abstract

Many rivers of the Saint-François Basin are prone to frequent flooding, which affects several of the region's communities. This was mainly due to heavy spring floods or ice jams on the river, which caused water levels to rise rapidly and river banks to overflow. In some cases, major flooding was caused by heavy summer or fall rain. The first objective of this study deals with the historical and chronological reconstruction of flood events, as well as the identification of the major floods that occurred in the last century. The second objective deals with the analysis of precipitation data and streamflow variations (discharge) over the past century and their link to the recurrence of flooding. Variations in river flow are also studied with respect to the major floods which have occurred over the past century in this area. The historical reconstruction of flood events in the study area was done using data obtained from different sources (e.g. government reports, regional monographs), and the hydrometeorological data provide from the database of governmental agencies. It can be noted that the flood rate has been on the rise since the 1970s, especially from 1970 to 1990. There appears to be a certain decrease in the flood frequency after this period. The fluctuations noted in terms of the rainfall and hydrological data follow roughly the same trends, which can also be found in flood frequency variations. The hydroclimatic factors (precipitation, streamflow) appear to play a major role in the increase of flooding in this area. Furthermore, anthropogenic factors may play a role in the exacerbation of flooding, but their impact is still difficult to determine.

Résumé

Plusieurs rivières du bassin de la rivière Saint-François sont affectées par de fréquentes inondations, touchant ainsi plusieurs municipalités sises le long de ces cours d'eau. La plupart de ces inondations sont dues aux crues printanières et aux embâcles qui causent un rehaussement rapide du niveau des eaux et un débordement des rivières.

Des inondations importantes sont parfois causées par de fortes pluies estivales ou automnales. Le premier objectif de cette étude est la reconstitution chronologique des événements d'inondation, ainsi que l'identification des inondations majeures qui se sont produites depuis un siècle. Le deuxième objectif est l'analyse des variations pluviométriques et d'écoulement en rivière (débits) et leurs liens possibles avec la récurrence des inondations. Les variations de débits des rivières sont aussi examinées en regard des inondations majeures qui se sont produites depuis plus d'un siècle dans cette région. La compilation historique des données des inondations est basée sur la consultation de différentes sources documentaires (rapports gouvernementaux, monographies régionales, etc.), alors que les données hydrométéorologiques proviennent principalement des bases de données des agences gouvernementales. On peut noter une augmentation des inondations depuis les années 1970, avec une hausse plus marquée entre la période de 1970 à 1990. Après cette période, on note une certaine diminution de la fréquence des inondations. Les facteurs hydroclimatiques (pluviométrie, écoulement) apparaissent comme des facteurs clés dans l'explication de l'augmentation des inondations. Cependant, les facteurs anthropiques doivent également être considérés comme des facteurs d'aggravation des inondations, bien que leurs impacts demeurent encore difficiles à mesurer.

Introduction

Recently, we have seen in Canada a growing number of studies dealing with climatic change and its impact on the hydrologic regime (Leith and Whitfield 1998, Yulianti and Burn 1998, Southam *et al.* 1999, Mortsch *et al.* 2000, Muzik 2001, Whitfield 2001). Several of these studies aim at determining the impact of climatic change on hydrologic phenomena by using climatic models. Based on the models used, some areas will see decreased precipitation, which would affect river flow and lake water levels (Leith and Whitfield 1998, Yulianti and Burn 1998, Southam *et al.* 1999, Mortsch *et al.* 2000), while other areas will experience increased precipitation, which could have a marked effect on flood frequency (Shrubsole *et al.* 1993, Akinremi *et al.* 1999, Mortsch *et al.* 2000, Muzik 2001). In fact, these different studies show that the anticipated climate changes will result in varied environmental responses depending on the areas involved, which is why it is important to deal with the issue of global change on a local or regional scale in order to better understand the impact of these changes on river systems. In the context of these different studies, we found it useful to reconstruct for the Saint-François Basin the flood events and precipitation and hydrologic variations on a long scale, i.e. over the last century. The first part of this study mainly deals with the historical and chronological reconstruction of flood events, while the second part deals with the link between the flood events and climatic (precipitation) and hydrologic variations (discharge) on a secular scale. The hydrographic area includes the catchments in the Saint-François Basin and Sub-basins, which contain a number of rivers, several of which are subject to high water levels and flooding.

Location of study area

The study area is located in southern Québec and extends from the south shore of the Saint-Laurent River to northern Vermont in the United States (Figure 1). This drainage basin has an average altitude ranging from 304 m to 762 m, with the higher altitudes located on the American side (Adirondack Mountains). The Saint-Laurent Lowlands and the Appalachian Mountains are the two major phys-

Figure 1. Location of study area with major rivers and gauging stations

iographic divisions that characterize this large drainage basin. There are major variations in the relief of this area from the head of the basin to its outlet. Upstream from the basin, the relief is characterized by mountains, hills and valleys dominated by vast wooded areas, while in the downstream part of the basin there are large plane surfaces mainly dominated by farmland (crops and animal breeding) and urban areas. The basin has a total surface of 10 221 km^2, with the Saint-François River as its main waterway. Our study conducted on the physical and hydrographic characteristics (Saint-Laurent *et al.* 2001) reveals that the middle of the basin serves as a point of convergence for several major tributaries, including the Magog, Massawippi, and Eaton rivers, which feed into the Saint-François. In all likelihood, these rivers considerably modify the hydrological balance of the Saint-François River during freshets or extremely high water levels. The Magog River, for example, which junctures with the Saint-François River in Sherbrooke, adds a considerable volume of water to the Saint-François during flood periods, thereby increasing the risk of flooding in this region (see also Jones, 1999).

Methods

The historical reconstruction of flood events in the study area was done using data obtained from different sources (e.g. government reports, regional monographs). An initial reconstruction of the flood events was compiled using flood records and other documents provided by the Ministère de la Sécurité civile (DRMC) basically covering the period from 1964 to 1998 (Saint-Laurent *et al.* 2001). Flood events prior to 1964 were reconstructed using different documents, including reports from the Quebec Streams Commission (1912–1952), a review of various local newspapers indexed by the Société d'histoire de Sherbrooke, as well as regional monographs and published papers (Jones 1999, 2002, 2004; Saint-Laurent and Saucet, 2003). Local newspapers and government archives proved to be an important source of information for identifying flood events. In fact, this type of document source was often used in other studies for historically reconstructing flood data (Shrubsole *et al.* 1993, Jones 1999; Barriendos *et al.*, 2003).

In order to evaluate the precipitation variations recorded for the past century in the study area, rainfall and snow data were analyzed based on Environment Canada's historical climatic data (HACDC 2004). Six stations were selected: Bell Falls, Disraëli, Drummondville, Lambton, Lennoxville and Sherbrooke (Table 1). The precipitation data (rainfall and snow) were compiled to represent the climatic anomalies, based on the 1971–2000 climatic reference period (Environment Canada 2001). The gauging stations were selected based on the most complete and long-duration hydrological series (Table 1). The hydrologic variables selected for the study

Table 1 – Hydrometeorological stations used for compilation and data analysis

Meteorological station[1]	**Number**	**Location**	**Altitude (m)**	**Precipitation (mm)**
Bell Falls	7030640	45° 46′ N–74° 41′ W	122	1932–1994*
Disraëli	7022000	45° 55′ N–71° 24′ W	350	1908–1991*
Drummondville	7022160	45° 53′ N–72° 29′ W	82	1914–2003*
Lambton	7024000	45° 50′ N–71° 05′ W	366	1916–1994*
Lennoxville	7024280	45° 22′ N–71° 49′ W	181	1915–2003*
Sherbrooke	7028124	45° 26′ N–71° 41′ W	241	1904–2003*
Gauging station[2]	**Number**	**Location**	**Basin area (km^2)**	**Period observed**
Saint-François River	02OE001	45° 56′ N–71° 16′ W	1 230	1968–1997
Magog river				
Sherbrooke Centrale	02OE006	45° 24′ N–71° 53′ W	2 020	1919–1994
Saint-François River				
Westbury Centrale	02OE007	45° 29′ N–71° 37′ W	3 330	1929–1987
Au Saumon River	02OE016	45° 37′ N–71° 23′ W	839	1938–1977*
Saint-François River				
Weedon Centrale	02OE017	45° 39′ N–71° 27′ W	2 930	1939–1987
Massawippi River	02OE019	45° 17′ N–71° 57′ W	619	1952–1997
Coaticook River	02OE022	45° 17′ N–71° 53′ W	521	1959–1997*
Saint-François Reservoir	02OE024	45° 56′ N–71° 16′ W	1 200	1919–1977*
Eaton River	02OE026	45°28′ N–71° 39′ W	642	1932–1945*
	02OE027			1953–1997*
Au Saumon River	02OE032	45° 34′ N–71° 23′ W	738	1974–1996*
Eaton River	02OE033	45° 20′ N–71° 34′ W	197	1966–1982*
Saint-François River	02OE062	45° 39′ N–71° 28′ W	2930	1979–1997
Saint-François River Richmond	02OF001	45° 39′ N–72° 08′ W	9 170	1915–1965*
Saint-François River Hemmings Falls	02OF002	45° 51′ N–72° 27′ W	9 610	1925–1994 and 1995–2003
Saint-François River Windsor	02OF004	45° 33′ N–72° 00′ W	8680	1935–1973*

Sources: Environment Canada 2004, [1]AHCCD: [2]HYDAT 2002 and MEQ (CEHQ) 2004
(note: asterisk (*) indicates some years or months are incomplete).

include the annual mean flow, the monthly mean flow, and the annual maximum daily flow. The data was obtained from Environment Canada's recently updated data bank (HYDAT CD-Rom, 2002). The gauging stations retained for the study are located along the Saint-François River (stations 02OE007, 02OE024, 02OF001, 02OF002, 02OF004), Magog (02OE006), and Eaton rivers (02OE027). Station 02OF002 covers the longest observation period, while the other stations provide data for periods spanning more than 30 years (Table 1). The most recent hydrological data (post 1994) for the same gauging stations were supplemented with data from the Québec environment ministry's Centre d'expertise hydrique (CEHQ).

Results

Historical flood records and frequency

The inventory of flood events covers the period from 1865 to 2005 for the entire study area (Figure 2). The flood events were compiled for each event inventoried in the documents consulted, while also taking into account annual and seasonal flood frequencies. For instance, the years 1900, 1928, 1938, 1940, 1990, 1996 and 1998 included more than one flood per year (see Table 2). The past century has seen an increase in the number of floods, especially since the 1970s. The period spanning 1970 to 1990, in particular, wit-

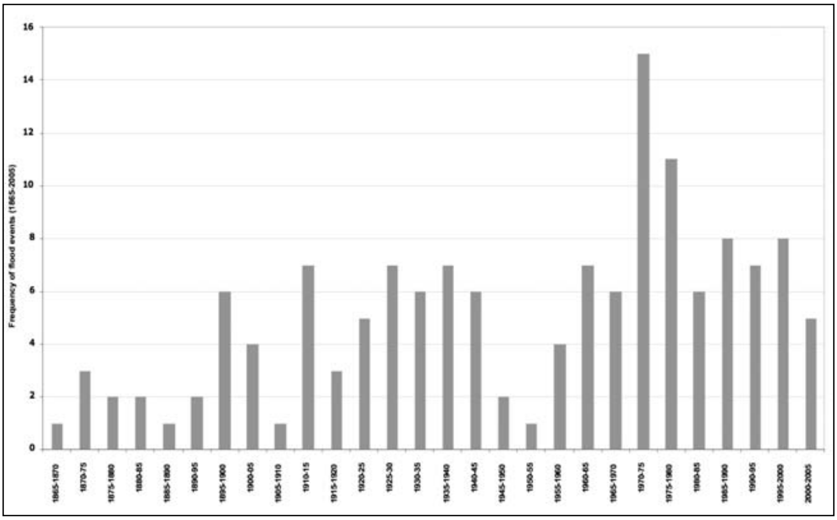

Figure 2

Histogram showing the historical flood record for 1865–2005 in the study area. The figure includes total flooding for each year (see also Table 2).

Table 2 – Date of flood events by years and months

1865-May-11	1916-Jul-16-17	1943-Jun-15-17	1973-Jul-02-04	1986-Mar-26-27
1874-Jan-16	1918-Apr-03-04	1944-Apr-26?	1973-Dec-27-29	1989-Mar-15-16
1874-Jun-17-19	1919-Mar-22-30	1945-Mar-20	1974-Jan-29-30	1989-Mar-28-31
1875-Spring-?	1921-Mar-10	1947-Avr-13-14	1974-Mar-08-09	1990-Mar-18-20
1876-May-12-19	1922-Jun-19-21	1948-Mar-19-22	1974-Apr-04-05	1990-Oct-19-25
1879-Apr-27-May- 02	1924-Sep-08-11	1949-Mar-23-24	1974-Apr-30-May-02	1990-Dec-22-31
1883-Apr-19	1925-Sep-11	1954-Apr-17	1975-Apr-19-20	1991-Mar-06
1885-Apr-28	1927-Nov-03-05	1959-Jun-28-30	1976-Mar-26-Apr-03	1991-Apr-09-10
1887-Apr-22-May-05	1928-Jan-10	1960-Apr-1-20	1976-Jun-22?	1992-Mar-10-13
1892-Apr-08	1928-Mar-14-15	1961-Jul-21-22	1976-Aug-11-18	1992-Apr-23
1894-Apr-27-28	1928-Apr-07-09	1962-Mar-30-Apr-02	1976-Dec-03 et 23	1993-Apr-11-13
1896-Mar-06	1928-May-26	1962-Apr-30-May-01	1977-Mar-15-17	1994-Apr-17-18
1897-May-5	1929-Apr-09-10	1963-Mar-27-28	1978-Apr-13	1995-Jan-16-18
1898-Mar-14-16	1930-Jan-08-09	1963-Aug-23	1978-Apr-21-24	1996-Jan-17-25
1900-Mar-30	1931-Apr-25	1964-Mar-05-06	1979-Jan-01-05	1996-Feb-26
1900-Apr-18-19	1932-Jul-08?	1964-Apr-15-16	1979-Mar-05-08	1996-Aug-09
1900-Oct-10-11	1933-Apr-16-19	1966-Aug-08	1979-Jun-01	1997-Feb-16
1901-Apr-18	1933-Aug-24-26	1967-Apr-03-04	1980-Mar-17	1998-Jan-02
1901-Jun-27	1934-Apr-11-13	1967-Aug-10-11	1981-Feb-22-25	1998-Mar-29-Apr-04
1902-Mar-01-03	1935-Jan-10-11	1968-Mar-24-26	1982-Apr-17-20	1999-Jan-25
1903-Mar-?	1936-Mar-13-19	1969-Apr-11-20	1983-Feb-17	1999-Aug-09
1910-Mar-02-03	1938-Mar-23-24	1970-Apr-18-25	1983-Mar-19-21	2000-Feb-27-29
1911-Apr-14-15	1939-Apr-22-25	1971-May-06	1983-Sep-17	2003-Mar-28
1912-Apr-08-18	1940-May-01-03	1971-Aug-30	1983-Dec-07-22	2003-Oct-30
1912- May-28-Jun-1	1940-Jun-03-04?	1972-May-05-09	1985-Feb-22-26	2004-Aug-29-Sep-02
1913-Mar-23-28	1941-Avr-15-17	1972-Jul-16-17	1986-Jan-27-29	2005-Apr-04-08
1914-Apr-19-21	1942-Avr-26?	1972-Aug-08-10	1986-Mar-26-31	2005-Oct-16-19
1915-Feb-24-26	1942-Jun-14-16	1973-Mar-17-18	1987-Apr-01	

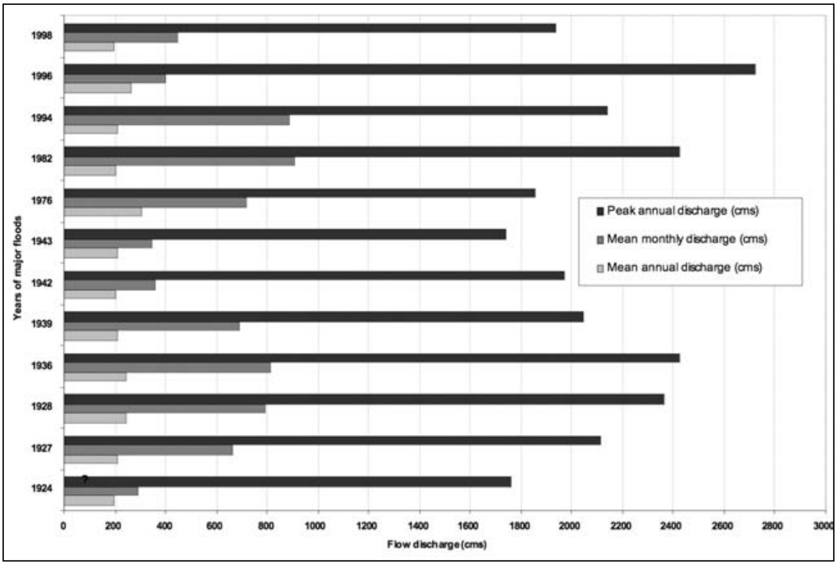

Figure 3
Histogram showing major floods, mean annual and monthly discharges and peak annual discharge at the Saint-François River for 1904–2004 (gauging stations: 02OF001 and 02OF002).

nessed a considerable number of flood events. In fact, there was practically one flood a year during the 20-year time-span. There was a slight decrease in flood frequency after this period. However, to determine whether the trend continues, a longer series would be required spanning at least another decade.

The increase in flooding since the start of the century was also noted in nationwide studies conducted by Tucker (2000), who found a notable increase in floods since the early 20th century, i.e. twice the frequency since 1970. As Tucker notes, “A number of factors may explain this trend: the occurrence of more extreme events, an increase in disasters proportional to the increase in population, better reporting of events in more recent years and/or increased concentration of population and wealth in vulnerable area” (Tucker 2000, p. 78). One could argue that all these factors could occur concomitantly, in which case it would be useful to attempt to determine which of them plays a predominant role in the occurrence of flooding while taking into account the climatic and anthropogenic changes in the study area.

Major flood events

Based on the reports of the Quebec Streams Commission (1912–1952) as well as local newspapers, we were able to determine the most disastrous years in terms of the municipalities affected by flooding. The years 1924, 1927, 1928, 1936, 1939, 1942, 1943, 1976, 1982, 1994, 1996 and 1998 (Figure 3) were the worst flood years in the Saint-François Basin. In many cases, the floods occurred in the spring, but there was also flooding at other times of the year, i.e. in the summer (June 16, 1942 and June 17, 1943) and fall (November 3–5, 1927). Among the above flood events, one of the worst cases recorded in the last century occurred in the spring of 1982, leading to the overflowing of several rivers, including the Saint-François, Massawippi, Magog, Coaticook, Saumon and Ascot, and impacting several municipalities located along these rivers. This severe flood appears to have been caused both by exceptional rain which occurred on April 17th and 18th and by the rapid melting of a substantial snow cover assessed at 50–200 mm above the median for mid-April (Hoang 1982; see also Jones 2004). The 1942 and 1943 floods are similar in severity to the 1982 flood, and also resulted in the overflowing of several rivers and substantial material damage. 1865 and 1892 were also disastrous years for southern Québec in terms of flood damage (Watt *et al.* 1990, p. 19). There were also human fatalities associated with these flood events.

Variability of precipitation (1904–2004)

The analysis of the distribution of the total mean annual precipitation in the study area shows considerable variability in the distribution of precipitation over more than one century. This observation is in fact made in several studies on precipitation in Canada (Findlay *et al.* 1994, Mortsch *et al.* 2000). In this respect, the latter two authors mention that the variability observed in relation to precipitation makes it difficult to detect any data distribution trends. Precipitation would seem to be a more variable parameter over time than temperature data, for instance. With respect to our study area more specifically, the detailed analysis of total mean annual precipitation data (precipitation anomalies) also shows a major variation in precipitation. However, it is possible to detect certain upward or downward precipitation trends from 1904–2004. Rainy years occurred from 1932 to 1954 and from 1971 to 1983, while the period 1956–1966 is characterized by years with less rain (Figure 4). A rainier period can also be noted early in the last century (1904–1912) for the Sherbrooke station, which is followed by a less

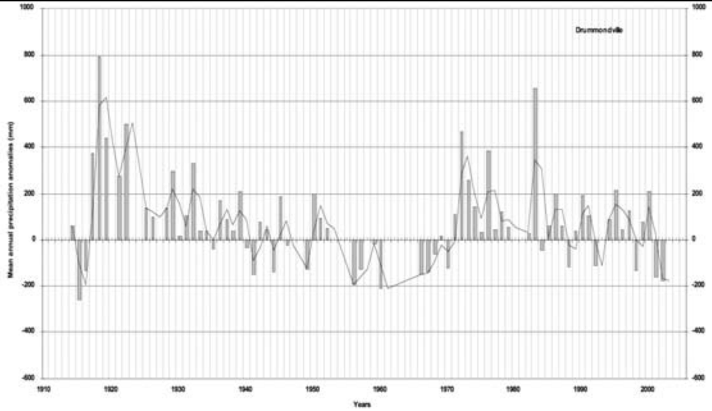

Diagram of mean annual total precipitation at the Drummondville station

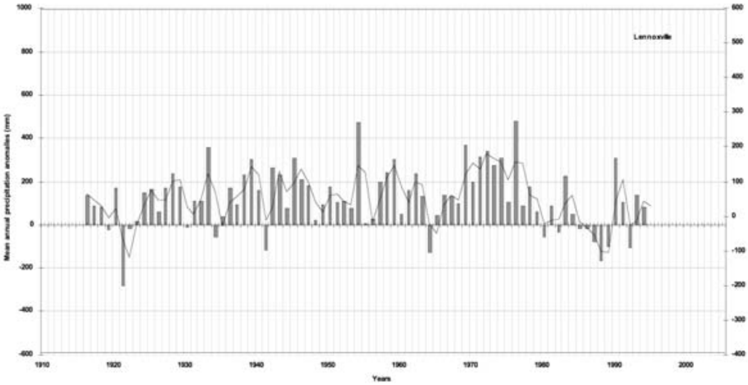

Diagram of mean annual total precipitation at the Lennoxville station

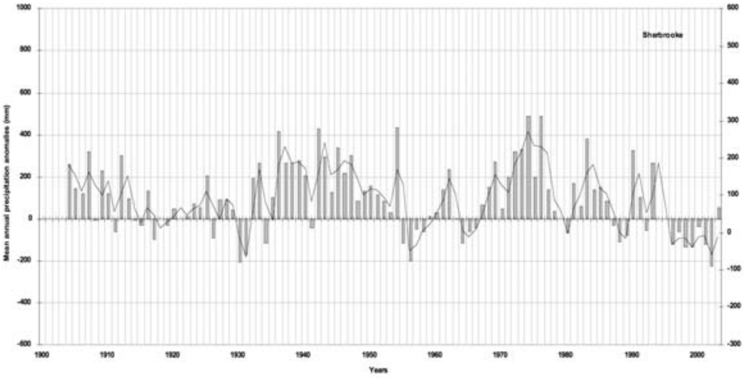

Diagram of mean annual total precipitation at the Sherbrooke station

Figure 4

Table 3 – Standard deviation of total mean annual precipitation for identification of highest and lowest years (period 1904–1994)

Stations	Number	N	Mean	Standard deviation	Min	Max
BEF	7030640	44	1136.2	149.9	833.9	1452.7
DIS	7022000	68	1256.4	171.3	865.2	1636.8
DRU	7022160	67	1214.4	199.9	867.5	1919.4
LAM	7024000	59	1204.8	182.1	804.1	1643.2
LEN	7024280	79	1162.9	141.4	758.7	1520.5
SHE	7028124	88	1259.6	161.1	940.4	1636.6

Note: All stations have missing data; source: Environment Canada (2004).

rainy period from 1917 to 1919. At the Drummondville station, the period 1917–1919 is instead characterized by a significant increase in precipitation (Figure 4). These differences are likely due to the fact that atmospheric conditions differ substantially between the St. Lawrence Plain, where the Drummondville station is located, and the Appalachian Foothills, where the Sherbrooke station is found. A study conducted in the south central part of Québec in fact shows major variations in precipitation between the St. Lawrence Lowlands and the Appalachian Foothills (Siew-Yan-Yu *et al.* 1998).

Figure 5 shows, for all the stations studied (i.e. Bell Falls, Disraëli,

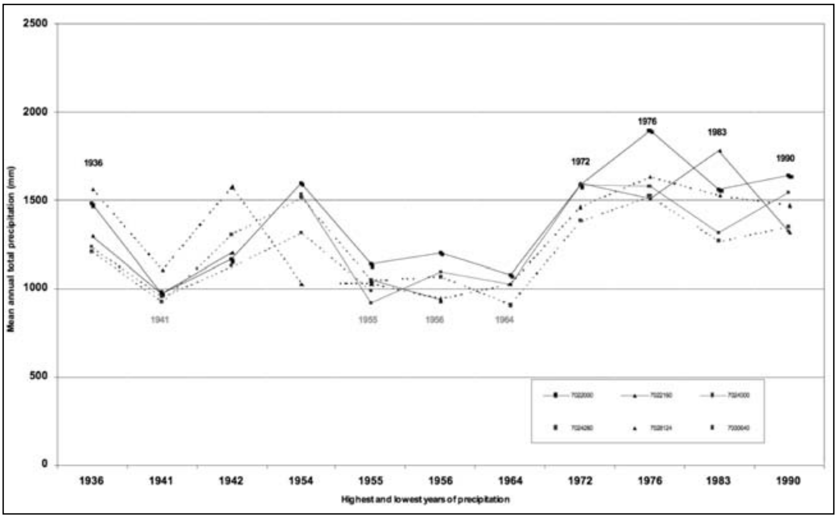

Figure 5

Diagram of mean annual total precipitation with the highest and lowest years of precipitation (Stations 7030640, 7022000, 7022160, 7024000, 7024280, 7025440, 7028124)

(Notes: In this case, the highest years of precipitation represent more than 1200 mm/yr and the lowest less than 1200 mm/yr. Some precipitation data after 1994 are not available for the study area.)

Drummondville, Lambton, Lennoxville and Sherbrooke), variations in the precipitation over the last century (see also Table 3). It can be noted that the rainiest years (more than 1200 mm/yr) were 1936, 1972, 1974, 1976, 1983 and 1990. A flood event was recorded for all of these years. The years 1974 and 1976, in particular, are two years with heavy flooding that affected several riverside municipalities. Several floods in fact occurred in 1976 that affected a number of municipalities. Although records indicate that 1982 was one of the worst flood years in the last century, the weather stations did not show it to be an especially rainy year. For instance, the total mean annual precipitation recorded at Lennoxville in 1982 was 1006.3 mm, while the mean annual volume over the last 30 years was 1039.7 (Environment Canada 2001). It should be noted, however, that on April 17 and 18, 1982, exceptional rain occurred, followed by rapid melting of the thick snow cover, which led to major flooding in the entire Saint-François River Basin (Hoang 1982; see also Jones 2004). For this major flood event, the daily rainfall rates provide a better explanation for the flooding than the annual mean volume, which is why it is important to study flood phenomena at different analytical levels. In fact, extreme events related to heavy rain, for instance, are not always evident in annual or monthly means. This is the case for 1942, 1943 and 1982, years characterized by catastrophic flooding. Lastly, with respect to the years that show a certain shortfall in annual precipitation (less than 1200 mm/yr), there are four such years, i.e. 1941, 1955, 1956 and 1964. For these years, no flood events were recorded in the study area, except for 1964, which was marked by spring flooding in March and April in different areas.

Link between major flood events and hydrological data

The investigation of flooding requires that one considers both climatic and anthropogenic factors that impact river flow variations in different ways (Costa and O'Connor 1995). The parameter most often used to measure river flow variations is the discharge (cubic metres per second or cms) recorded at different gauging stations located throughout the watershed under study. Variations in river flow discharge are in fact the catchment's response to the conditions generated by the climate and the impact of various human activities (e.g. intensive deforestation, riverbank development). In this context, it would be useful to investigate discharge variations over an extended period of time in order to detect major trends in river flow variations over the entire watershed. As a first step, the mean annual discharge values of the different rivers located in the study area have been analysed. Note that discharge variations are relatively substantial over the last century (Figure 6). Meanwhile, an increase in river flow discharge is evident, especially after the 1970s, and particularly between 1970 and 1990, preceded by a decrease in flow around 1964 and another decrease after 1996. These upward and downward variations were in fact noted at all the stations investigated. For instance, a slight increase in discharge is observed from 1969 to 1976 (Figure 6), especially at stations 02OE007 and 02OF002 (Saint-François River) and 02OE027 (Eaton River). The years 1974, 1976 and 1996 have the highest discharge at stations 02OE007, 02OE027 and 02OF002, and 1936, 1954, and 1969 are years marked by high discharge at almost all the stations. In short, there are peaks of high discharge in 1928, 1936, 1954, 1969, 1974, 1976, 1983, and 1996 (Figure 6). Furthermore, there are also years marked by a decrease in the mean annual discharge, particularly 1931, 1941, 1948, 1949, 1964, 1980 and 1988. These decreases in the mean annual discharge are found at most of the stations (02OE006, 02OE007, 02OE027 and 02OF002). Lastly, though there is a relative increase in the mean annual discharge during the period of 1974–1994, there appears to be a downward trend after 1996 (station 02OE027). However, additional data covering the next few decades (post 2000–2020) could help determine whether the trend continues.

Figure 7 shows the peak discharge for the stations analyzed over nearly a century. The variations in the peak discharge are generally very similar to the variations in the mean annual discharge. The years 1928, 1936, 1942, 1974, 1976, 1994 and 1996, which are characterized by the highest peak discharge, are thus easily located on the mean annual discharge graph, particularly 1928, 1936, 1976 and 1996 (Figure 6). The decrease in discharge recorded around 1964 is also clearly visible in Figure 7. Furthermore, the years marked by high discharge are generally years with considerable rainfall. This is the case for 1936, 1974 and 1976. The peak discharge recorded for rivers is a more or less rapid response to extreme events that occurred in terms of the watershed, such as heavy rainfall or extensive abundant rainfall. In the analysis of the flood events, it was important to study the close relationship between the peak discharge recorded in the study area and the major floods recorded in the different documents consulted. For this example, the longest record discharge data (station 02OF002) was used. By examining the two sets of data (flood and peak discharge), one sees

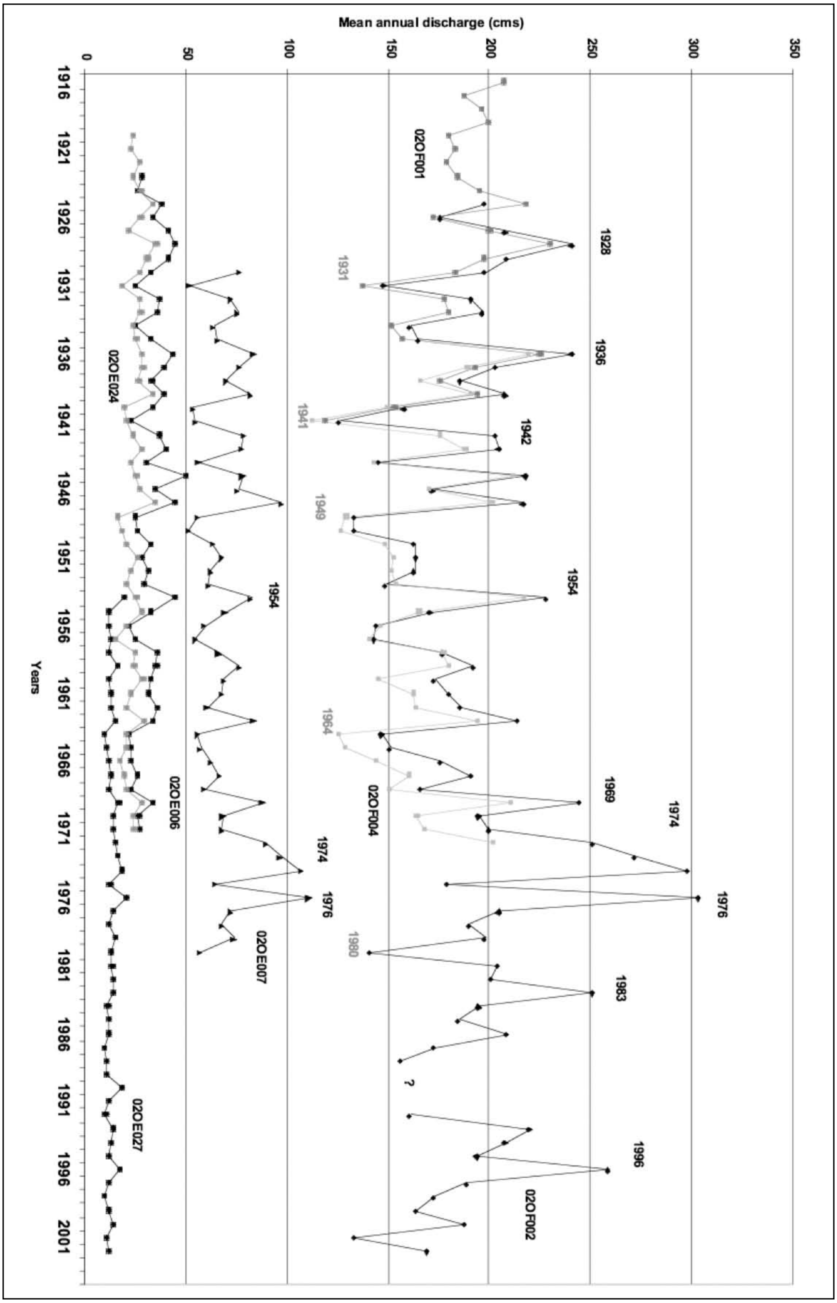

Figure 6.
Diagram of mean annual discharge at different stations (gauging stations: 02OE006, 02OE007, 02OE024, 02OE027, 02OF001, 02OF002 and 02OF004)
(Sources: Environment Canada, HYDAT CD-Rom, 2002; MDDEP, CEHQ, 2004)

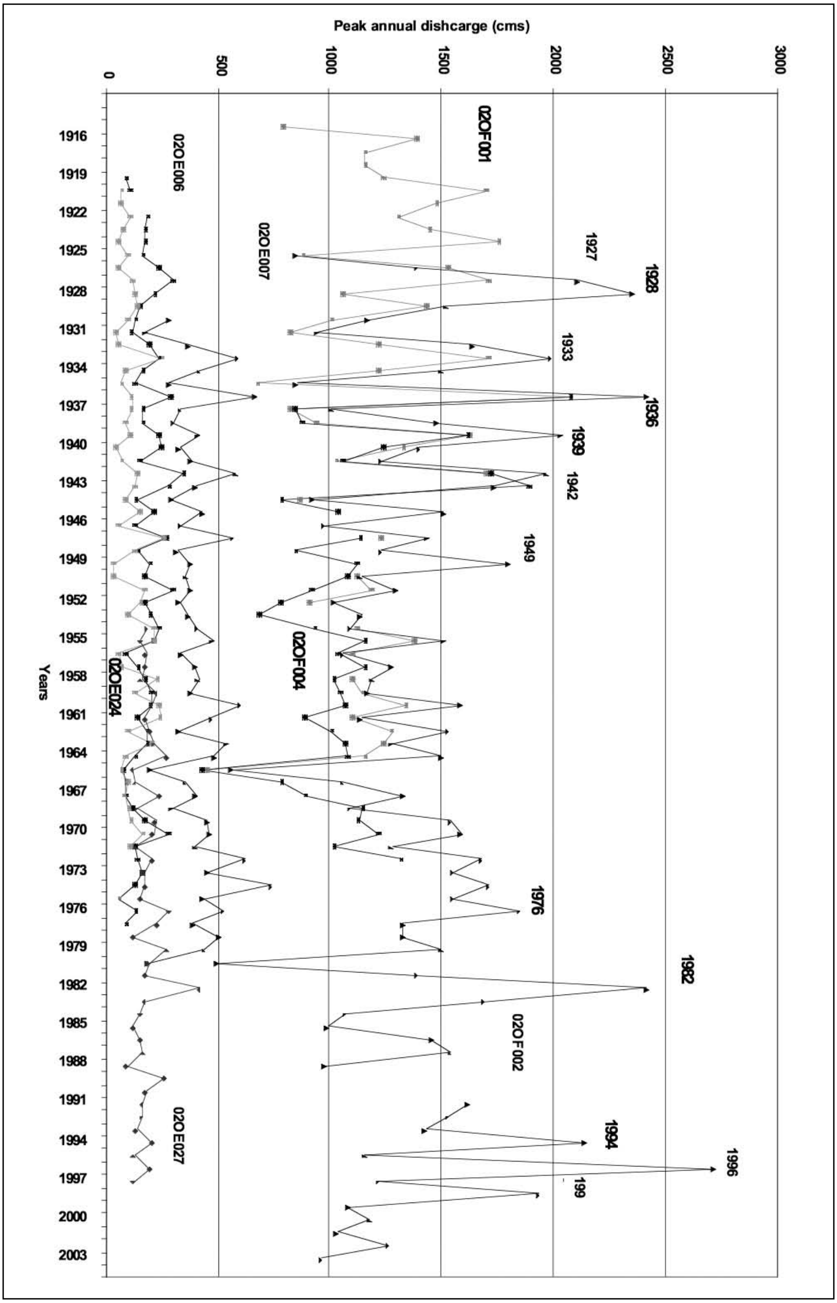

Figure 7

Diagram of peak annual discharge at different stations

(gauging stations: 02OE006, 02OE007, 02OE024, 02OE027, 02OF001, 02OF002 and 02OF004)

(Sources: Environment Canada, HYDAT CD-Rom, 2002; MDDEP, CEHQ, 2004).

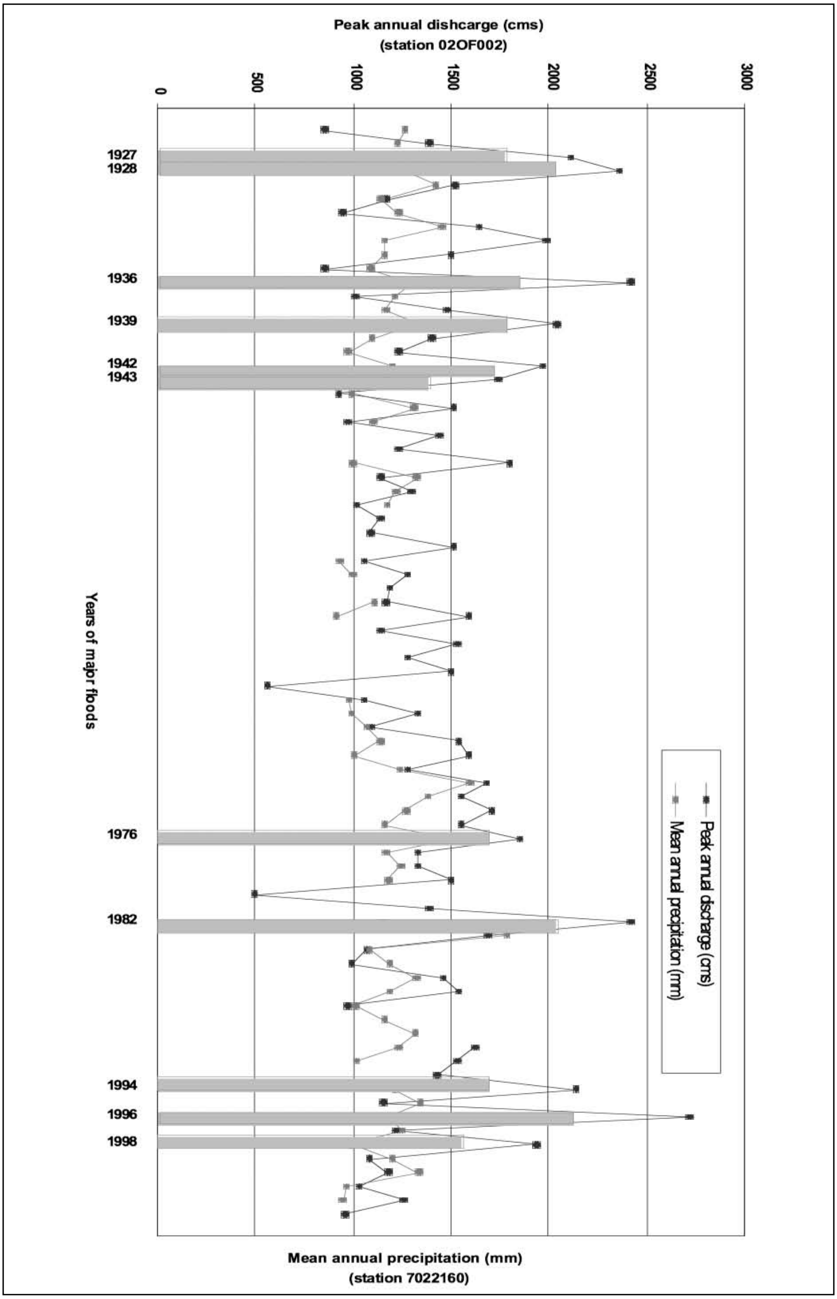

Figure 8

Diagram of peak annual discharge with years of major flood event recorded (gauging station 02OF002 and meteorological station 7022160. (Source: Environment Canada, HYDAT CD-Rom, 2002) that the peak discharge generally corresponds to the major floods mentioned in the literature. This is the case for the years 1927, 1928, 1936, 1939, 1942, 1943, 1976, 1982, 1994, 1996 and 1998 (Figure 8). The year 1982 is considered as the worst flood event of the last century and this is clearly displayed on the graph (Figure 8). Also, it is interesting to note that the spreads between the monthly and annual discharge values and those of the peak discharge values are very significant when compared together (Figures 3 and 7). In some cases, the peak discharge values are 7 to 9 times greater than the values usually recorded in the same year. For instance, in 1927, the peak discharge recorded was 2110 m^3/sec, which is 9 times greater than the value recorded during the year. This is in fact comparable to several of the discharge values recorded in the various gauging stations. At this level of analysis, the peak discharge values thus appear as a parameter that is highly correlated with major flood events.

Finally, the first half of the last century, especially from 1924 to 1944 (Figures 2 and 7), is characterized by a long period of peak discharge which is also found in the recurrence of flood events, and the same holds true for the late 20th century, which is also characterized by years of peak discharge coupled with years of major flooding. Furthermore, the 1950s and 1960s saw a significant drop in river flow, which leads to a decrease in flooding recurrence.

Conclusion

This study mainly deals with flood records (1865 to 2005) identified using various sources (e.g. government reports, regional monographs). The other part of the study investigated the links between flood events recorded in the literature and climatic data (precipitation) and hydrologic data (discharge). It can be noted that the flood rate has been on the rise since the 1970s, especially from 1970 to 1990. There appears to be a certain decrease in the flood frequency after this period. Several of the years identified as major flood years (e.g. 1942, 1943 and 1982), are years associated with peak discharge, and the years associated with other more minor flood events also appear in the mean annual discharge and peak discharge graphs, but are less significant. Furthermore, several of the years characterized by considerable rainfall are generally associated with heavy discharge. In fact, the fluctuations noted in terms of the rainfall and hydrological data follow roughly the same trends, which can also be found in flood frequency variations. For instance, the period in the last century with the lowest rainfall, i.e. 1955 to 1957, also corresponded to years with low streamflow characterized by a decrease in flood frequency. Lastly, in light of current data, it would appear difficult to establish a correlation between the frequency of flooding since the early 1900s and recent climatic changes. Additional and more complete data covering the next decades (post 2000–2020) will be required to measure the actual impact of climatic variations on flooding frequency.

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