

**VARIATIONS OF CLIMATE AND STREAMFLOW
OVER THE SAINT JOHN BASIN SINCE 1872**

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Abstract

A study is presented of variations in recorded climate and streamflow over the Saint John Basin above Fredericton, NB. The treatment is based chiefly on long climatic records at Fredericton, on data from Presque Isle ME, and on streamflow measurements at Pokiok-Mactaquac and Grand Falls. Other studies have shown that these fairly homogeneous records are representative (as regards time variation) of the entire basin above Fredericton. Mean annual air temperature has risen 1.3°C since 1871, or about 1° per century. There has been no enduring change in mean annual precipitation or streamflow, but both appear to have entered a more variable régime in 1950, which still endures. The freshet has become earlier since 1972, with many years of high flow. Only a small rise of spring temperatures is detectable, but snowy or wet winters, coupled with high interannual variability, have caused earlier thaws and several major flooding and ice-jam events. There is a risk of extreme rainstorms at the time of the freshet, which would lead to higher flows than have so far been recorded.

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INTRODUCTION

We have examined climate and streamflow records for the Saint John River Basin of Québec, Maine and New Brunswick. Agreements for the joint management of the Saint John River have long been in place (World Meteorological Organization, 1978; Inland Waters Directorate, 1973), and long-term observational series exist. An inspection of this long record can throw light on what may happen in the Basin's future. The same is true of other comparable regions.

In the past four decades the Saint John River has appeared to change its habits. The spring freshet has tended to come earlier since 1972, and to have increased in volume. Heavy damage has been done in several springs by flooding, and by ice-jams, including the destruction (in April, 1987) of the CPR bridge across the Saint John at Perth-Andover. These events pose the question: is climatic change responsible? To answer such questions one needs to understand the recent history of climate and streamflow, and the extent to which the Basin's experience reflects broader-scale changes over North America and the globe. Action to cope with future outcomes will depend on such understanding.

THE BASIN: PHYSICAL CHARACTERISTICS

The Saint John River is 708 km from source to mouth (Figure 1). It drains a basin estimated at 55,167 square kilometres (km^2). The headstreams include tributaries draining forested, hilly and thinly-populated districts of Maine and eastern Québec. The main channel runs north-eastward to Edmundston, where it begins a south-eastward curve towards Grand Falls, from which it flows southwards to Woodstock, just east of the Maine border. It then turns eastward, and flows past Mactaquac and Fredericton to Gagetown, where it enters the broadened channels, lakes and intervening ridges making up the lower Basin. The channel enters Kennebecasis Bay, as does the Kennebecasis River. Tidal interaction of Kennebecasis Bay with the Bay of Fundy occurs at Reversing Falls in Saint John, and tidal influences are felt at times of very low flow as high as Keswick, near Fredericton. For practical reasons we have hence confined our treatment to the middle and upper reaches. Table I lists the main dams and hydraulic stations above Mactaquac (about 71 per cent of the entire Basin area).

The Basin is a hard rock, recently-glaciated, thin-soiled, formerly forested area that has been extensively cleared of virgin cover in the past century and a half. Above Gagetown the river is incised into a gently rolling plateau in the altitude range 150-450 metres above sea-level. Isolated hills rise above this plateau by a maximum of 500 metres. Much higher ground lies north-east and south-west of the upper reaches. In fact the upper Basin (above Beechwood) is a broad depression between the hills of eastern Québec and a tract of higher ground approaching the river on either bank between Perth-Andover and Hartland.

Table I: Hydroelectric Plants

Plant	Catchment Area(km ²)	In Service Date*	Present Installed Capacity (MW)	Plant Discharge Capacity (m ³ s ⁻¹)	Spillway Capacity (m ³ s ⁻¹)
Grand Falls ¹	22,272	1928 - 31	63	207	3,680
Second Falls (Green R.) ²	1,037	1912	2.9	69	-
Sisson (Tobique) ¹	311	1953 (storage) - 65	10	128	170
Tobique Narrows ¹	4,326	1953	20	128	2,605
Tinker (Aroostook) ³	6,065	1922	33	164	-
Caribou (Aroostook) ³	5,036	1926	0.9	23	-
Beechwood ¹	33,280	1957- 62	115	850	9,910
Mactaquac GS ¹	39,424	1968 - 80	680	2,378	20,104

* first date indicates first unit on stream, second date indicates when all units were commissioned.

1. New Brunswick Power Corporation

2. City of Edmundston

3. Maine Public Service Company

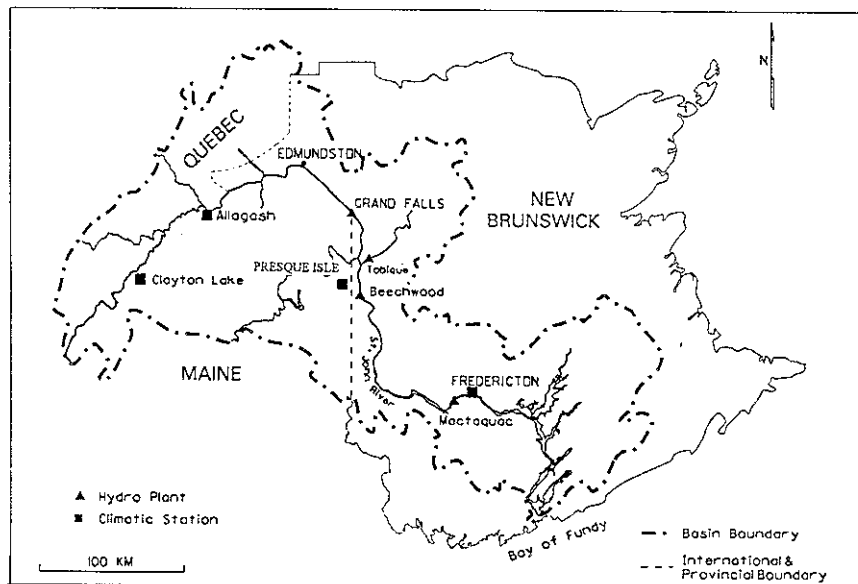


FIG. 1: SAINT JOHN RIVER BASIN

THE CLIMATOLOGICAL RECORD

We now consider the climatological records of the past century, to update the analysis of Inland Waters Directorate (1973) and Dickison and Steeves (1989). We have depended primarily on the long climatic records from Presque Isle and Fredericton but have examined the records from other stations. We have also used streamflow data from gauging stations on the Saint John River and the Aroostook and Tobique Rivers, together with snowcover data. The quality and homogeneity of the records have been discussed elsewhere (Dickison, 1966, 1995a and b; World Meteorological Organization, 1978; Dickison and Steeves, 1989).

Temperature

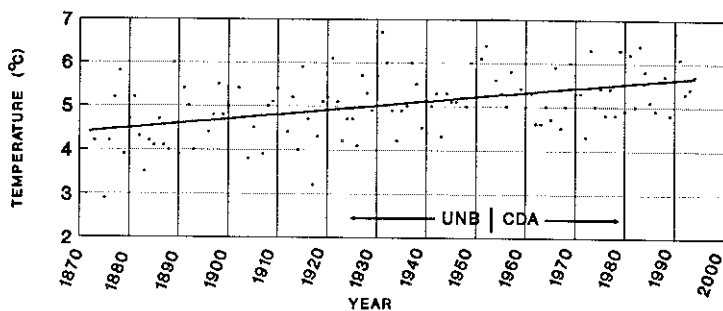
Figure 2-I, updated from Dickison and Steeves, 1989, shows the variation of mean annual surface air temperature from 1872 until 1995 at Fredericton, using the back-to-back records of the University of New Brunswick, UNB (1872-1951) and Canada Department of Agriculture, CDA (1952-1995). A rise of 1.3°C since 1872, and an upward linear trend of 1°C per century are visible, and are significant at the 5 per cent level. The upward trend closely resembles that for Canada as a whole (Findlay et al., 1994). The latter source indicates a warming of only 0.3°C per century for Atlantic Canada.

Other records through the middle and upper Basins (Hare, 1995) confirm the Fredericton record as reasonably representative of the entire Basin as regards time-variation, but not, of course, spatial distribution. A warming over the past century has affected the north-eastern United States (Karl et al., 1994, 1996), with values near 2°C per century in Maine. A smaller warming has affected the Great Lakes/St. Lawrence region of Canada (Findlay et al., 1994). Fredericton's warming is closer to that of these areas than to the rest of Atlantic Canada.

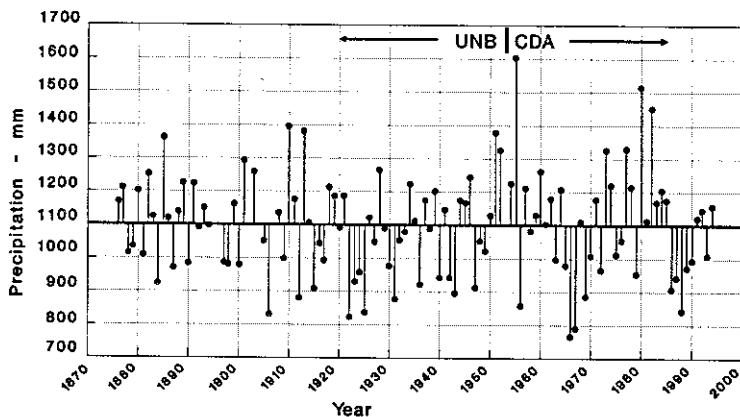
Precipitation

We have estimated the time variation of annual precipitation from the long records at Fredericton UNB and CDA (figure 2-II). The records show: a long-term mean annual value close to 1,100 mm, with a root-mean-square deviation near 180 mm (considered good estimates for the Basin above Fredericton); no enduring trend of annual precipitation; hints of quasi-periodic, longer-term variations after 1950; and high interannual variability, which has increased. Records from other stations in the basin (notably Presque Isle) show similar characteristics, though with substantial inter-station differences. The post 1950 quasi-periodic rhythm is largely accounted for by winter variations (figure 6).

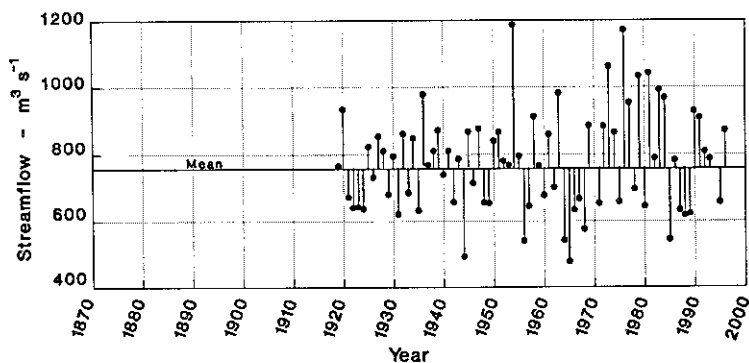
The lack of upward trend is at variance with events for Atlantic Canada as a whole since about 1915 (Findlay et al., 1994, p. 806), and over much of the central and eastern US over the past century (Karl et al., 1996, p. 282). The latter source, however, records a significant decrease in northern New England, especially in northern Maine, which includes the upper Saint John Basin.



I - Mean Annual Air Temperature for Fredericton



II - Total Annual Precipitation at Fredericton - Departures from Mean



III - Mean Annual Streamflow at Mactaquac - Departures from Mean

FIG. 2: HYDROMETEOROLOGICAL TIME SERIES

There have been suggestions that the interannual and longer-term variability of precipitation may have increased on the continental or world-wide scales. Figure 3-b shows decadal arithmetic means of interannual differences of precipitation, **without regard to sign**, at Fredericton since 1871. Typically this difference has lain in the range 145-155 mm, as it did in the period 1921-1956. It was significantly higher in the decades of the 1960's and 1970's, but fell below 150 mm in the 1980's.

HYDROCLIMATOLOGICAL REGIME

Mean Annual Streamflow

Figure 2-III, shows mean annual flow (in cubic metres per second, $\text{m}^3 \text{s}^{-1}$) at Pokiok-Mactaquac. The values are 24-hour means averaged over a year, so that effects of action by generating station operators to control headpond level or ice movement are minimized (they are in any case small). The Grand Falls record reflects outflow from the upper Basin. The Mactaquac site was moved from Pokiok (now in the headpond area) to below the dam in 1967, but the effect cannot be detected in the figure.⁴ When averaged by decade, annual flow at Grand Falls has been near 53 percent of that at Mactaquac. At East Florenceville, below Beechwood, the corresponding ratio since 1952 has been 81 to 86 percent.

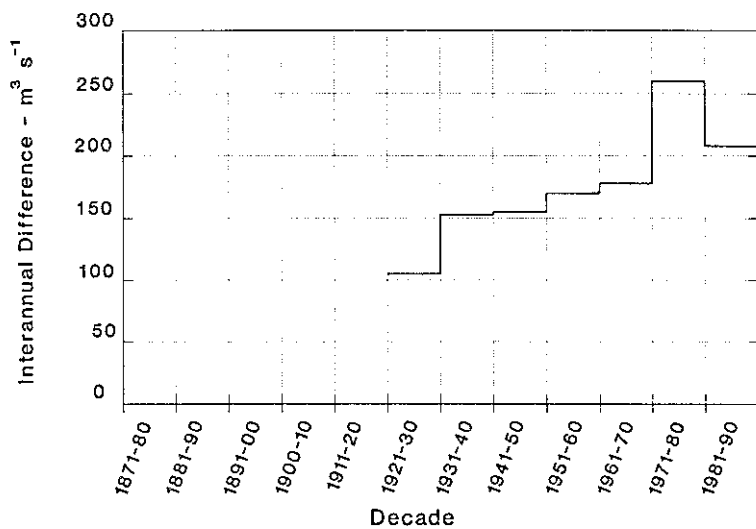
There has been no overall trend of mean annual streamflow since the Mactaquac record began in 1919, and that of Grand Falls in 1931; the régime thus reflects a stability similar to that of annual precipitation and is at variance with recent increases in streamflow across parts of the US (Lins and Michaels, 1994).

Interannual variability in streamflow, however, increased markedly after 1950. Figure 3-a shows decadal averages of interannual flow differences at Mactaquac, without regard to sign. Clearly the short term variation culminated in the 1970's, but has remained high into the mid-1990's.

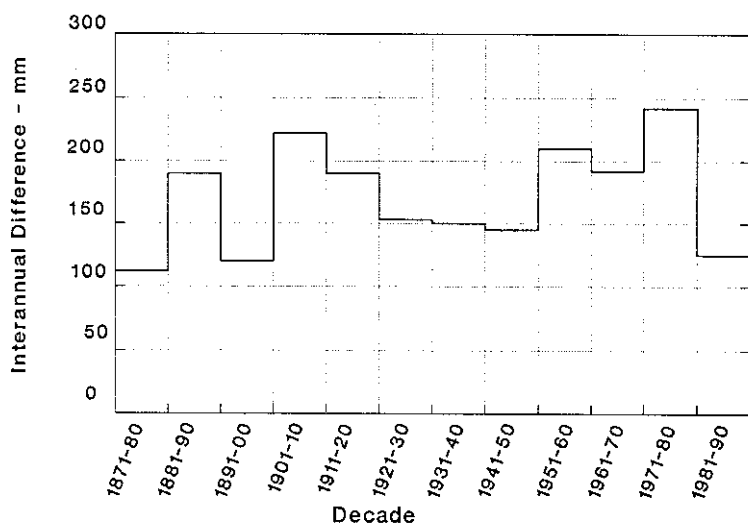
The Spring Freshet: Dates and Volumes

The Saint John Basin above Gagetown contains very few lakes, and engineered structures have barely altered this lack of storage. **The freshet** often causes flooding and ice-jams, some of which can be very destructive. There is low flow during the freezing season, and from July through September. A minor peak occurs in autumn before the freeze-up in mid- or late-December. But the dominant fact is the high flow in April and May, often extending well into June. Mean flow in April and May is five or six times as great as in winter. Mean annual flow is $405 \text{ m}^3 \text{s}^{-1}$ at Grand Falls, or 53 per cent of that at Mactaquac ($760 \text{ m}^3 \text{s}^{-1}$).

⁴the usual title for the site is "below Mactaquac". We have generally omitted the "below".



a : Streamflow at Mactaquac



b : Precipitation at Fredericton

FIG 3: MEAN INTERANNUAL DIFFERENCES

The spring thaw comes at various dates, some early, some late. A typical freshet at Mactaquac sees flow briefly exceed $5,000 \text{ m}^3 \text{ s}^{-1}$, and 24-hour mean values up to (in two cases exceeding) $10,000 \text{ m}^3 \text{ s}^{-1}$ have been recorded. Such enormous volumes are comparable with the mean annual discharge of the St. Lawrence into its estuary. For a brief spring period the Saint John thus flows on the scale of the St. Lawrence, whereas for much of the year it is a quiet, pleasantly meandering stream. The huge freshet may have two or even three peaks, the first of which is likely to carry away most of the river ice. We delimit the freshet in terms of specific thresholds — the dates between which flow exceeds $25,000 \text{ cfs}$ ($708 \text{ m}^3 \text{ s}^{-1}$), $50,000 \text{ cfs}$ ($1,416 \text{ m}^3 \text{ s}^{-1}$) and $100,000 \text{ cfs}$ ($2,833 \text{ m}^3 \text{ s}^{-1}$), together with the equivalent dates during the diminishing phase.

Figures 4 and 5 show the decadal average dates when these thresholds were traversed at Grand Falls and Mactaquac respectively, together with individual recent years. The freshet emerges as a period of seven to ten weeks of augmented flow. Onset is somewhere between mid-March and May 10th. Peak flow occurs on the average on April 27th at Mactaquac, and on April 29th at Grand Falls. The figures also show dates of peak flow and associated streamflow volumes. Since the low flows of the mid-1960's there has clearly been a marked tendency for earlier and high volume peaks. At Mactaquac freshet and interannual flow variability (figure 3) increased over the post-1920 period, with a slight reversal in the 1980's. The five highest 24-hour flows at Mactaquac have all occurred in or since 1973, when flow reached $11,105 \text{ m}^3 \text{ s}^{-1}$. In 1979 it again reached $10,000 \text{ m}^3 \text{ s}^{-1}$.

A feature of the freshet régime in the past two decades has been an increase in the contribution of the Basin below Grand Falls to peak flows at Mactaquac. Mean annual streamflow at Grand Falls has averaged 53 per cent of that at Mactaquac. The comparable peak flows have been close to 60 per cent, though since 1979 this has fallen to 56 per cent. But many recent years have shown much higher flows at Mactaquac. The added flow at Mactaquac comes from the Aroostook, Meduxnekeag and Tobique tributaries, as well as numerous smaller streams. Elsewhere we have shown that the correlation between precipitation at Fredericton and streamflow at Mactaquac rose to 53 per cent explained streamflow variance in the years 1951-1990 (Hare et al., 1997). This does not, of course, imply that Fredericton's precipitation causes the discharge from a basin that it lies outside; it means that both the records are similarly affected by the regional climate.

The Spring Freshet: Causes

The onset of the freshet is determined by the start of persistent thaw. Its volume, on the other hand, depends on several factors, such as: the water-equivalent of the winter snowpack; the rapidity of thaw, once established; the capacity of soil and vegetation to retard run-off; the volume and temperature of river ice; the extent to which river ice obstructs free flow, in particular by the formation of ice-jams; and further precipitation during the freshet.

Figure 6 shows the variation of winter precipitation (December 1st - March 31st) at Fredericton CDA and Presque Isle since 1913. There was a snowy phase in the 1950's, and another after 1970. The diagrams offer a rough indication of the water supply available for the freshet in the year

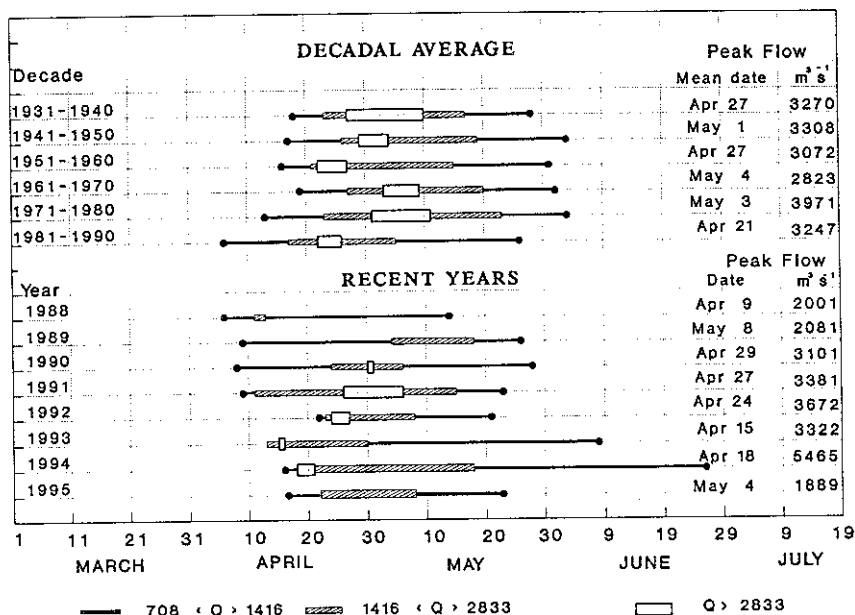


FIG. 4: INCIDENCE OF FRESHET FLOWS AT GRAND FALLS

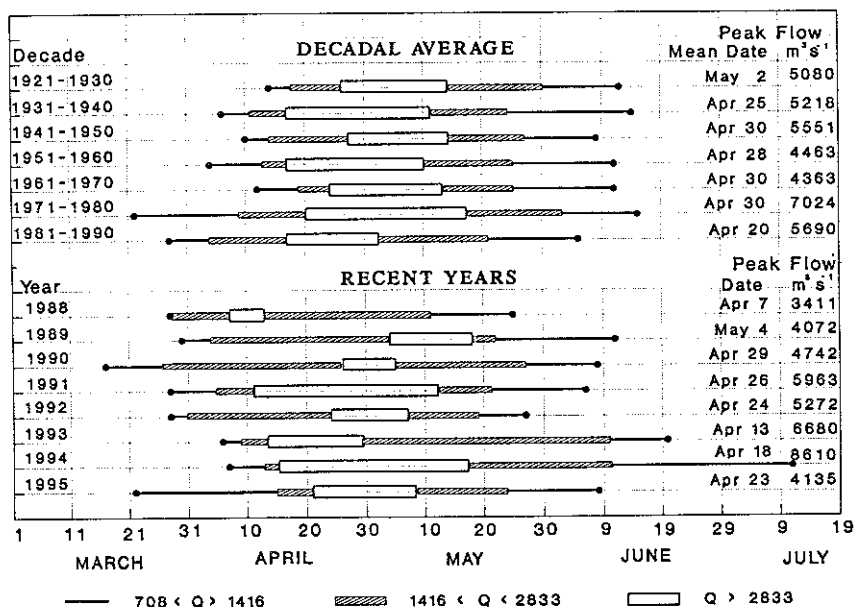


FIG. 5: INCIDENCE OF FRESHET FLOWS AT MACTAQUAC G.S.

indicated, at least in nearby reaches of the Basin. The mid- and late-1980's were much drier, but high totals resumed in 1989. The incomplete record at Presque Isle shows a similar sequence, but the 1950's were much wetter than the 1970's and 1980's. At Fredericton, 56 per cent of the precipitation fell as snow, whereas at Presque Isle the figure was near 75 per cent. Most but not all winter rainfall refreezes into the snowpack, the proportion rising with distance inland and with altitude.

Since 1961, snowpack surveys of the entire Basin have been carried out by the Saint John River Basin Co-Operative Snow Survey, and the results published by Environment New Brunswick (annually). Devenney (1977) used these to compile a map of mean snowpack water equivalent for the Basin. Table II shows snowpack water equivalents in mid-March from 1979 until 1995, during which period the density and quality of the data input were reasonably consistent. Snow and rain may fall after this date, but since the persistent thaw usually starts in late March or early April, the figures give a good estimate of the stored water available to feed freshet volume.

The stored snow and ice available for the thaw is on the average equivalent to 201 mm of rainfall above Beechwood, and 143 mm below. No simple relation to peak flow is apparent for either Grand Falls or Mactaquac. The water content above Beechwood is fairly similar to the accumulated winter precipitation at Presque Isle (figure 6), but a similar rule does not apply at Mactaquac, where winter thaws are commoner. Total volume over the freshet period is influenced by snowpack water equivalent, which does not control the dates and times of peak flow.

TABLE II
Snowpack Water Equivalents, March 15-20, Saint John Basin

Year	Above Beechwood		Below Beechwood		Whole Basin		Peak Flows ($\text{m}^3 \text{s}^{-1}$)	
	mm	% of normal*	mm	% of normal*	mm	% of normal*	Grand Falls	Mactaquac
1979	234	116	156	109	208	112	6,281	10,004
1980	170	85	75	52	184	100	1,911	4,112
1981	145	72	140	98	144	78	2,161	5,032
1982	256	127	151	106	223	121	3,882	7,363
1983	121	60	66	46	104	56	5,002	8,444
1984	318	158	207	145	282	152	4,442	6,283
1985	193	96	115	80	169	91	2,781	4,082
1986	196	98	125	87	174	94	2,621	4,352
1987	186	93	196	137	189	102	4,402	9,124
1988	210	104	198	99	206	111	2,001	3,411
1989	169	84	129	90	153	83	1,991	4,072
1990	199	99	160	112	184	100	3,100	4,472
1991	257	128	165	115	227	123	3,381	5,963
1992	185	92	128	90	166	90	3,672	5,272
1993	173	96	115	80	161	87	3,322	6,680
1994	202	101	155	108	191	103	4,049	8,610
16-year mean	201	-	143	-	185	-	3,437	6,092

Source: Saint John River Basin Co-Operative Snow Survey, Annual Reports; New Brunswick Power data files.

*i.e., the 1979-1994 means at bottom of table.

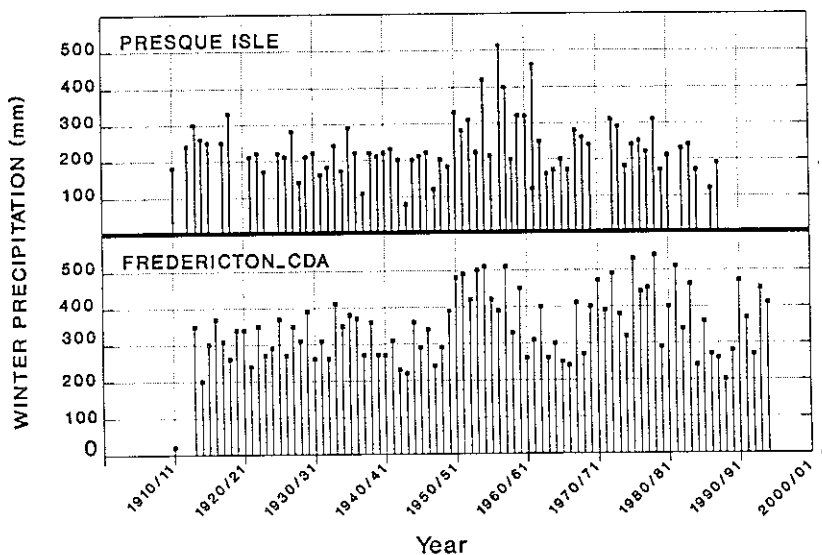


FIG. 6: WINTER PRECIPITATION (DEC. 1 to MAR. 31)
AT FREDERICTON-CDA AND PRESQUE ISLE

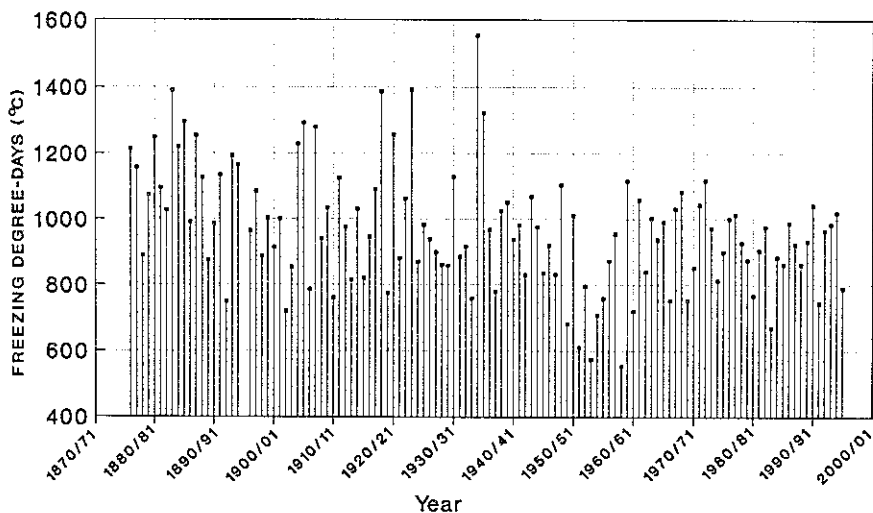


FIG. 7: WINTER SEVERITY: CUMULATIVE FREEZING DEGREE-DAYS
AT FREDERICTON (DEC. 1 to MAR. 31)

Although we have no data on the thickness and characteristics of the river ice that provides the raw material for ice-jams, we can offer a surrogate measure — the accumulated freezing degree-days (i.e., the day-by-day sum of degrees Celsius below 0°C) over complete winters (from October of one year to April of the next). Figure 7 shows this parameter for the entire period of record at Fredericton. The chief points of interest are: a cold phase in the period ending near 1900, with high variability; a prolonged spell of highly variable winters from 1900 to 1950, with a mean value of approximately 1000 deg-days, and a few very cold years, notably 1933-34; a mild spell in the period 1950-1956; and a prolonged spell, still in progress, with a mean value near 900 deg-days, with moderate interannual variability.

Great cold in late winter (as, for example, in March, 1987) permits hardening and renewed freezing of river ice, and also the refreezing of ice-jams into a welded mass (T. Lavender, 1995, personal communication).

The Freshet Peaks: Characteristics and Cases

Increase in river flow starts when about 50 thawing degree-days have accumulated (Galbraith, 1981). The flow then tends to increase rapidly. It may be slowed by renewed cold weather, or augmented by heavy rainfall. But the prime cause of rapid growth in flow is warm southerly or southwesterly winds. A spell of particularly warm weather — a thaw within a thaw — leads to very rapid rises in volume.

The first peak is associated with the onset of thaw, when the flow is impeded by channel ice, especially near obstacles, which are major hazards on the Saint John. The second (and occasionally third) peak or peaks result from specially warm episodes (thaws within thaws), or from rainfall, or from both. The first peak is normally the highest, but some of the highest — for example 1973 and 1979 — were later peaks induced by excessive rain before the snowcover had fully melted.

Freshet peaks are normally of short duration — flow remaining at very high levels for only 24 to 36 hours. If they are attended by ice moving down the channels, they may be catastrophic in nature, eroding the banks, re-aligning the channel and damaging shore facilities. But water levels tend to drop rapidly thereafter.

Although there has been an increase in scale and frequency of such early freshets, the actual spring warming has been quite small. Table III shows by decade the mean thawing degree-day totals (above 0°C) at Fredericton CDA on March 31st, April 30th and May 31st. Also shown are the decadal mean dates on which specific thresholds were reached. Thawing degree-day totals since 1971 have indeed lain above the longer-term average, after the cold 1960's. On the other hand, the date on which 50 degree-days had accumulated, though very variable from year to year, has been fairly stable from decade to decade. We conclude that the higher incidence and volume of early freshets has arisen more from the increased winter variability of precipitation and streamflow since 1950, than from marked spring warming.

TABLE III

Thawing degree-days ($>0^{\circ}\text{C}$) March, April and May, with dates when threshold values of 50, 100, 200 and 400 were exceeded, Fredericton CDA

Decade or part of	Accumulated thawing Celsius degree-days (decadal means)			Dates (numbered from March 1st) when threshold values were exceeded (decadal means)			
	Total to March 31	April 30	May 31	>50	>100	>200	>400
1914-20	26	149	461	42	53	70	88
1921-30	34	157	486	40	52	67	86
1931-40	29	165	501	41	51	65	85
1941-50	33	158	492	41	53	67	85
1951-60	22	172	508	41	51	65	84
1961-70	26	134	440	43	55	70	89
1971-80	38	161	505	38	52	67	84
1981-90	34	185	535	37	49	63	82
1991-95	33	174	520	39	49	65	83
1921-90 means	31	162	495	40	52	66	85

Source: Compiled from Atmospheric Environment Service archival data

We offer two examples of recent freshets, those of 1987 and 1994, both of which caused significant flooding, and in the case of 1987 massive ice-jam formation and damage.

Figure 8 shows the progress of events in March and April, 1987 — overall, one of the driest recent springs. The parameters plotted include: 24-hour mean streamflow of the Saint John below Mactaquac; accumulated precipitation prior to the onset of thaw on March 19th, and accumulated precipitation after the onset, at Fredericton CDA; and thawing degree-days, which in 1987 accumulated without hesitation, until by April 18th the thaw had surpassed even 1936, though not 1979, as the fastest recorded.

A rapid rise of flow began as thawing degree-days approached 50 (on March 31st), a warming that came even earlier in the upper Basin. By April 2nd, twenty-four hour mean flow at Mactaquac reached $9,124 \text{ m}^3 \text{ s}^{-1}$, the third highest on record. The 1987 single peak was actually the highest-ever for a first peak (1973 and 1979 were later, rain-augmented events). Moreover the weather prior to the 1987 thaw had been bitterly cold, so that the channel was choked with thick, firm and very cold ice. The outcome was catastrophic as the ice was swept downstream towards vulnerable targets.

This event arose from the sudden arrival of warm winds on March 19th, which brought the thaw. Little rain fell below Grand Falls during and after this thaw, and there was no return to freezing. Snowpack was below normal in the upper Basin, but was unusually abundant below Beechwood. The peak flow arrived almost simultaneously along the entire river. The tendency of the Basin to react as a single unit is typical. This enormous event occurred during a dry spring, which of itself did not protect the river from a massive freshet.

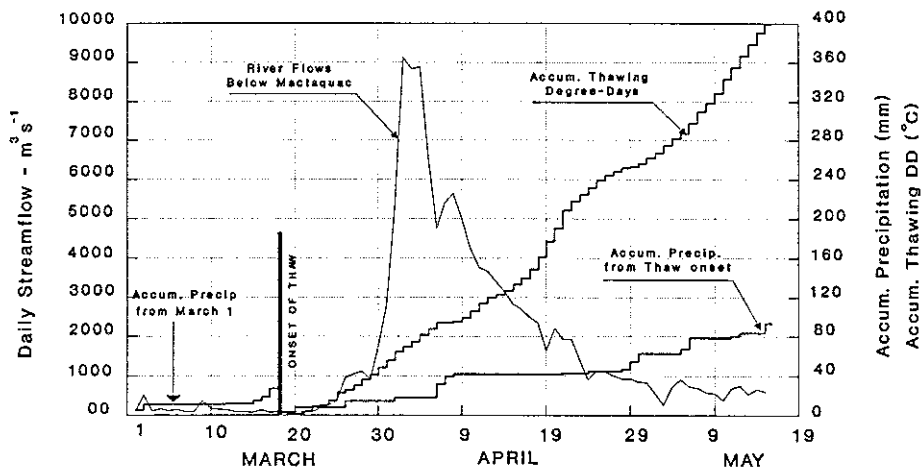


FIG. 8: HYDROMETEOROLOGICAL TIME SERIES FOR 1987 FRESHET PERIOD
(MACTAQUAC G.S. AND FREDERICTON CDA)

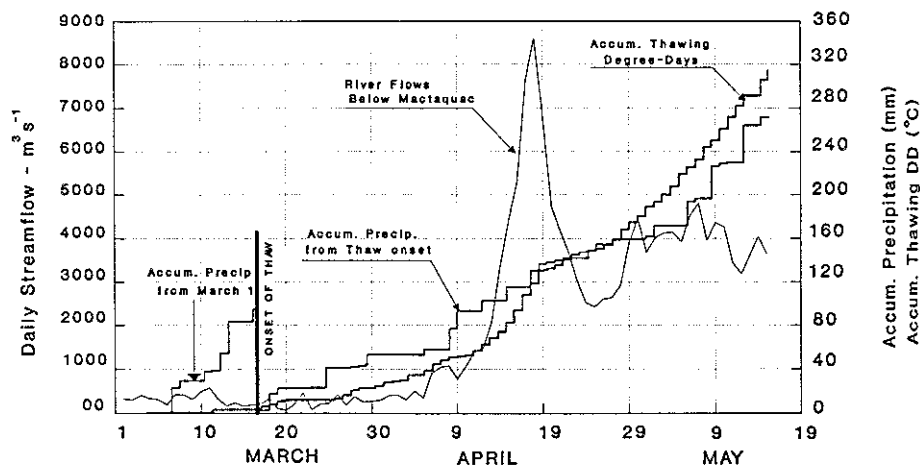


FIG. 9: HYDROMETEOROLOGICAL TIME SERIES FOR 1994 FRESHET PERIOD
(MACTAQUAC G.S. AND FREDERICTON CDA)

The 1994 event (figure 9) was very different. Thaw began on March 13/14 at Fredericton. It was very slow, and thawing degree-days did not reach 50 until April 6th. Thereafter flow at Mactaquac rose more rapidly, reaching $8,610 \text{ m}^3 \text{ s}^{-1}$ on April 18th, the fourth highest annual peak. Snowpack was near normal. In this case, there was frequent heavy precipitation before and after the peak. This precipitation — largely rain — augmented the peak flow, and also led to abundant flow for several weeks afterwards.

Incidence of Heavy Precipitation Events

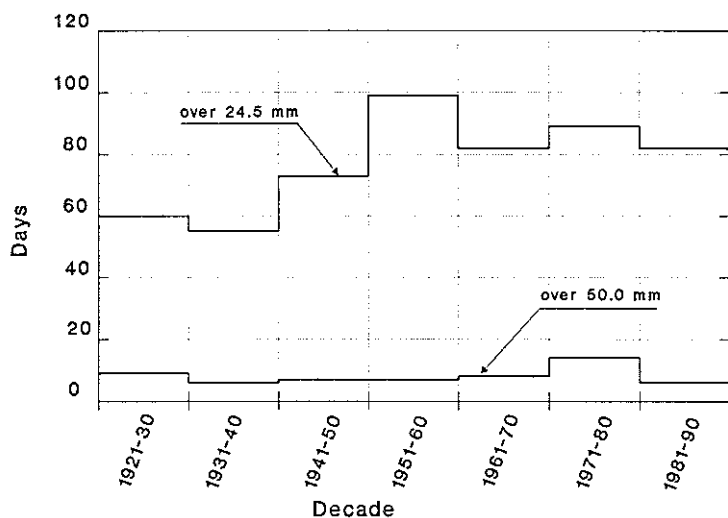
Several studies have identified apparent increases in frequency of heavy one-day rainfalls. Karl et al. (1996) showed that the area of the US with the number of wet days much above normal increased progressively between 1910 and 1980, and remained high in the early nineties. The same authors also showed an increase between 1920 and the present time in the US area with rainfall from 1-day events of 51 mm or more. Tsonis (1996) found that mean annual precipitation at 5,328 land stations around the globe showed no trend since the mid-nineteenth century, a result consistent with a recent IPCC assessment (Eischeid et al., 1991). He demonstrated, however, a general increase in variance on the decadal and multi-decadal scales. He was unable to decide whether the high-frequency variability identified by Karl et al. (1996) was related to his own discovery of low-frequency events. We share his uncertainty, but are sure that one-day heavy rain or snow events have increased over the Basin.

Figure 10 shows the frequency of daily falls above 24.5^5 mm, totalled by decade at Fredericton CDA, together with annual totals and means, and the annual total of days with 50 mm or more. The 1950's, especially the early years, had the highest overall average frequency of wet days. The distribution was then distorted by two extraordinary years, 1979 and 1981, each of which had nineteen events. The late 1980's had low frequencies, whereas those of the early 1990's (not shown) were substantially higher. The total annual precipitation provided by such wet days was highest in the 1990's. The evidence thus tends to support the Karl et al. (1996) finding, but the distribution is too irregular for real assurance. This is unsurprising, since a single drainage basin's experience cannot fairly be compared with continental or global findings.

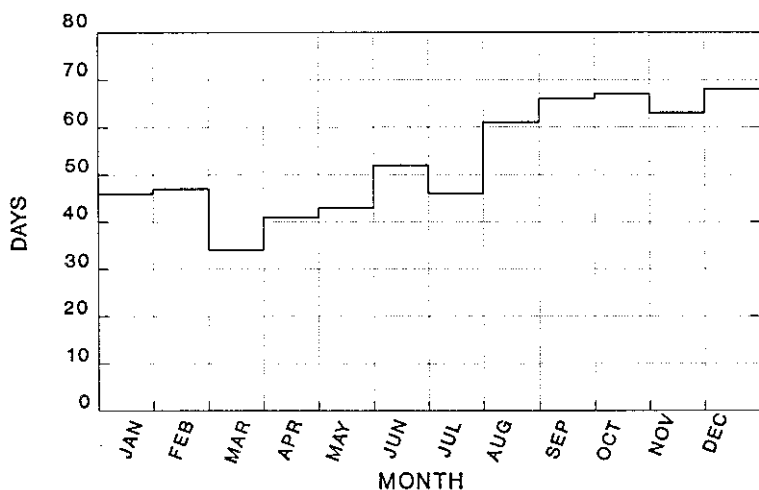
A major question concerns the possible occurrence of extreme rainfall events outside previous experience, such as the disastrous rainfalls over the Saguenay Basin on July 19th to 21st, 1996, when 180-280 mm fell over parts of that Basin. If such a major rainfall were to coincide with rapid snowmelt in the Saint John Basin, streamflows much above the present observed Mactaquac maximum of $11,105 \text{ m}^3 \text{ s}^{-1}$ (in 1973) would be probable.

The Saguenay storm was only 200 km north of the upper Basin. At least three other storms have come close enough to make speculation reasonable. The most extreme was the storm of May 25th-28th, 1961, which affected northern Maine and the whole of New Brunswick, including the Saint

⁵This approximation to 25 mm was adopted because of rounding-off procedures and other features at CDA.



a: Days per Decade with One-Day Precipitation Exceeding 24.5 and 50.0 mm at Fredericton CDA



b : Number of Day Since 1913 with Precipitation Over 24.5 mm

FIG 10: DAYS WITH PRECIPITATION EXCEEDING 24.5 AND 50.0 mm AT FREDERICTON CDA

John Basin, total falls exceeding 50 mm everywhere below Edmundston. At Fredericton CDA 162 mm fell between May 25th and 30th inclusive. The maximum impact was below Fredericton, in a region with high storage capacities. Flow of the Saint John was already subsiding at Pokiok from a late freshet peak of $6,823 \text{ m}^3 \text{ s}^{-1}$ on May 16th, and had fallen to $2,041 \text{ m}^3 \text{ s}^{-1}$ by May 26th. The deluge that followed drove flow back up to $7,053 \text{ m}^3 \text{ s}^{-1}$ on May 29th, a rise of $5,012 \text{ m}^3 \text{ s}^{-1}$ in three days. If the storm had come earlier by two weeks, and falls had been a maximum 50-100 km north of the actual peak area, the consequent flow in the reaches below Beechwood would have been very much higher (Cuthbertson and Dickison, 1962).

Two other storms of the same type — east coast cyclones stalled or moving slowly across the region in such a way as to combine rain from low level Atlantic easterlies with that from southerly and southwesterly airstreams above the warm fronts or occlusions (trowals) — occurred in early April 1987, and again narrowly missed a disastrous impact on the Saint John.

Between March 30th and April 2nd, 1987, very heavy rain (with some snow on the highest ground) fell across Maine and New Hampshire. Some stations on the eastern slopes of the White Mountains received over 150 mm, and falls over 50 mm were widespread. Moreover, the rain occurred at the time of onset of freshet flows. Fortunately for the Saint John, totals over the Basin were much lighter. Estimated average falls were 33 mm above Grand Falls, 15 mm in the Grand Falls-Beechwood reach, and 6 mm below Beechwood, in each case falling largely on April 1st and 2nd (when thaw-induced peak flows were being approached along the Saint John). The only impact was to prolong the peak flow event by 24-36 hours. In effect, the storm rainfall followed immediately on the heels of the thaw-generated freshet peak. Had the main falls associated with this cyclone affected the middle and upper Basin, flows would have greatly exceeded the already high levels observed.

A few days later another storm of the same type, following almost the same track, produced a similar deluge between April 6th and 8th. This time the heavy falls — over 100 mm — affected primarily Connecticut, Massachusetts and southern Maine, but significant rain fell over the Basin. These rains produced the brief interruption in the decrease of streamflow visible on figure 8. Thereafter, 1987's spring reverted to the dry pattern peculiar to the year, and flow decreased to very low values.

These four storms indicate that the Saint John Basin is potentially within the reach of much greater rainfalls and streamflows than have so far been recorded. Moreover, two of the storms were nearly simultaneous with the persistent thaw and the onset of the freshet. Although no exact coincidence in timing and location has yet been observed, the event of March 31-April 2, 1987 came perilously close.⁶

Bruce and Sporns (1963) calculated that maximum storm rainfalls over the Saint John Basin, for a hypothetical area of $2,600 \text{ km}^2$, would be at their highest for both 24-hr and 96-hr periods in August or September, largely because of tropical storms or hurricanes, a few of which affect the Maritimes in most years. But they also found that the risk would remain above 50 per cent of this maximum

⁶Thanks are due to F. Parkinson for comments on this event.

throughout the year. Our data (figure 10-b) slightly modify this conclusion. At Fredericton CDA 80 events with over 24.5 mm in 24 hours can be expected in each decade. The probability of such events is a minimum in March, April and May — the thaw period — and a maximum in the months August-December. About one-tenth of all cases will produce over 50 mm in 24 hours.

The likelihood of heavy precipitation is thus highest in late summer and fall, though the rain is not exclusively derived from tropical disturbances crossing the region. Heavy precipitation may occur during the spring freshet. As we have shown certain years, especially 1961 and 1987, have produced near-misses between thaw-induced freshet flows and excessive rainstorms. The probability of such coincidences has lain below once a century, but the increased variability of recent decades in both precipitation and streamflow may indicate a rising risk.

DISCUSSION

The usual perception of recent climatic variation over Atlantic Canada is clearly wrong when applied to the Saint John Basin, whose climate behaves more like that of New England and the Great Lakes-St. Lawrence region. Benchmark stations on the Atlantic coast, such as Moncton, give a false impression of events in an inland Basin sheltered from the coast by hills.

What we have found — and what the regional population has had to cope with — is that the Basin appears to have shared in the global warming of the past century, very much like Canada as a whole. We have, however, detected no enduring change in mean annual precipitation and streamflow. There has been an increase in short-term variability, which has affected several aspects of the hydrological régime. In particular, the spring freshet on the Saint John has become progressively more variable: the likelihood of early peak flows with high volume has certainly increased, and may well continue to do so. We have no evidence, however, that this change has been caused by the greenhouse effect. Rainfall, snowfall and streamflow time series often appear to be quasi-periodic and the effects we have described may be no more than fluctuations. The warming since the nineteenth century seems, however, to be definitely established.

River basin analysis is a valuable tool in the study of regional climatic change, because streamflow is an excellent measure of a spatially-integrated kind. Without the stream-gauging evidence used in this report we could not properly have analysed the narrowly climatological evidence. **Streamflow is, in fact, an essential climatological parameter, and should whenever possible be emphasized in the detection of regional climatic variation.**

We are disturbed by the evidence of changing patterns of variability. Changes of mean values can be accommodated by hydrometeorological models, provided that they are properly identified. But changes in the modes of variation shown clearly in figures 2 and 6 cannot readily be dealt with. Given the very high flows repeatedly observed in and since 1973, several of them with long calculated return periods, we think it important that estimates of possible maximum flows be revised, most probably upwards (Dickison, Curry and MacDougall, 1968).

It will not be easy for provincial and municipal governments, utilities and resource corporations to cope with the changes that are becoming evident. Climatic change, and the ecosystem changes that

go with it, are spatially intricate processes. The details of what we can expect are not adequately predicted by the general circulation models in current use — and it may be impossible to model on the scale required by engineers and provincial governments. We therefore advocate the closest possible examination of the recent climatic record. Such examination can never yield adequate predictions of future events. But it can suggest the nature and scale of suitable precautionary measures.

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The paper presented herein is one of three overlapping papers emerging from the 1987 freshet problems on the Saint John River, and discussed in Hare 1995 (see References.) The first paper (by Hare alone) was a short overview delivered to the 1997 H.G. Acres Seminar held at Niagara Falls, Ontario, on May 9th, 1997. The second paper (by all three authors) will be published in "Climate Change Digest", Issue 1997/2. The present paper elaborates the various themes involved in descriptive and historical terms.

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