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Background information for the modeling of the Montréal / Trois-Rivières river reach

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Abstract

An essential step in the production of representative hydrodynamic simulations is the thorough characterization of the temporal and spatial behaviour of the main physical variables such as river discharge, water level, wind and temperature. The simulations can then be used in studies of the effects of water levels on the various life forms of the St. Lawrence River ecosystem.

An analysis of reconstructed series of discharges for the St. Lawrence River and its major tributaries between 1932 and 1998 indicates that the regulation of the Great Lakes has resulted primarily in a flow reduction in the spring and a flow increase in the fall in the Sorel area. A similar effect is noted for the Ottawa River basin, although it is 10 times greater than that induced by the Great Lakes during floods. Therefore, the regulation of the Ottawa River should be given the same consideration as that of the Great Lakes in any procedure to introduce environmental criteria in the management plans for the Great Lakes/St. Lawrence system.

Limit conditions were defined for winds and air temperatures for the purpose of developing biological models which will be combined with physical models, providing a more complete integration of all the data and their distribution over the study domain.

A total of 13 reference scenarios were identified from the distribution of river discharges at Sorel. These scenarios apply to the ice-free periods in the spring (8 scenarios) and summer (5 scenarios). Winter was not considered because of the ice-cover, and fall was not retained due to the absence of aquatic plants. For each scenario defining boundary conditions, hydrodynamic simulations were conducted, accounting for such factors as the presence of aquatic plants and wind.

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1 Introduction

One of the main objectives of the Biodiversity section of the St. Lawrence Action Plan III (SLAP III) is to quantify the impact of water level fluctuations on the river ecosystem. This ambitious objective requires the integration of physical and biological data and background knowledge. These data and knowledge, coupled with numerical simulation models of hydrodynamics, waves, aquatic plant distribution, wildlife and fish habitats will eventually be part of a Decision Support System. Resulting from this approach, this document provides some necessary bases for the modeling of the river reach between Montréal and Trois-Rivières (Figure 1).

The study area stretches over 150 km between the outlet of the La Prairie basin and Trois-Rivières, and varies in width from 1 km at Lanoraie to nearly 13 km at Lake Saint-Pierre. Tide, clearly perceived at Trois-Rivières, is barely felt in Lake Saint-Pierre and is present only as weak oscillations at the Port of Montreal. Important uses occur in the river reach, including commercial fishing and shipping. The natural environment has been modified by dredging of the shipping channel and by the construction of the Sorel weirs.

The objectives of this report are to 1) document the hydrology and the climate in the reach to prepare the physical modeling of the system and 2) produce a limited number of reference events representative of the system's complexity. To reach these goals, several tasks have been initiated. A history of the main modifications to the river, such as dredging, bridges and weirs is presented. Hydrological (levels and discharges) and meteorological (winds and temperatures) data have been gathered in a database and partially analyzed. The river discharges at Sorel and Trois-Rivières were reconstructed for the period 1932-1998. The regulation of the Great Lakes and of the Ottawa River is analyzed. Finally, the discharge recurrence periods are examined and reference events are defined.

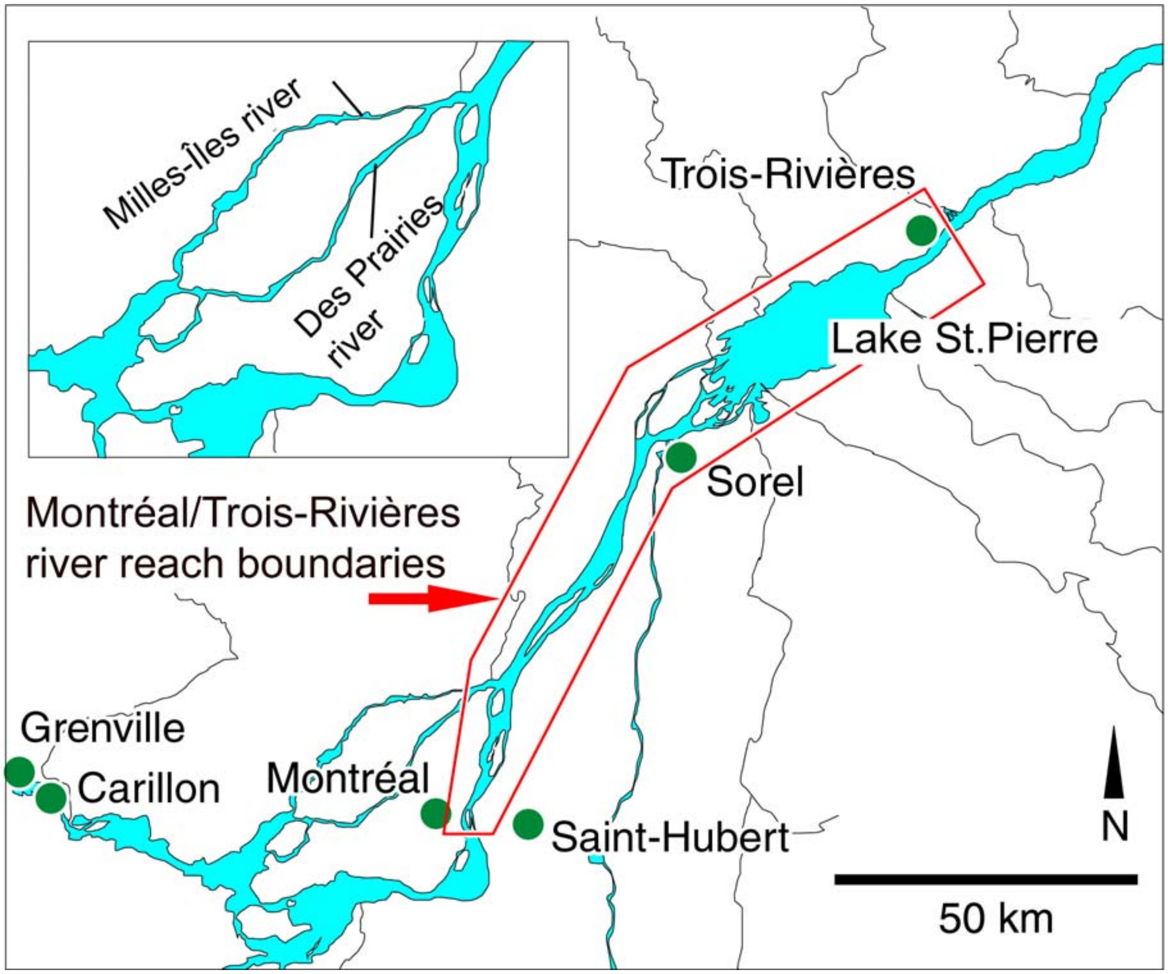


Figure 1 : Study area.

2 Engineering works

The river reach between Montréal and Trois-Rivières has been considerably altered by dredging in the shipping channel, construction of weirs in the Sorel area, and, to a lesser extent, modifications to the river bed induced by the crossing of pipelines, high voltage power lines, bridges and tunnels.

It will be essential to comprehend the spatial and temporal distribution of the physical modifications in order to ensure proper interpretations when analyzing physical and biological data series. For example, proper interpretation of fish habitat models requires that changes in substrate composition, suspended matter, current velocities, etc. resulting from dredging operations are taken into account.

2.1 Dredging and sludge disposal

The shape of the St. Lawrence river bed has been greatly modified over most of the reach between Montréal and Trois-Rivières by dredging operations. Although river topography changes are major, there are very few studies assessing the direct interventions on the environment. A thorough description has to be done, representing a huge task.

Several authors have described the evolution and the impact of the St. Lawrence Seaway in terms of construction costs, and regional economical gains and losses (Lassère, 1971 ; Corley, 1961 ; Sandwell, 1930). These studies give a portrait of dredging operations in the St. Lawrence prior to 1958. The work of Robitaille *et al.* (1988) have resulted in a summary map of the dredging and disposal zones for the period from 1945 to 1984. However, these studies give no information on when dredging occurred or the volumes involved. Finally, Lapointe (1994) conducted a detailed analysis of the evolution of the river bottom topography in the Contrecoeur area.

Only data available in the studies cited above are integrated in Table 1. The first interventions were limited to Lake Saint-Pierre which, for a long time, was the shallowest sector of the river; but as the depth requirements increased in the shipping channel, longer sections had to be dredged. The most important operations occurred in the 1950s.

Table 1 : Sequence of dredging operations in the St. Lawrence River.

Period	Depth	Width	Location
Prior to 1844	Max 3.2 m	~	
1844-1847	4.2 m	45 m	Sand and clay bank, limited sector in Lake Saint-Pierre, aborted attempt to create a straight line channel
1850-1851	4.2 m	45 m	Mostly dredging in the natural channel of Lake Saint-Pierre
1854-1856	4.8 m	45 m	Lake Saint-Pierre, and other sites
1856-1865 1888 1888-1907	6.1 m 7.6 m 8.4 m 9.0 m	75 m 135 m 135 m	Lake Saint-Pierre, and other sites
1912-1930	10.7 m	168 m	Montréal to Batiscan
1952-1954		245 m straight 457 m curve	Montréal to Québec
1954-1971			Localized works
1973-1974			Mooring area, Montréal-Nord

2.2 Weirs

The Sorel Island weirs were constructed as the result of a study of water levels between Montréal and Lake Saint-Pierre (CDMF, 1915). The study suggested the construction of five hydraulic structures to increase the water level up to the Port of Montréal to prevent an eventual decrease in water level liable to affect commercial shipping. The weirs were constructed between September 1928 and November 1931 (Pasin, 1979 ; Briand, 1963). Five structures were constructed between the following islands 1) aux Barque and du Moine, 2) de Grace and Ronde 3) Ronde and Madame, 4) Saint-Ignace and Dorvilliers and 5) Dorvilliers and du Milieu.

The structures resulted in an estimated increase of 0.12 m at the Port of Montreal, and 0.29 m at Sorel. The flow in the main channel would have increased from 25% to 85% of the total discharge (Briand, 1963). Dumont (1996), using a 1D (STLT) model to study the effects of the weirs, concluded to a much lesser impact of 0.01 to 0.07 m at the Port of Montreal and 0.04 to 0.18 m at Sorel depending on hydraulicity.

Weir maintenance has caused problems because of the effect of strong discharges and ice on the stability of the materials they are built from. The weirs have been repaired frequently, in 1934, 1935, 1938, 1939, 1940 and 1941. It seems that after 1941, the weirs became more stable and were brought back to the 1931 design elevation (Briand, 1963). In 1953 and 1962, more stabilization works were conducted, but the 1931 design elevations were not reached. Following excessively low water levels in 1963 and 1964, the weirs were again brought back, at the end of the summer of 1965, to the 1931 elevations. These restoration works were insufficient to stop erosion, and some years later, the efficiency of the weirs was again questioned (LHL, 1989). Finally, in 1995, the Canadian Coast Guard had minor stabilization works done on the weirs and Dumont (1996) recommended restoration to the design elevations.

2.3 Other modifications

Several other interventions have occurred in the system. Most are located in the Montréal area and have a relatively limited impact. These include the digging of trenches in the river bed for the crossing of pipelines, power lines, and for the Lafontaine Tunnel (Dryade, 1981). Other modifications include shore stabilization and filling of wetlands.

3 Hydrology regimen, discharge

3.1 Background

The discharge in the Montréal/Sorel river reach comprises water masses from the Great Lakes, the Ottawa River and other tributaries around the Montréal Archipelago. From Sorel downstream, several tributaries contribute to the discharge; the most important are the Richelieu River, the Yamaska River and the Saint-François River. In the scope of this report, discharges in the St. Lawrence and its tributaries are reconstructed for the whole period from 1932 to 1998. A subsequent analysis of the discharges was conducted from the reconstructed data at the mouth of the tributaries and at two sections of the river, at Sorel and Trois-Rivières.

The methods used to reconstruct the discharge series are briefly presented in the following sections. The long term and annual discharge fluctuations of the river and its main tributaries are also presented. Finally, an analysis is made of the regulation of discharges.

3.2 Reconstruction of the river discharges

The discharge data series available for the St. Lawrence River are limited to the control sections. The Lasalle station, near the Lachine Rapids, is the furthest downstream. There are no discharge time series available for the segment downstream from Montréal to Trois-Rivières. Therefore, it was necessary to reconstruct them to generate a physical model of the system. Several discharge estimates have been attempted for the St. Lawrence River downstream of the Montréal Archipelago, with different goals and means.

Carrier (1976) estimated the monthly and yearly discharges of the St. Lawrence River at four specific locations, Trois-Rivières, Québec, Tadoussac and Baie-Comeau, but only for three flow conditions : a dry year (1964), a normal year (1950) and a wet year (1972). Two methods were tested : 1) the first is based on the calculation of the monthly and yearly discharges at the mouth of each river gauged and 2) the second uses a restricted number of tributaries and an extrapolation from the variations occurring in different watersheds.

Hoang (1980) conducted a hydrological study of the daily discharges of the St. Lawrence by adding the discharges measured at the Mille-Îles River, the des Prairies River and in the St.

Lawrence at Lasalle. This summation does not include the input of the local tributaries (Assomption, etc.) and the validity is limited to the upstream portion of the Montréal-Sorel segment since the downstream tributaries are not included.

Bourgault and Koutitonsky (1999) used two methods to estimate the discharge at Québec : a regressive model and a One-D model calibrated with discharge measurements over a full tidal cycle. They concluded that the One-D model was able to calculate the discharge at Québec with two water level gauging stations. However the measures from the two stations are limited to 1955.

While calibrating the STLT (One-D) hydrodynamic model, Morse (1990) proposed a method to estimate the St. Lawrence River discharge over a reach originating upstream with the two most important inputs, the outlet of Lake Ontario at Cornwall and the Ottawa River at Carillon, and ending downstream at Québec. This method takes into account the major tributaries of the St. Lawrence which are generally gauged, the non-gauged surface areas of these tributaries, and the non-gauged flows such as brooks or underground drainage. The river tributaries are represented by a total of 12 "lateral inputs".

The river discharges at Sorel and Trois-Rivières were reconstructed by adapting the method used by Morse (1990). The discharges are calculated between the Port of Montréal and Trois-Rivières by adding the discharges at Lasalle, at the Mille-Îles River, the des Prairies River and the tributaries (Figure 2). The discharges measured at the tributaries are corrected for the non-gauged areas by the equations presented in

Figure 3.

In order to be able to analyze the long term changes in the system, the discharges were reconstructed for the period from 1932 to 1998. This period represents the interval during which discharge data are available at the Lasalle station. To reconstruct discharges over such a long period constitutes a relatively complex task since the data from the downstream stations do not necessarily cover the whole period; and when the series are available, there are important gaps in the data.

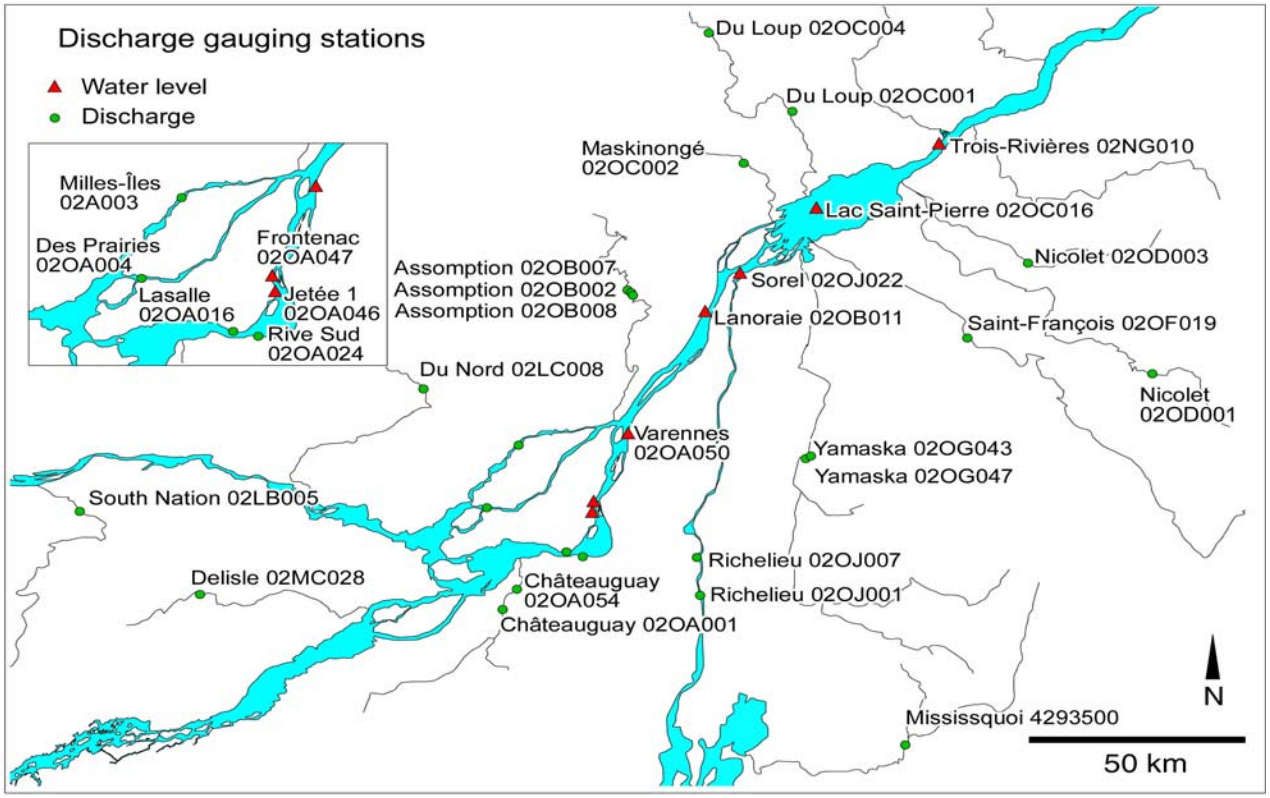


Figure 2 : Location of the level and discharge gauging stations used.

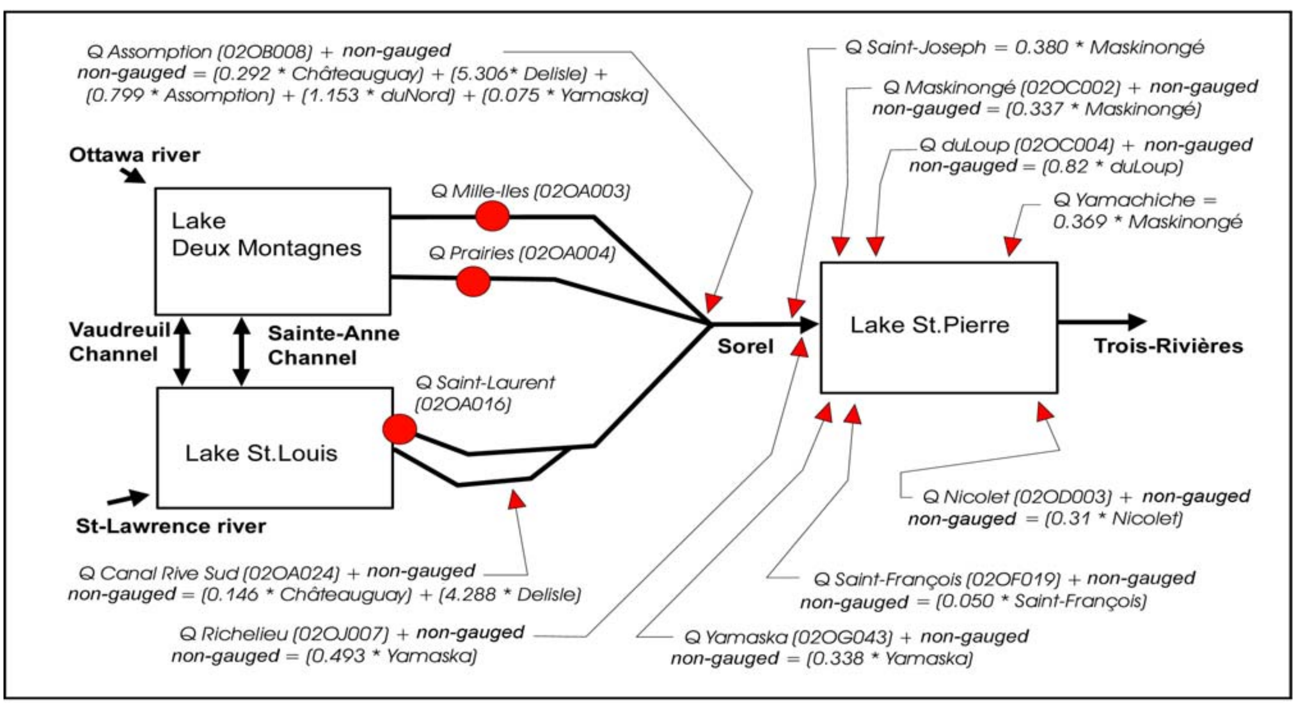


Figure 3 : Calculation method for the St. Lawrence River proposed by Morse (1990).

3.2.1 Methods used

The details of the method used to reconstruct the discharges are presented in Bouchard and Morin (2000). That report presents the data and the methods used to obtain complete discharge series between 1932 and 1998 for the whole segment between Montréal and Québec. The list of gauging stations available was established for the portion of the St. Lawrence watershed located between Cornwall and Québec. From this list, only the stations with a satisfactory time series and located near the reference stations used by Morse (1990) were retained for the reconstruction.

Two methods of reconstruction were used 1) calculation of the discharge at the reference station using the discharge measured at another station on the same river, corrected by the surface ratio of the watersheds drained at each station and 2) calculation of the discharge at the reference station by a regression equation using the discharges at a gauging station strongly correlated ($R^2>0.85$) with the reference station. A correlation analysis including all the gauging stations retained from the initial list was conducted to validate the stations used in method 1 and to identify relations usable in method 2.

For each reference station on each of the tributaries, calculated discharge series were generated using the regression equations (method 2) and, when possible, using method 1, thus producing several reconstructed series at each reference station. The statistical distributions of the reconstructed series were compared with the distributions at the reference stations to assess the appropriateness of the reconstruction methods in order to select, for each tributary, the method producing the best results. At station Delisle (02MC028), the absence of an appropriate relation and the absence of a station elsewhere on the river forced the use of the daily inter-annual average to complete part of the series. This method was also used to fill in the gap in the data for October 1998 on the Yamaska River. Finally, when isolated values were missing, a value was interpolated from previous and subsequent days.

Table 2 summarizes the stations used, the time series available and the actions taken to complete the series. For future analysis, the reconstructed daily discharge series were reduced to series of weekly averages, thus avoiding the errors generated by downstream transport time in the system.

Table 2 : Reconstruction methods for discharge data between Montréal and Trois-Rivières. MV = missing value, W = watershed, DIAA = daily inter-annual average.

Number	Station	Time series	Actions
02OA004	des Prairies	1922-1998	None, complete series
02OA003	Mille-Iles	1913-1998	None, complete series
02OA016	Lasalle	1955-1998	1932 to 1955 – Q/H relationship with 1932-1978 levels
02OA024	South Shore Channel	1959-1998	82 MV – Interpolation
02OA054	Châteauguay	1970-1998	1970-1998 - 25 MV – Interpolation 1932-1970 – W transfer upstream station (02OA001)
02MC028	Delisle	1985-1998	1985-1998 - 1 MV - Interpolation 1932-1985 - Regression with South Nation (02LB005) 1932-1985 - 2565 MV – DIAA Delisle (02MC028)
02OB008	Assomption	1970-1998	1970-1998 – 2 MV - Interpolation 1932-1965 – W transfer upstream station (02OB002) 1965-1969 – W transfer upstream station (02OB007)
02OG043	Yamaska	1983-1994	1983-1994 - 02OG043 ; 1994-1998 - 02OG047 1932-1983 - Regression with Mississquoi (04293500) 1983-1998 - 449 MV - Regression Mississquoi 1998 - 29 MV (October) – DIAA 02OG043
02OJ007	Richelieu	1937-1998	1937-1998 - 8 MV - Interpolation 1932-1937 – W transfer upstream station (02OJ001)
02OF019	Saint-François	1972-1998	1932-1971 - Regression Nicolet Sud-Ouest (02OD001) 1972-1998 - 252 MV - Regression 02OD001
02OD003	Nicolet	1966-1998	1932-1966 – W transfer upstream station (02OD001)
02OC004	du Loup	1965-1998	1965-1998 - 303 MV - Regression Assomption (02OB008) 1932-1965 – W transfer upstream station (02OC001)
02OC002	Maskinongé	1925-1998	1932-1998 - 2994 MV Regression Assomption (02OB008) 1932-1998 - 2 MV - Interpolation

3.3 Long term fluctuations

The mean long term discharge, between 1932 and 1998, at Sorel, is 9 918 m^3/s (1932-1958 : 9 410 m^3/s, 1960-1998 : 10 270 m^3/s). The discharge fluctuations around this mean can be important, depending on climate cycles which influence the amount of rainfall and evaporation over the whole watershed. The long term discharge fluctuations originating from the Great Lakes are known (Morin and Leclerc, 1998). These fluctuations have periods oscillating between 20 and 35 years with amplitudes ranging from 5 000 to 10 000 m^3/s. Because of the importance of the Great Lakes discharge (mean discharge of 7500 m^3/s) in comparison with other tributaries such as the Ottawa River (mean discharge of 2000 m^3/s), the long term discharge fluctuations at Sorel are the result mainly of the flow from the Great Lakes. The influence of tributaries is mostly felt during spring floods.

The series of calculated discharges at Sorel reveals clearly the fluctuations in spring floods as discharges during flood periods are easily distinguished and show the impact of the tributaries. These spring floods can be so important as to triple the amount of water coming from the Great Lakes (Figure 4), as in 1976 when the mean weekly discharge reached close to 19 350 m^3/s at Sorel. The period from 1961 to 1966 is singular in that the discharges are very weak even in the spring. A similar phenomenon can be observed in the 1930s with weekly discharges in the order of 6 390 m^3/s.

3.4 Seasonal fluctuations

The large Seaway works over the whole system were completed in 1958 so that regulation of the discharges makes comparison hazardous between the post-1959 series and the pre-1959 series. At Sorel, these two portions of the series indicate changes in the discharge distribution throughout the year, caused by the regulation of the Ottawa River and the Great Lakes (section 3.6). To eliminate the period of implementation of the discharge regulation, the seasonal fluctuations are analyzed for the period 1960 to 1998.

The seasonal discharge fluctuations at Sorel are important and are mostly caused by the tributaries' floods, especially the spring flood in the Ottawa River. Figure 5 shows the inter-annual weekly mean of the series calculated at Sorel between 1960 and 1998. On average, the spring flood begins at the end of April with a discharge of nearly 13 000 m^3/s, while periods of low discharges occur at the end of August and in January at around 9 000 m^3/s. The period with high discharges in the spring may begin as early as mid-February (1981) or as late as the end of May (1974). Figure 5 presents some curves of weekly means highlighting the fluctuations during the flood period and the low water period for some typical and untypical years. In some years, such as 1966, the discharge is very high in the fall and can be compared to spring discharges. The year 1976 was exceptional, showing a strong spring flood beginning very early. It should be noted that the standard deviation of the inter-annual means is very small in the winter, and relatively small during the aquatic plant growth season, between mid-June and the end of October.

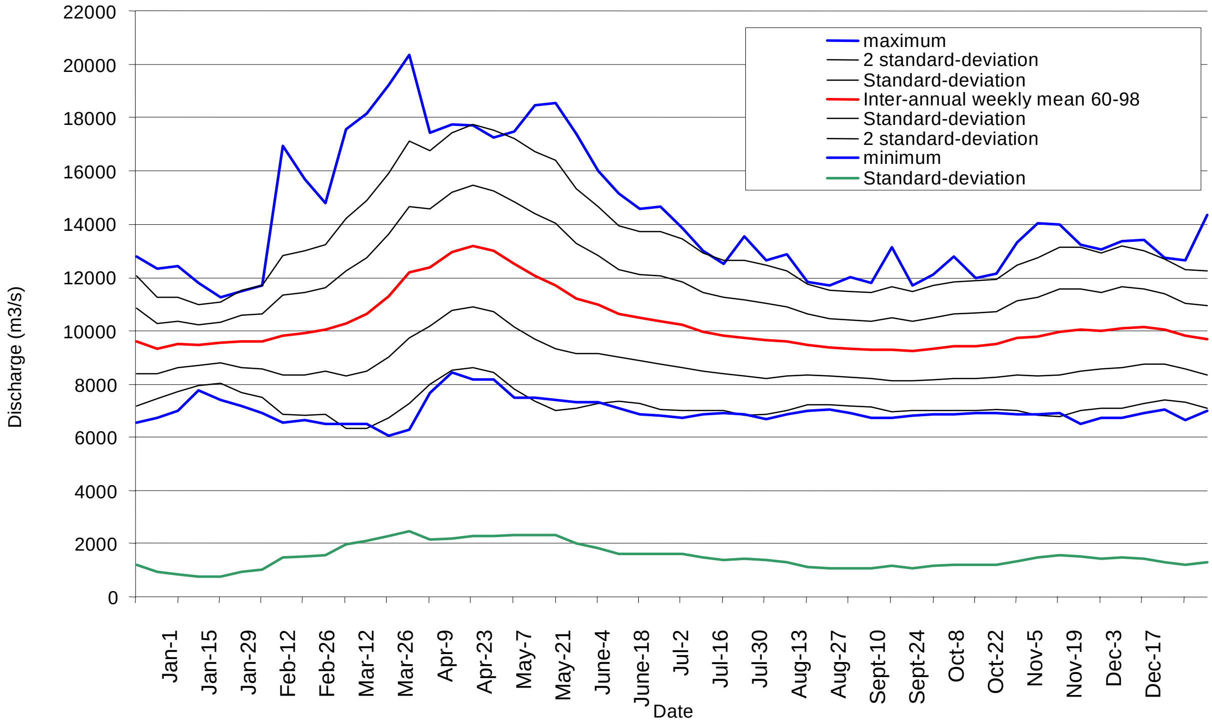


Figure 4 : Inter-annual weekly mean, standard deviation and weekly minimum of discharges from 1960 to 1998 at Sorel.

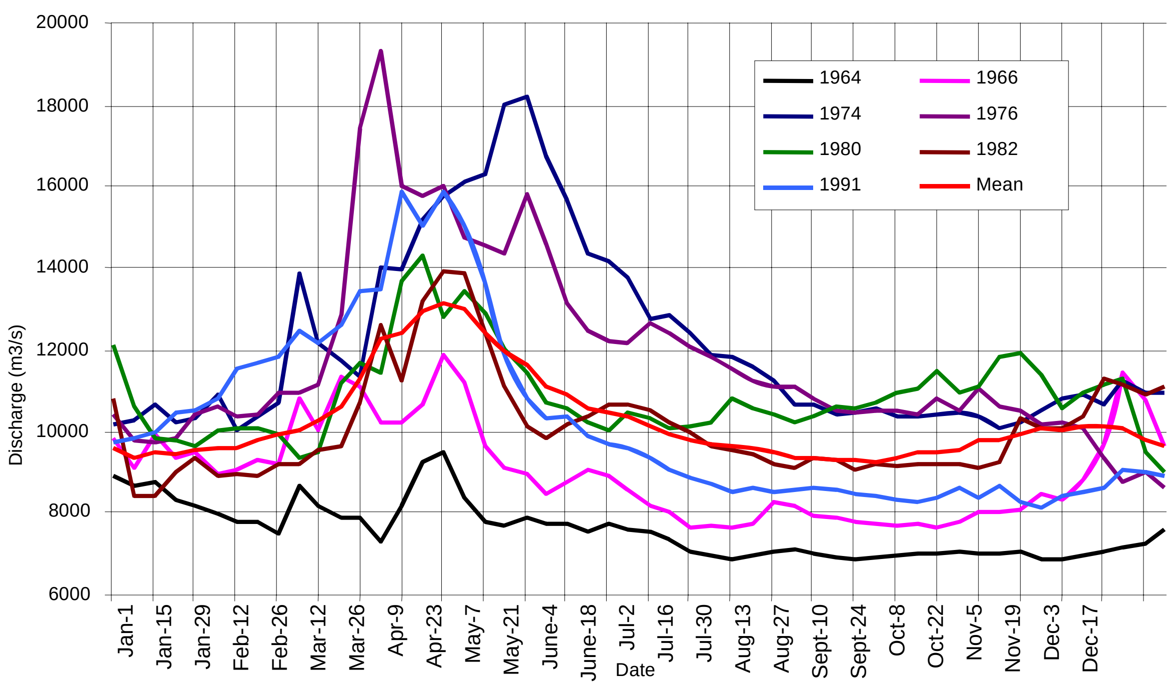


Figure 5 : Inter-annual weekly mean of the discharge calculated at Sorel between 1960 et 1998.

3.5 Tributaries

As mentioned above, the discharges of the tributaries were reconstructed for the period 1932 to 1998 (see section 3.2). However, in order to be able to compare them with the St. Lawrence discharges, only the period between 1960 and 1998 was analyzed. The Assomption River is the only important tributary in the sector above Sorel, while downstream from Sorel, there are several tributaries discharging into Lake Saint-Pierre. The largest (Richelieu, Yamaska, Saint-François and Nicolet) are located on the south side of the lake (Figure 1). On the north side, the Maskinongé, du Loup and Yamachiche rivers are much smaller. Several other small tributaries, such as the Saint-Joseph, Chicot, Bayonne, la Chaloupe, petite Yamachiche and aux Glaises rivers, are not considered in this section. Table 3 summarizes some characteristics of the main tributaries located between Montréal and Trois-Rivières.

Table 3 : Characteristics of the watershed and the discharges of the tributaries at their mouth for the period 1960-1998 (upstream to downstream).

Tributaries	**Watershed** Km^2	**Mean discharge** m^3/s	**Minimum discharge** m^3/s	**Maximum discharge** m^3/s
Assomption	4234	89	9	844
Richelieu	23720	385	61	1469
Yamaska	4784	69	1	1283
Yamachiche	380	7	0.2	67
Saint-François	10228	209	3	2520
Nicolet	3398	43	0.7	998
Maskinongé	1096	26	0.7	243
Du Loup	1409	23	0.9	286

Figure 6 shows the fluctuation of the weekly inter-annual mean of the main tributaries of the reach. In general, the tributaries have a relatively varied range of discharges : strong in the spring, minimum in summer and winter, and average in the fall. The maximum spring flood in the tributaries on the north side of the St. Lawrence occurs from one to two weeks later than in the tributaries on the south side. The Richelieu River differs from the other tributaries of the south side by a later spring flood caused by the almost natural regulation resulting from the presence of

Lake Champlain at the head of the watershed.

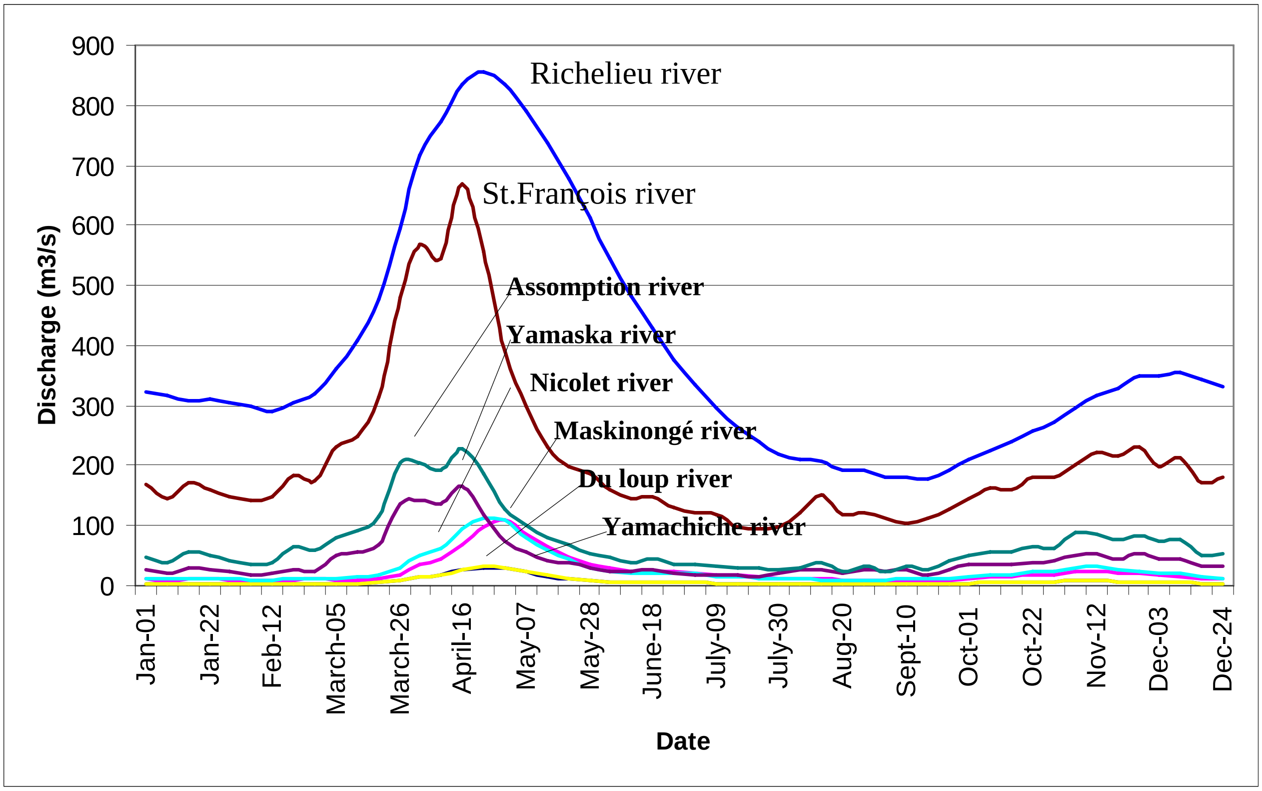


Figure 6 : Weekly inter-annual mean discharge of the main tributaries in the Montréal/Trois-Rivières reach between 1960 and 1998.

3.6 Discharge regulation

The end of the 1950s marks a turning point in the hydrology of the St. Lawrence River as the Great Lakes discharges become regulated by the construction of the Moses-Saunders dam. This dam now controls the level and the outflow of Lake Ontario. The reconstruction of the discharge series at Sorel between 1932 et 1998 provides an analysis of the long term evolution of the water input fluctuations. To quantify the impact of the regulation of seasonal discharges at Sorel, the pre-1959 and post-1959 discharges were compared as Quarter-month Inter-Annual Mean (QIAM). The regulation of the Lake Ontario discharge is well documented; therefore, it is possible to assess its effect on the discharge at Sorel.

3.6.1.1 Impacts at Sorel from 1932-1959 to 1960-1997

In this section, the period of analysis ends in 1997, the pre-regulation data not being available for 1998 (D. Fay, pers. comm.). The QIAMs of the discharge at Sorel indicate an important difference between the 1932-1958 and 1960-1997 periods (Figure 7A). However, the two curves can hardly be compared because the mean discharges of the two periods are different. A form of standardization is needed for the purpose of comparison. The method used is very simple and allows to transform the mean annual discharge of the 1932-1958 series to the same value as the 1960-1997 series. The contribution of each quarter-month is reported as a proportion of its contribution on the annual discharge with the following equation :

$$Q_{sta} = Q_{raw} \cdot Q_{target\_annual\_avg} / Q_{series\_annual\_avg}$$

where Q_{sta} is the standardized quarter-month discharge, Q_{raw} is the quarter-month discharge of the raw series, $Q_{target\_annual\_avg}$ is the target mean annual discharge and $Q_{series\_annual\_avg}$ is the mean annual discharge of the series to be standardized. Figure 7B shows the 1960-1997 calculated series and the 1932-1958 series standardized at the 1960-1997 mean discharge. The differences between the QIAMs are important : the distribution of discharge over the year shows a typical effect of regulation. The spring discharges are reduced as water is accumulated in the reservoirs, and the water volumes are released when discharges are normally lower, in our case between August and December. The increase of discharge in winter in the 1932-1958 series is probably caused by the effect of ice on the sills where the discharges were measured. The maximum differences between the series occur in the spring. The mean discharge was 1020 m^3/s superior at the beginning of May during the period 1932-1958 and 950 m^3/s inferior at the beginning of December. In brief, the result is a reduced amplitude of the annual hydrological cycle.

3.6.1.2 Lake Ontario outflow

The outflow of Lake Ontario has been regulated since 1960. The QIAM of the 1960-1997 gauged series is presented in Figure 7C. The "natural" outflow of the Great Lakes for the 1960-1997 period was reconstructed using the stage-discharge relationship occurring at the Galop Rapids before the construction of the Moses-Saunders dam (D. Fay, pers. comm.). The validity of this relationship is assessed by using the series measured at Iroquois, since the discharge at Iroquois is similar to the discharge at Cornwall because there are no tributaries between the two stations.

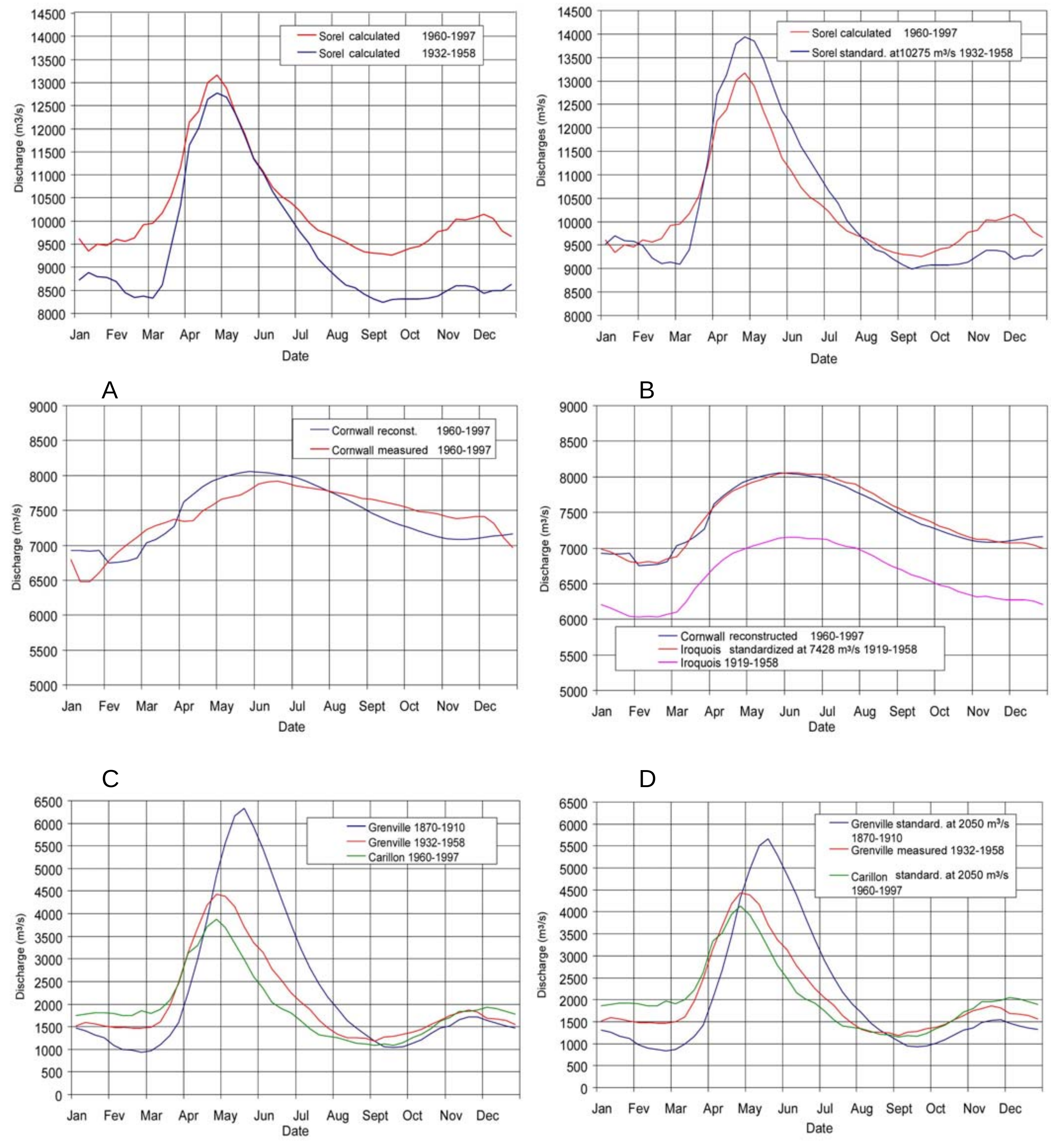


Figure 7 : Quarter-month Inter-Annual Mean of the discharges at Cornwall, Sorel and Grenville.

Figure 7D shows the QIAM of the series measured at Iroquois between 1919 and 1958. In order to compare this QIAM, which represents the unregulated discharge of the St. Lawrence, with the unregulated QIAM reconstructed for the 1960-1997 period, the Iroquois QIAM was standardized to

the mean discharge (7428 m^3/s : 1960-1997).
Figure 7D shows the similarity between the reconstructed series (unregulated) and the standardized series from Iroquois, thus validating the discharge standardization method.

The reconstructed discharge (Figure 7C) at Cornwall shows significant differences in the distribution of water input during the year : the regulated discharge is weaker in the spring and stronger in the fall. The poundage and flow release periods are the same as those observed on the series calculated at Sorel. However, the poundage discharges are maximum at 380 m^3/s in April and the released discharges are maximum in October at nearly 300 m^3/s, approximately 700 m^3/s less than the impact of nearly 1 000 m^3/s observed at Sorel (Figure 7B).

3.6.1.3 Ottawa River watershed

The Grenville station has been operated by the federal government from 1870 to 1997. The daily level measurements are available for almost the whole period. The station was located at the upstream end of the Grenville Canal. A stage-discharge relationship was maintained and the control section would not have been modified until the construction of the Carillon dam between 1958 and 1960. The discharge measurements are available (WRB, 1961) and have resulted in the production of a stage-discharge relationship valid for the period 1870 to 1958, which has the following form :

$$Q = \mu L(h - h_0) \cdot (2g(h - h_0))^k = 0.561 \cdot 154.9(h - 37.884) \cdot (2g(h - 37.884))^{0.650}$$

where Q is the discharge at the sill, L is the width of the corresponding section, h_0 is the base of the corresponding section and h is the water level measured.

The Grenville series has not been entirely integrated in the HYDAT database for unknown reasons; however, it was found in the databases of the Ministère de l'Environnement du Québec. This series appears extremely interesting since it describes the total discharge of the Ottawa River for the period preceding the regulation.

The Ottawa River watershed has been transformed by human activity. Forest clearing and the construction of regulation dams, wood rafting dams and hydropower dams have all modified the discharges. The number of dams, all sizes included, would be more than 1400 (CTRO, 1965). The first important dams were built as early as 1911 (Table 4). The total retention capacity of all the reservoirs is 14.2 km^3. Most of these reservoirs are at the head of the watersheds and have a limited control on the daily management of discharges entering the St. Lawrence around the Montréal Archipelago. The reservoirs are managed with the objective of maximizing the accumulation of melt water in the spring to produce power during the rest of the year.

Table 4 : Historical sequence of the important reservoirs in the Ottawa River watershed, modified from CTRO (1965).

Reservoir	**Retention capacity (km^3)**	**Year construction**
Quinze-Simard ; Témiscamingue ; Kipawa	3.12 (1.31 ;1.21 ;0.60)	1911-1914
Baskatong ; Cabonga	4.28 (2.65 ;1.63)	1927-1929
Rapide des Cèdres	0.63	1930
Mitchinamécus	0.56	1942
Dozois	1.87	1948
Kiamika	0.38	1954
Others	3.36	1911-1960
Total	**14.2**	

The QIAM of the 1870-1910 and 1932-1958 series provide the basis to compare the inter-annual discharge conditions before regulation. The discharge series which follow the construction of the Carillon power plant have to be handled with care since these data have an estimate error of nearly 10% (J.-F. Cantin, pers. comm.). Figure 7E shows the QIAM of the two parts of the Grenville series and Figure 7F shows the same series standardized to the 1932-1958 mean discharge. The 1870-1910 QIAM has a spring flood which appears two weeks later and smaller fall and winter discharges than during the 1932-1958 period when regulation was completed. Between the 1870-1910 and 1932-1958 periods, the discharges retained in the reservoirs are around 3 200 m^3/s in April and the discharges released are maximum in March and in December at nearly 1 500 and 1 200 m^3/s, respectively. By using the same method with the data collected between 1960 and 1997 at Carillon, a similar, if somewhat more intense, regulation pattern is obtained.

3.6.1.4 Regulated and "natural" discharge at Sorel

The impact of the regulation of the Great Lakes discharge on the QIAM of the discharge at Sorel can be calculated on the quarter-month of the QIAM as follows :

$$Q_{\text{Sorel - GL}} = Q_{\text{Sorel 1960-1997}} - Q_{\text{Cornwall measured 1960-1997}} + Q_{\text{Cornwall simulated 1960-1997}}$$

where $Q_{Sorel\ –\ GL}$ is the QIAM of the discharges at Sorel for the 1960-1997 period without the regulation on the Great Lakes, $Q_{Sorel\ 1960\text{-}1997}$ is the QIAM of the calculated discharges at Sorel, $Q_{Cornwall\ measured\ 1960\text{-}1997}$ is the QIAM of the discharges measured at Corwall and $Q_{Cornwall\ simulated\ 1960\text{-}1997}$ is the QIAM of the simulated discharges (pre-regulation) for Cornwall. Figure 8 shows the QIAM of the discharges at Sorel without the regulation of the Great Lakes.

The impact of the regulation of the Ottawa River can be calculated in a similar way. However, since the 1960-1997 series of the Ottawa River is not available, the 1932-1958 portion is used as the following relation :

$$Q_{Sorel\ –\ GL\ –\ Ottawa1932\text{-}1958} = Q_{Sorel\ 1932\text{-}1958} - Q_{Grenville\ 1932\text{-}1958} + Q_{Grenville\ 1870\text{-}1910\ standardized}$$

where $Q_{Sorel\ –\ GL\ –\ Ottawa1932\text{-}1958}$ is the QIAM of the unregulated discharge at Sorel, $Q_{Sorel\ 1932\text{-}1958}$ is the QIAM of the discharges at Sorel for the 1932-1958 period, $Q_{Grenville\ 1932\text{-}1958}$ is the QIAM of the discharges at Grenville for the 1932-1958 period and $Q_{Grenville\ 1870\text{-}1910\ standardized}$ is the QIAM of the discharges measured at Grenville (1870-1910) standardized to the 1932-1958 mean discharge. In order to obtain the QIAM of the unregulated discharges at Sorel, the QIAM ($Q_{Sorel\ –\ GL\ –\ Ottawa1932\text{-}1958}$) must be standardized to the 1958-1997 mean discharge (Figure 8). The Carillon series measured from 1960 to 1997 can be used similarly by subtracting the QIAM standardized series from the Sorel QIAM for the same period. This method produces similar results, although it shows a slightly less intense regulation.

The regulation of discharges upstream has changed the distribution of discharges during the year. At Sorel, the QIAM discharges are reduced by a maximum in the spring of nearly 2 500 m^3/s and increased between September and May by 600 to 1 000 m^3/s (Figure 8). Thus the spring flood is reduced in terms of discharge, the period of maximum is three weeks earlier and the flood duration is also reduced. The impacts of the duration of floods on the decrease of levels in the spring, and on the increase and stabilization of the discharges in the summer must be taken into consideration.

The validation of calculations relating to regulation can be made by the estimation of the volumes of water retained according to the unregulated discharge curve, by estimating the volumes of water retained in the reservoirs as the surface under the curve of the retained discharges as estimated in the QIAM of the unregulated discharges at Sorel. The integration of the discharges indicates a retention of 14.5 km^3 in the reservoirs of the Ottawa River watershed calculated from the Grenville series and of 10.2 km^3 from the Carillon series, which is relatively close to the total retention capacity volumes of 14.2 km^3. It appears that the Grenville series tends to overestimate while the Carillon series tends to underestimate the impact of the regulation of the discharge of the Ottawa River.

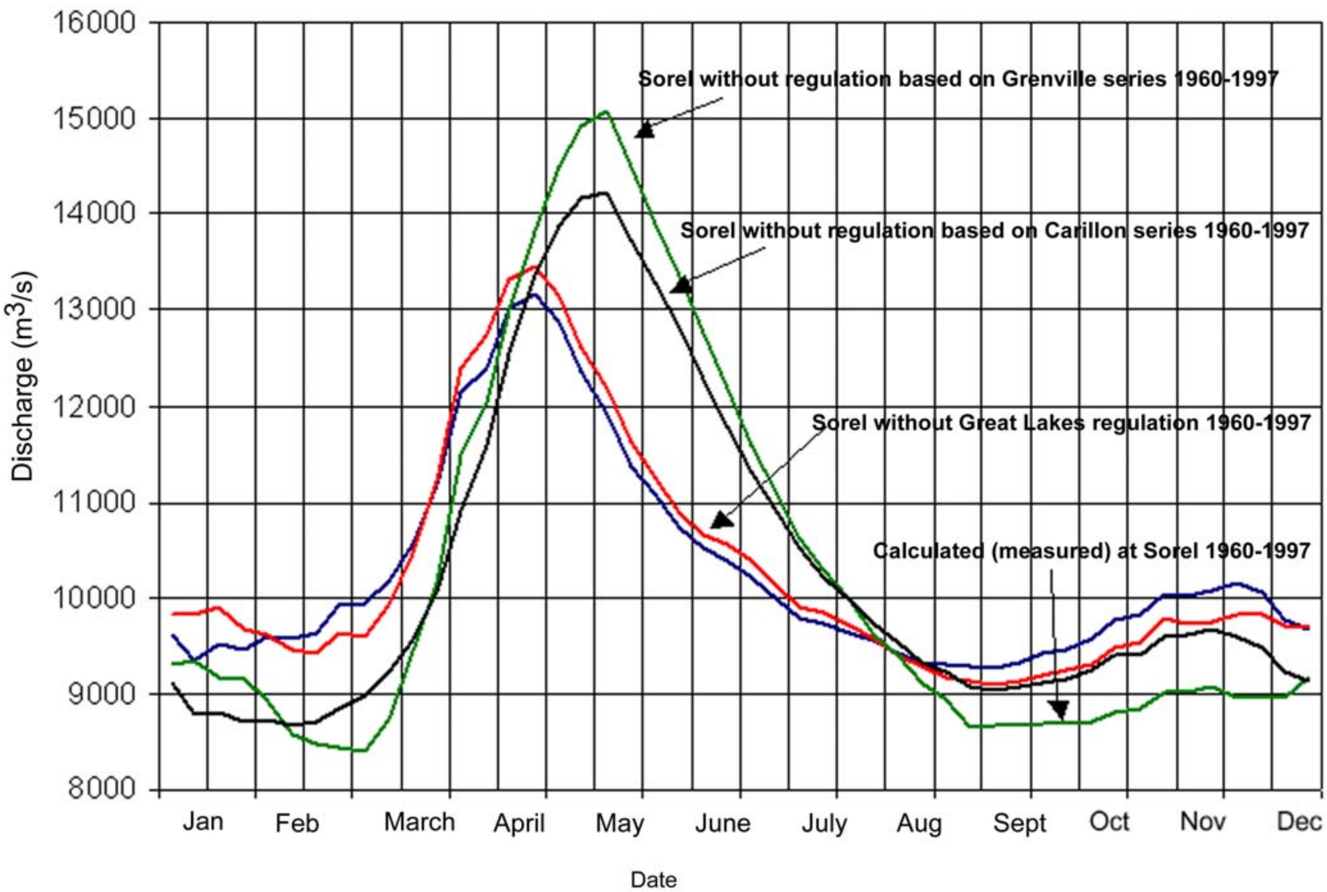


Figure 8 : QIAM of the discharge at Sorel : as calculated (1960-1997), without the effect of the regulation of the Great Lakes and without the effects of the regulation of the Great Lakes and of the Ottawa River. -1958 and 1960-1997

4 Water level

4.1 Background

The water level fluctuation in the Montréal/Trois-Rivières reach are determined by several factors, including the friction caused by plants in summer and ice in winter, the discharge of downstream tributaries and the water level at Lauzon near Québec. This section presents a summary of the complexity of the water level fluctuations in the reach. Only inter-annual means of the level and the free surface slope are presented, mainly for the 1960-1998 period. The effect of the tide is also presented. The link between the discharge and the water levels is not described, being partially addressed in Chapter 7 : *Reference scenarios*, which describes in detail the mean levels associated to discharge values, depending on the typical conditions of the system.

4.2 Water level patterns

The Daily Inter-Annual Mean (DIAM) of the level between 1960 and 1998, at various stations in the Montréal/Trois-Rivières reach, show a mean annual fluctuation of 2.0 m at Trois-Rivières and of 1.5 m at the Port of Montréal (Figure 9). The level is highest in the spring during the spring flood of tributaries, and lowest in summer during the low water period. The discharges corresponding to this DIAM of levels are presented in Figure 7A. The same image has been prepared for the 1932-1958 period (Figure 10), but the two periods can hardly be compared because the mean discharges are different (1932-1958 : 9 410 m^3/s, 1960-1998 : 10 270 m^3/s). Despite the difference in mean discharges, it can be noted that the influence of ice on the levels in winter was clearly greater than what it is since the opening of the channel to winter shipping in 1959-1960.

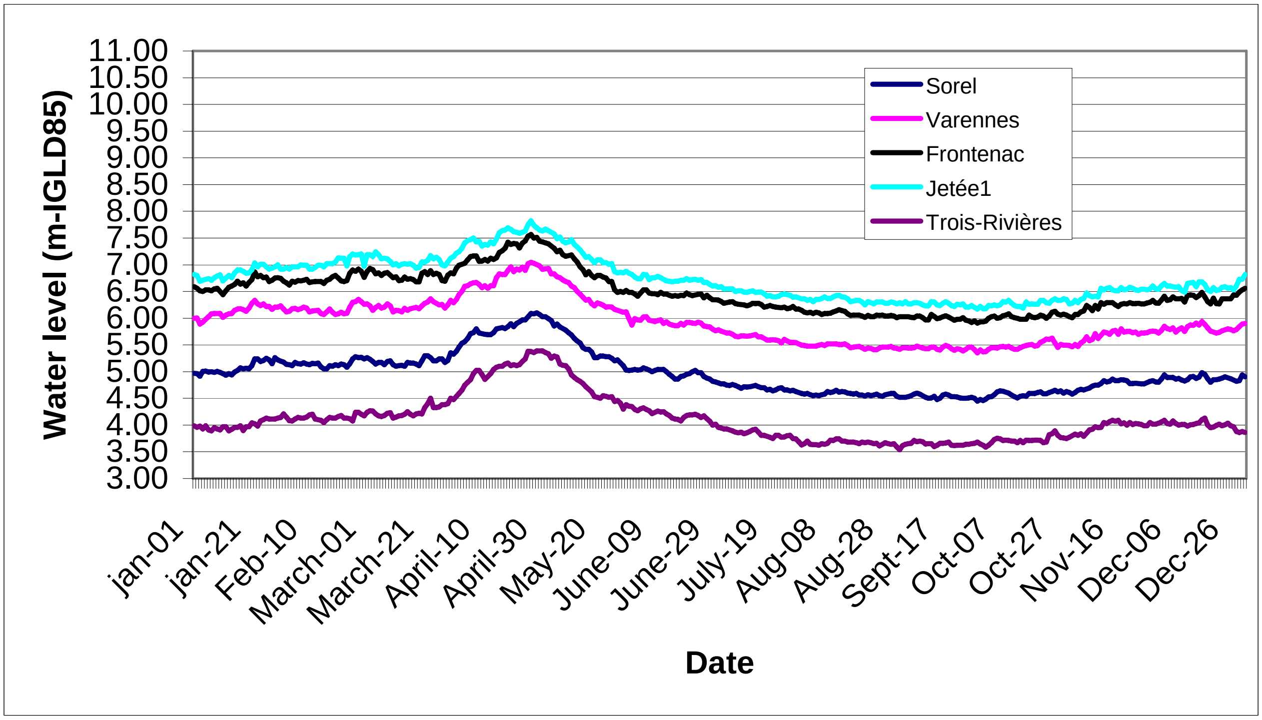


Figure 9 : Daily inter-annual mean of levels at five stations between Montréal and Trois-Rivières in 1960-1998.

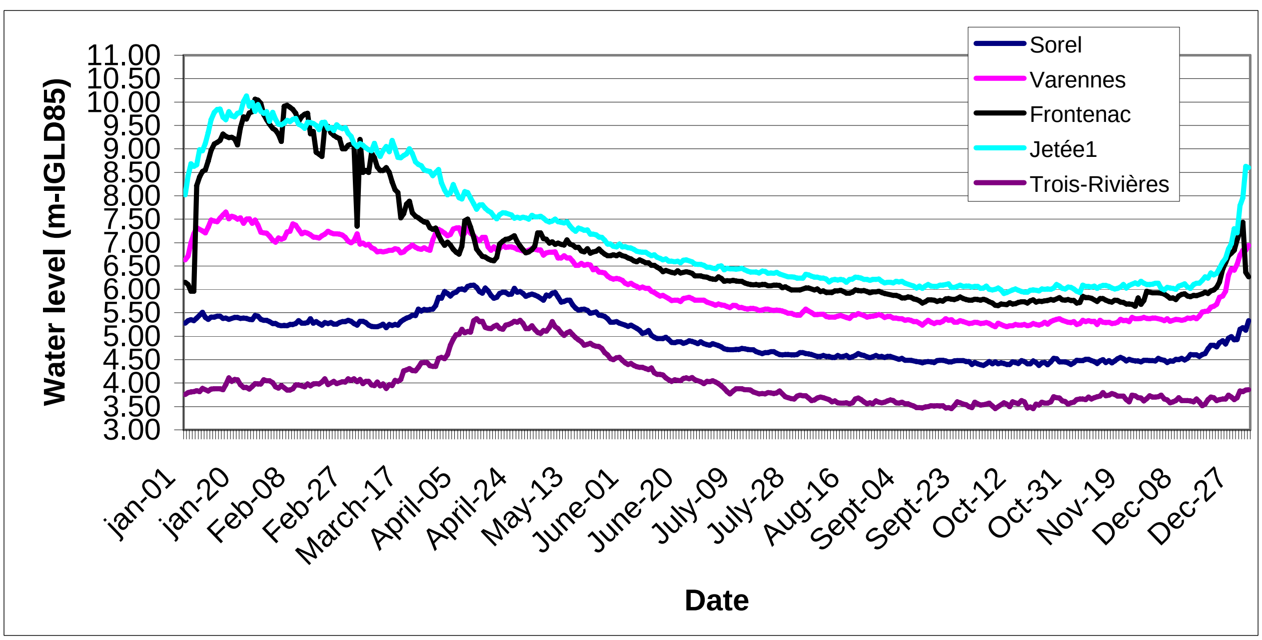


Figure 10 : Daily inter-annual mean of levels at five stations between Montréal and Trois-Rivières in 1932-1958.

4.3 Free surface slope

The free surface slope is obtained by dividing the difference of level between two stations by the distance separating them. Figure 11 shows the mean water levels of each season as a function of the distance between gauging stations. It reveals the relative slope between the different stations of the reach. The slope is steep upstream between Jetée #1/Varennes and Port Saint-François/Trois-Rivières, average between Varennes and Sorel and gentle between Sorel and Port Saint-François. The relative slope varies all year around as suggested by the seasonal curve.

Figure 12 shows the variation of the monthly inter-annual mean of the slope for three segments of the reach. The effect of ice in winter and plants in summer is apparent for each segment. In the segment Jetée #1/Varennes, even if it is difficult to discuss the slope without looking at the influence of the discharge, it is apparent that the influence of ice is relatively important and that it is of the same order of importance as the influence of aquatic plants in summer. In that segment, the surface occupied by aquatic plants is important, especially around the Boucherville islands. In the Sorel/Trois-Rivières segment, plants and ice have a significant impact because of the great surface available to plants and the surface ice on Lake Saint-Pierre. The Varennes/Sorel segment is influenced by ice, but the effect of plants, less abundant in this area, is not perceived.

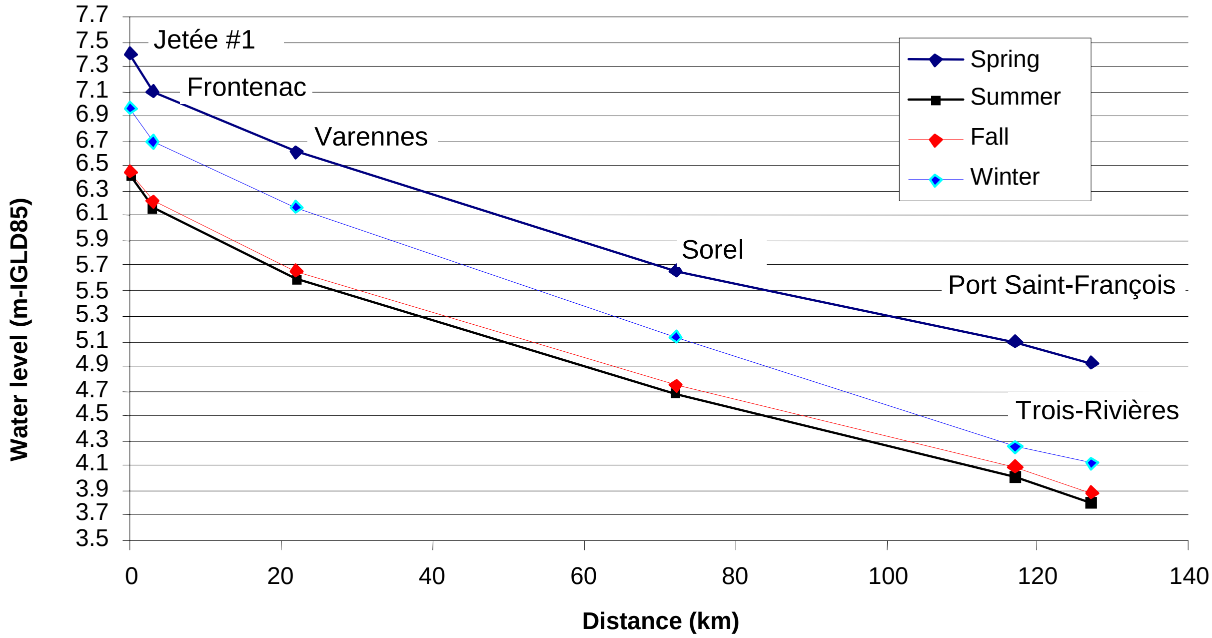


Figure 11 : Mean free surface slope between Montréal and Trois-Rivières at each season between 1960 and 1998.

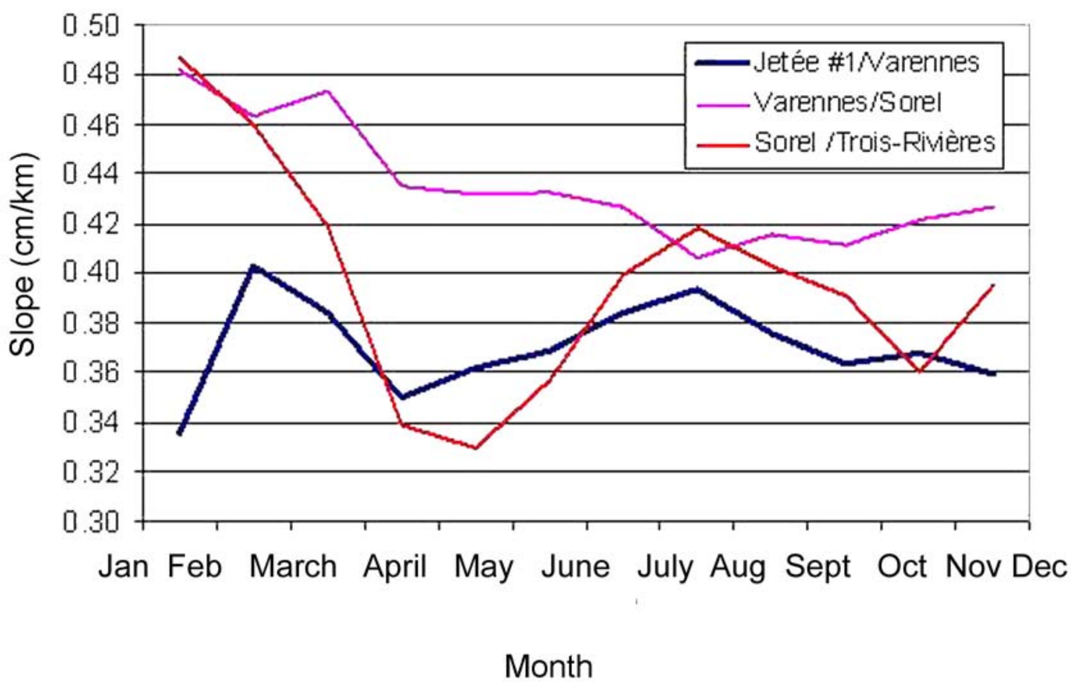


Figure 12 : Monthly inter-annual mean of the free surface slope between various stations in 1960-1998.

4.4 Effect of tides

The effect of tides is perceived in the St. Lawrence River up to Montréal. The fluctuations of level caused by tides have already been addressed in detail by INRS-Eau (1990), Morse (1990) and Forrester (1983); only a brief overview of the effects is presented. There are two types of tide signals in the study area : a semi-diurnal tide and a long term effect related to the moon cycle.

The semi-diurnal tide has a period of 12 hrs 25 min and its impact on the water level is mostly felt below Trois-Rivières. Above Trois-Rivières, this signal is weak and is barely felt above Sorel. Table 5 presents the water level corresponding to the effect of the semi-diurnal tide above Trois-Rivières. These are only approximate and correspond to a mean discharge of the river. During periods of extremely low discharge, the tidal signal should be more important.

The semi-lunar signal has a period of 14 days and its effect is maximum at full moon and, to a lesser extent, at new moon. In order to reveal the effect of the semi-lunar tide, a running mean of 14 days is applied on the series of daily measurements for the summer of 1998, and the mean obtained is subtracted of the measurements, highlighting the effect of the semi-lunar tide. Figure 13 shows the fluctuating component of the semi-lunar tide at various level gauging stations on the river. Table 5 presents the impact of tides. Because of the small amplitudes of the semi-diurnal signal above Trois-Rivières and of the very large period of the semi-lunar signal, the impact on velocities in Lake Saint-Pierre is relatively weak. The effect of tides will not be considered in the rest of the document.

Table 5 : Mean approximate fluctuations of level related to semi-diurnal and semi-lunar tidal effects. Modified from Morse (1990), INRS-Eau (1990) and B. Labrecque (pers. comm.).

	Approximate fluctuations	
Gauging station	**Semi-diurnal**	**Semi-lunar**
Jetée #1	< 1 cm	15 to 20 cm
Contrecœur	2 cm	18 to 25 cm
Sorel	5 cm	25 to 35 cm
Port Saint-François	10 cm	35 to 45 cm
Trois-Rivières	15 cm	40 to 50 cm

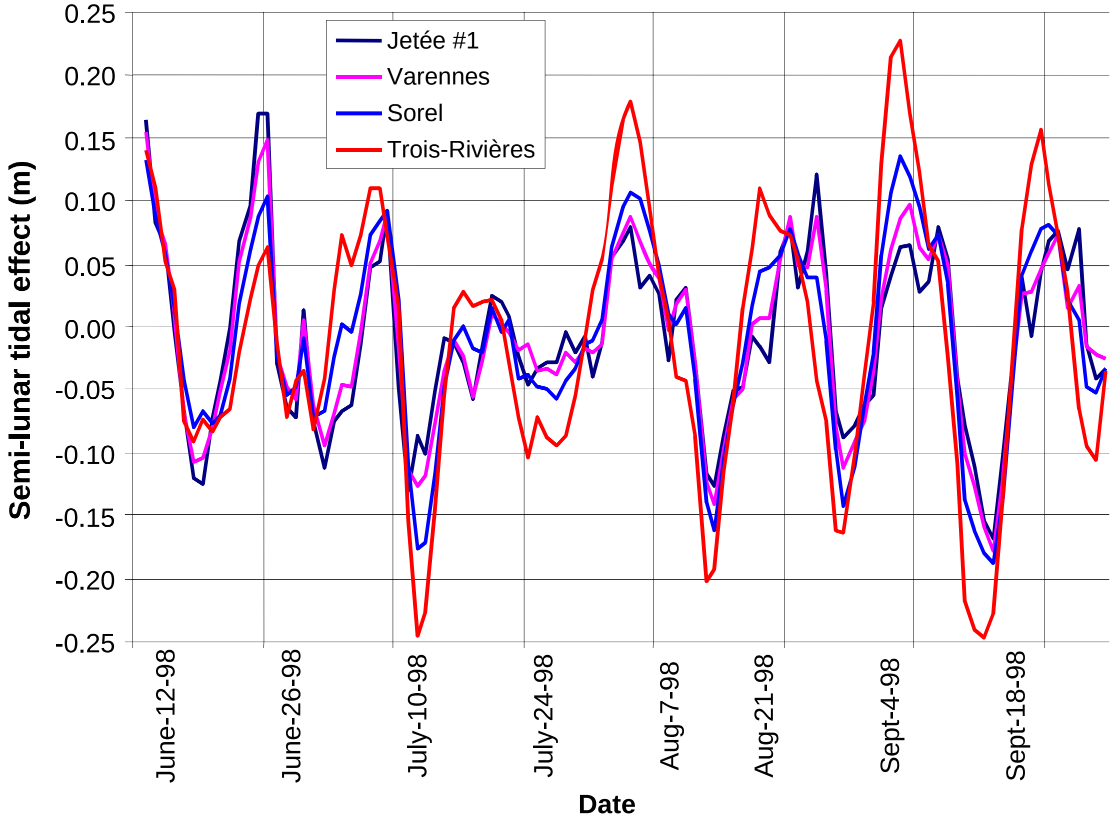


Figure 13 : Level fluctuations related to the semi-lunar tidal effect (14 days) at various stations in the summer of 1998.

5 Winds

In this chapter, the following abbreviations are used : N-North, S-South, E-East and W-West. Winds play an important role in the dynamics of the river reach, especially in Lake Saint-Pierre since the fetch can be as much as 30 km when the wind is blowing in the SSW-NNE axis. In the Montréal/Sorel segment, certain sectors are also very influenced by waves. Wind data are essential to produce wave models. In addition, winds can be used in hydrodynamic modeling since wind action can displace large masses of water or influence the direction of currents.

5.1 Data and methods

The wind data used originate from Environment Canada. For the Lake Saint-Pierre area, two stations were retained : Nicolet station (7025442) and Trois-Rivières station (701HE63). These stations have data on wind direction and strength, in hourly average, for periods extending respectively from 1992 to 1999 and from 1991 to 1999. The wind data are available in 36 compass divisions (10 degrees). Since the wind directions and strengths are very similar at the two stations, only the data from the Trois-Rivières station are presented. The Montréal/Sorel segment has been characterized using data from the Saint-Hubert station (7027320). The series covers from 1993 to 1999 and also contains hourly data in 36 compass divisions.

5.2 Results

The wind strengths measured during 1993-1999 reach a maximum value of 60 km/h. Figure 14 shows the distribution of frequency of the wind strengths for the Trois-Rivières station. The Saint-Hubert station shows a similar distribution. In order to simplify the analysis, wind strengths were subdivided into four classes : low (0-9 km/h), moderate (10-24 km/h), high (25-44 km/h) and extreme (45-60 km/h). The classes correspond roughly to changes in the distribution of intensities and occupy respectively around 40 %, 50 %, ~9 % and ~1 % of the frequencies in the distribution.

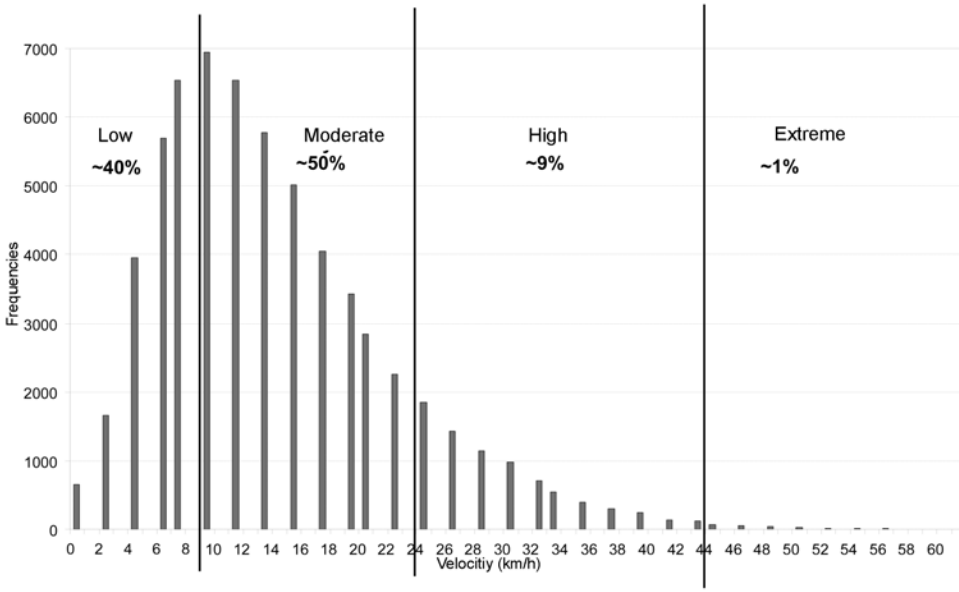


Figure 14 : Distribution of frequencies of wind strengths at the Trois-Rivières station.

5.2.1.1 Lake Saint-Pierre (Trois-Rivières)

In the Lake Saint-Pierre area, the dominant winds are from the SSW, NE and NW. In general, the low winds come from several directions, the moderate winds come mainly from the SSW, NW and NE while the strong and extreme winds blow mostly from the SSW. The season has a considerable influence on the wind regime. Figure 15 shows the distribution of winds by season for the four strength classes. Winter, fall and, to a lesser extent, spring have the most frequent strong and extreme winds : from 11.2 % to 9.2 % are strong winds, and from 0.34 % to 0.12 % are extreme winds (Table 5). During summer, strong winds account for 7.7% of the observations while extreme winds are very rare, with only 0.04 % of the observations. Summer seems peculiar since the SSW winds are dominant in the intensities ranging from moderate to extreme.

5.2.1.2 Montréal-Sorel (Saint-Hubert)

The winds measured at Saint-Hubert have general directions and strengths very similar to those measured at Trois-Rivières. However, there are clear differences in wind directions, mainly for weak to moderate winds (Figure 16 and Table 7). At Saint-Hubert, weak winds have dominant north-south directions while they are north and west at Trois-Rivières. The strong and extreme winds are similar at both sites, except that they are SW to WSW at Saint-Hubert and SW to SSW at Trois-Rivières.

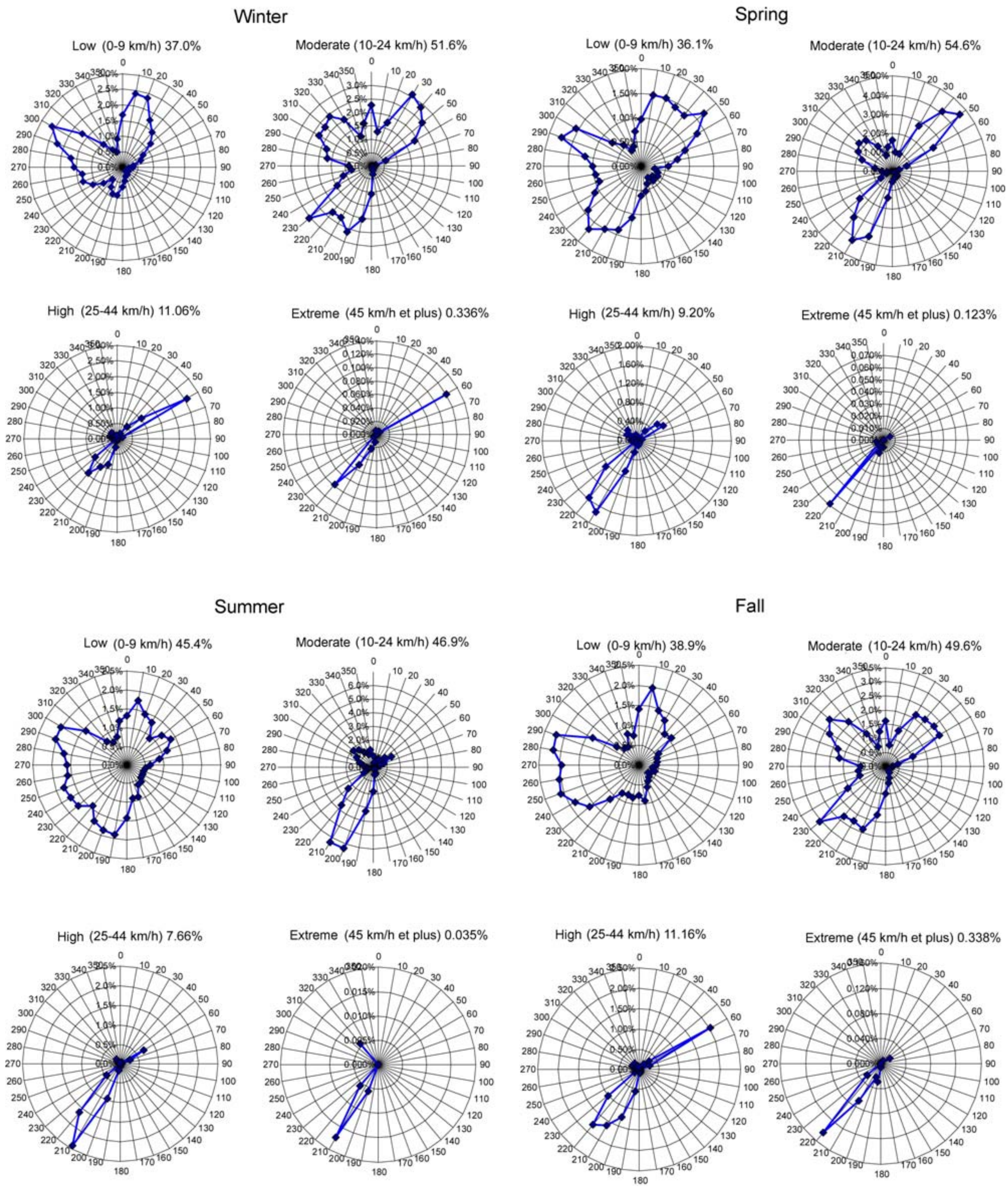


Figure 15 : Compass card of four intensities for each season at Trois-Rivières between 1991 and 1998 in 36 compass divisions.

Table 6: Percentage of wind strengths and directions in 16 compass divisions and 4 strength classes at Trois-Rivières between 1993 and 1999.

		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	%
		0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	saison
Spring	weak	2.5	3.5	3.6	2.6	1.3	0.9	0.8	0.9	1.7	3.3	3.6	2.4	2.5	3.7	1.7	1.1	36.1
	moderate	3.3	4.1	9.8	3.4	0.5	0.4	0.8	0.9	1.8	8.3	6.3	1.2	1.4	4.2	5.1	2.9	54.6
	strong	0.18	0.06	0.98	0.73	0.06	0.02	0.11	0.19	0.25	2.45	2.79	0.12	0.09	0.35	0.58	0.24	9.20
	extreme			0.001	0.005					0.010	0.024	0.076	0.003	0.004				0.123
Summer	weak	3.2	3.3	2.6	2.7	1.5	1.1	1.3	1.8	3.2	4.2	3.7	4.0	3.7	4.5	2.7	1.9	45.4
	moderate	1.9	1.3	2.2	2.4	0.7	0.3	0.4	0.9	4.4	13.4	7.2	1.4	1.2	2.6	4.0	2.7	46.9
	strong	0.02		0.20	0.89	0.05	0.01		0.03	0.23	3.20	2.50	0.05	0.02	0.12	0.24	0.10	7.66
	extreme										0.021	0.009				0.006		0.035
Fall	weak	3.3	3.5	2.4	1.2	1.0	0.9	0.9	1.4	2.0	1.9	3.2	4.7	4.8	4.4	1.6	1.7	38.9
	moderate	3.0	3.7	5.2	3.3	0.7	0.4	0.4	0.9	2.5	5.2	6.0	2.9	2.7	4.7	5.3	2.6	49.6
	strong	0.10	0.05	0.90	2.08	0.05	0.03	0.07	0.17	0.48	2.99	3.08	0.21	0.10	0.36	0.33	0.16	11.16
	extreme			0.009	0.015					0.025	0.104	0.184	0.002					0.338
winter	weak	3.9	4.9	3.0	1.5	0.7	0.5	0.4	0.7	1.5	1.9	1.6	2.9	3.6	5.2	3.2	1.5	37.0
	moderate	4.2	5.0	6.1	2.4	0.2	0.1	0.2	0.4	2.6	5.5	5.8	2.9	2.4	4.5	5.4	3.7	51.6
	strong	0.14	0.23	2.00	2.40			0.05	0.04	0.23	1.97	2.49	0.12	0.13	0.52	0.55	0.19	11.06
	extreme	0.004		0.034	0.101					0.007	0.078	0.110					0.002	0.336

Table 7 : Percentage of wind strengths and directions in 16 compass divisions and 4 strength classes at Saint-Hubert between 1993 and 1999.

		N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	%
		0°	22.5°	45°	67.5°	90°	112.5°	135°	157.5°	180°	202.5°	225°	247.5°	270°	292.5°	315°	337.5°	saison
Spring	weak	2.6	2.6	2.0	1.1	1.5	1.7	2.0	1.5	2.1	2.4	2.2	1.5	1.2	1.3	1.2	1.7	28.5
	moderat	4.3	5.0	4.0	1.3	1.3	1.3	1.5	2.5	3.9	2.1	5.0	7.7	3.7	3.7	3.6	3.3	54.3
	strong	0.62	0.97	1.31	0.27	0.07	0.04	0.11	0.68	1.94	0.30	1.22	4.56	2.09	1.13	0.84	0.61	16.78
	extreme			0.028	0.001				0.006	0.040	0.006	0.037	0.180	0.038	0.037	0.004	0.006	0.382
Summer	weak	2.4	2.8	2.0	1.3	1.5	2.2	3.0	2.8	4.2	3.3	2.8	2.0	1.7	1.4	1.5	1.6	36.4
	moderat	2.6	2.9	2.3	0.8	0.4	0.5	1.0	2.4	6.6	4.7	8.2	9.6	4.9	3.7	3.0	2.1	55.6
	strong	0.10	0.11	0.18	0.04	0.04		0.03	0.17	0.64	0.14	1.00	2.98	1.41	0.60	0.35	0.16	7.95
	extreme											0.006	0.032					0.038
Fall	weak	2.1	2.7	2.3	1.2	1.3	1.9	2.0	1.9	2.5	1.8	1.6	1.3	1.7	1.3	1.1	1.2	28.0
	moderat	2.6	5.0	5.4	1.1	0.9	0.7	1.2	2.1	6.0	2.9	3.9	6.7	7.3	5.7	2.6	1.7	55.6
	strong	0.22	0.56	0.75	0.26	0.06	0.05	0.10	0.61	2.60	0.33	1.40	3.75	2.84	1.72	0.48	0.24	15.97
	extreme		0.007	0.002					0.016	0.041		0.046	0.213	0.055	0.011		0.008	0.397
Winter	weak	2.9	2.9	2.3	1.3	1.3	1.5	1.6	1.5	2.3	1.7	1.5	1.1	0.9	0.9	0.9	1.5	26.3
	moderat	4.6	8.2	5.8	0.9	0.6	0.5	0.8	1.3	3.6	2.6	3.5	6.4	5.6	4.0	2.3	2.3	53.1
	strong	0.55	1.55	2.15	0.24	0.04		0.05	0.42	2.00	0.35	1.08	4.57	4.41	1.77	0.42	0.33	19.93
	Extreme	0.009	0.051	0.021					0.036	0.078	0.003	0.022	0.282	0.161	0.020	0.003		0.685

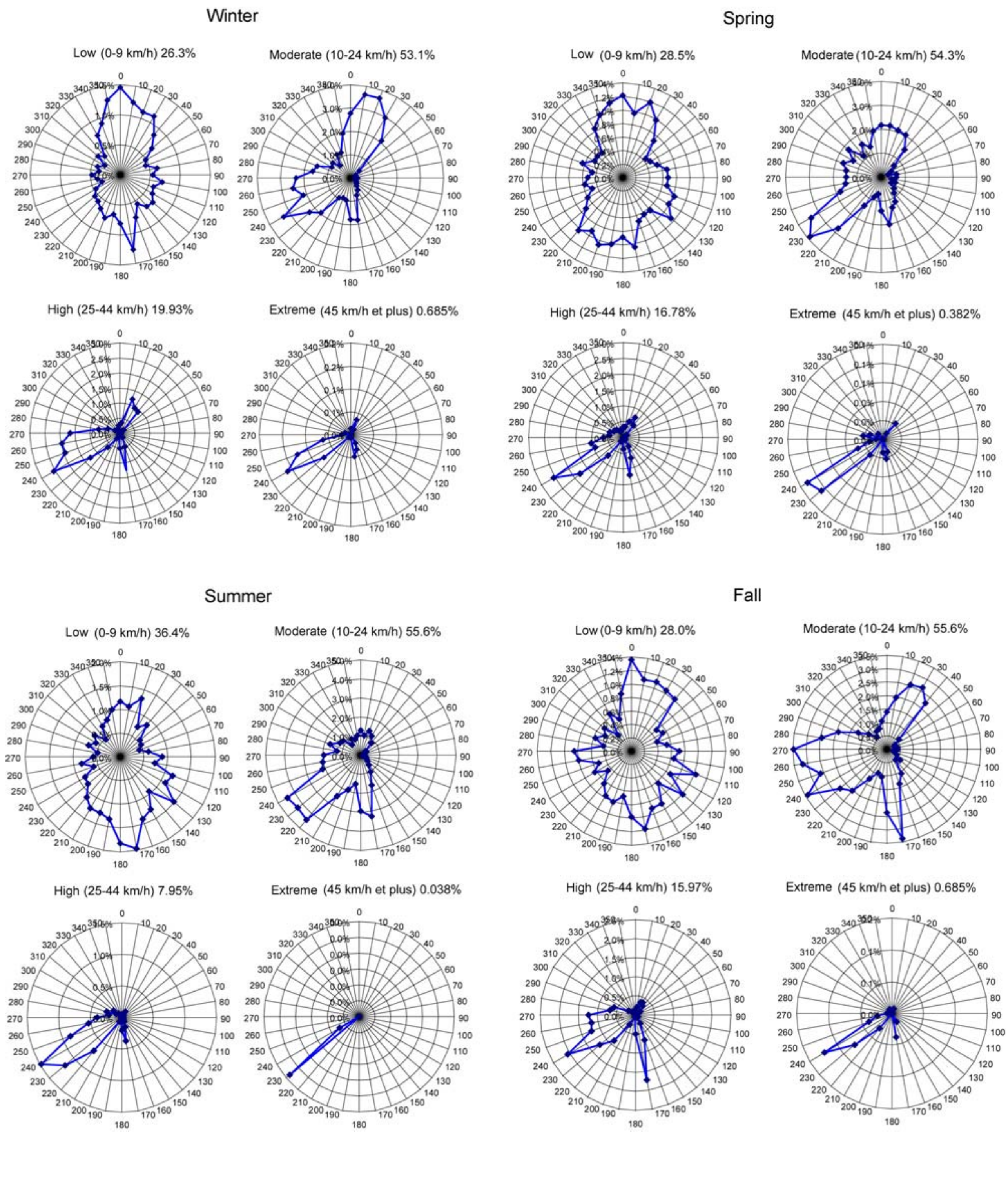


Figure 16 : Compass card of four intensities for each season at Saint-Hubert between 1991 and 1998 in 36 compass divisions.

The wind data analyzed are available in 36 compass divisions. In order to obtain a reasonable number of wave simulations, the wind data were brought down to 16 compass divisions corresponding to the standard compass card divisions: N, NNE, NE, ENE, E, etc.

Table 6 and Table 7 summarize the ratio of wind directions and strengths observed at each season at Trois-Rivières and Saint-Hubert, respectively.

6 Air temperature

6.1 Background

Air temperature is an important component of plant productivity and of the reproduction success of aquatic fauna. Therefore, temperature series are essential for the modeling of these biological components. The data series presented here are the mean and maximum air temperatures and the degree-days of growth (number of degree-days above 5°C). The weather data originate from the weather stations at Saint-Hubert (7027320) and Sorel (7028200), providing for full coverage of the study area. The Saint-Hubert (Figure 1) station started operating in 1928 and is still functional. The series is relatively complete except for a missing period between 1942 and 1949. The Sorel station (Figure 1) provides daily temperature data from 1914 to 1997 with only a few missing months. The complete series are presented in the form of weekly means for the maximum and mean temperature, and for the degree-days of growth. The daily data were used to produce inter-annual means of maximum and mean temperatures and of degree-days for the complete series available.

6.2 Long term temperature fluctuations

The Saint-Hubert station shows a variation of the weekly mean temperature values from year to year. The fluctuations are most evident during the summer. These fluctuations are usually less than 5°C from year to year with a mean value of near 23°C during summer and -16°C during winter. The data from the Sorel station show similar fluctuations, the relationship between the two series being characterized by an R^2 value of 0.98. The only exception occurs with the mean winter temperatures which is nearly 1°C colder at Sorel than at Saint-Hubert.

6.3 Seasonal temperature fluctuations

6.3.1 Mean temperatures

At the Saint-Hubert station, the highest mean temperatures are 21.4°C in July. During summer, the mean value is 19.4°C from June to August. In winter, the mean temperatures are the lowest in January at -11.7°C. From December to February, the mean temperature is -8,6°C with extreme fluctuations of ±15°C (Figure 17). The seasonal fluctuations of the mean temperatures at the Sorel station are similar. In summer, the mean temperature is 19.4°C with a maximum of 21.6°C in July (Figure 18). From December to February, the mean temperature is –10.2°C. The mean minimum temperature in January is –13.4°C.

6.3.2 Maximum temperatures

The maximum daily temperature fluctuations are similar to the mean temperatures. In the summer at Saint-Hubert, the mean maximum is 27.4°C in July, while the mean maximum temperature between June and August is 25.2°C. In winter, the lowest mean maximum temperature is –6.9°C in January (Figure 19). The Sorel station shows very similar results, with the difference that the mean winter maximum temperatures are slightly lower with a minimum of the maximum temperatures of –8.0°C in January (Figure 20).

6.3.3 Degree-days

The degree-days of growth represent the number of degrees higher than 5°C on a given day. As expected, the fluctuations of degree-days are similar to the mean temperature fluctuations. As for the inter-annual mean and maximum temperature, the maximum degree-days occurs in July. At Saint-Hubert, it is 16.4°C for a mean value of 14.4°C during June to August. The extreme values vary between 7.6°C and 21.2°C on average for that period of the year (Figure 21). At the Sorel station (Figure 22), the maximum observed is 16.6°C in July with a mean value of 14.4°C (from June to the end of August). The extreme mean values are 6.8°C and 22.0°C. In winter, the degree-day values are nil until April.

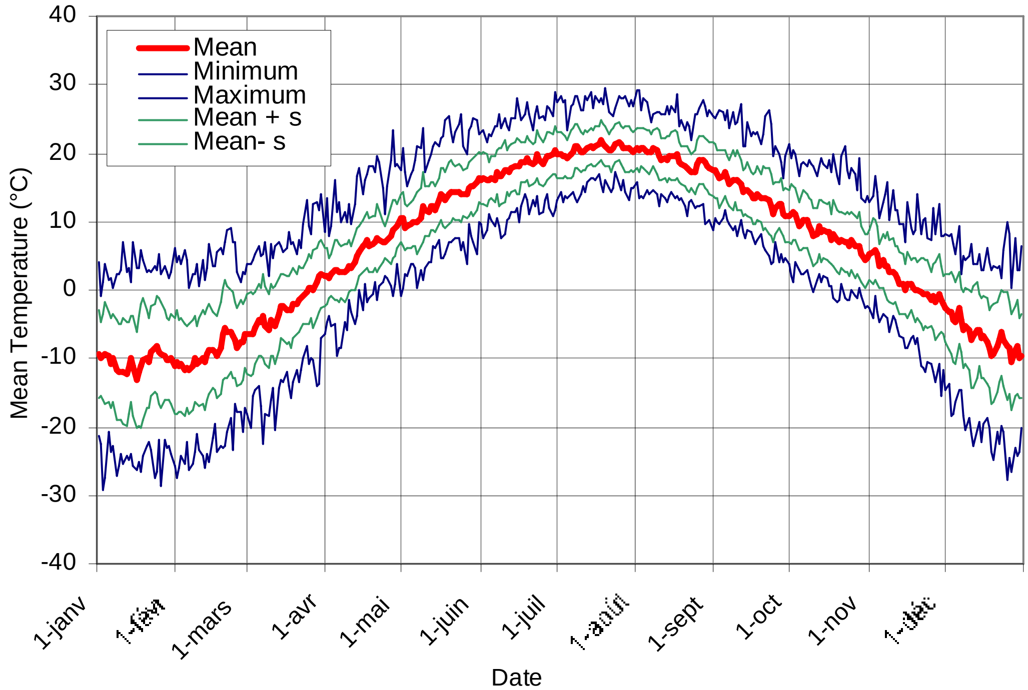


Figure 17 : Mean inter-annual temperature at the Saint-Hubert station from 1960 to 1997 (s = standard deviation).

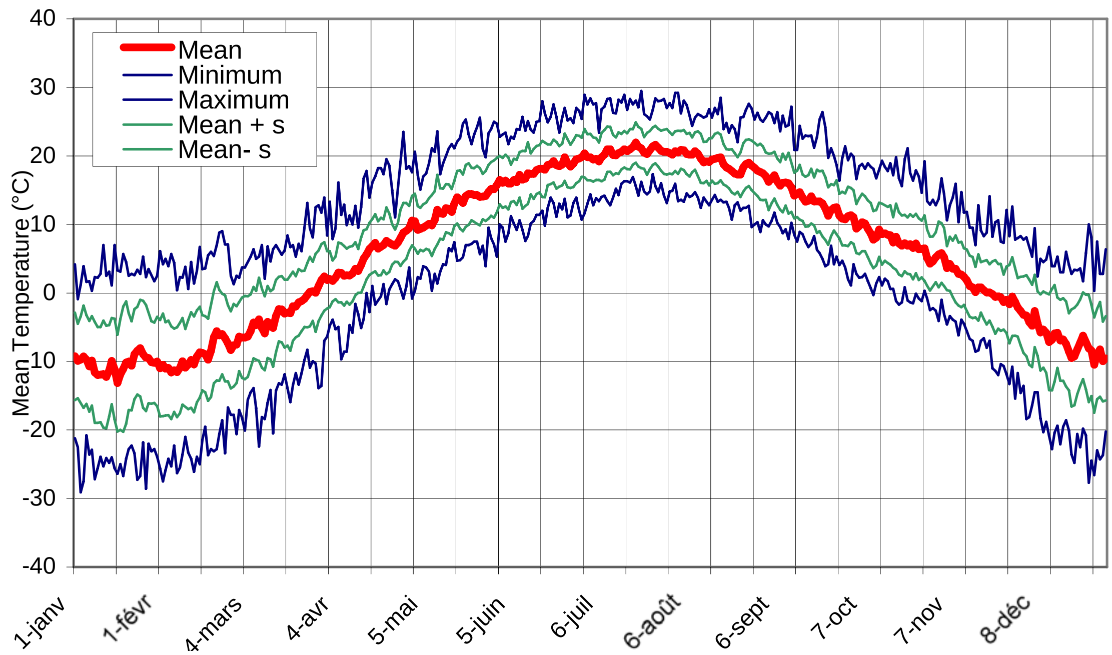


Figure 18 : Mean inter-annual temperature at the Sorel station from 1960 to 1997 (s = standard deviation).

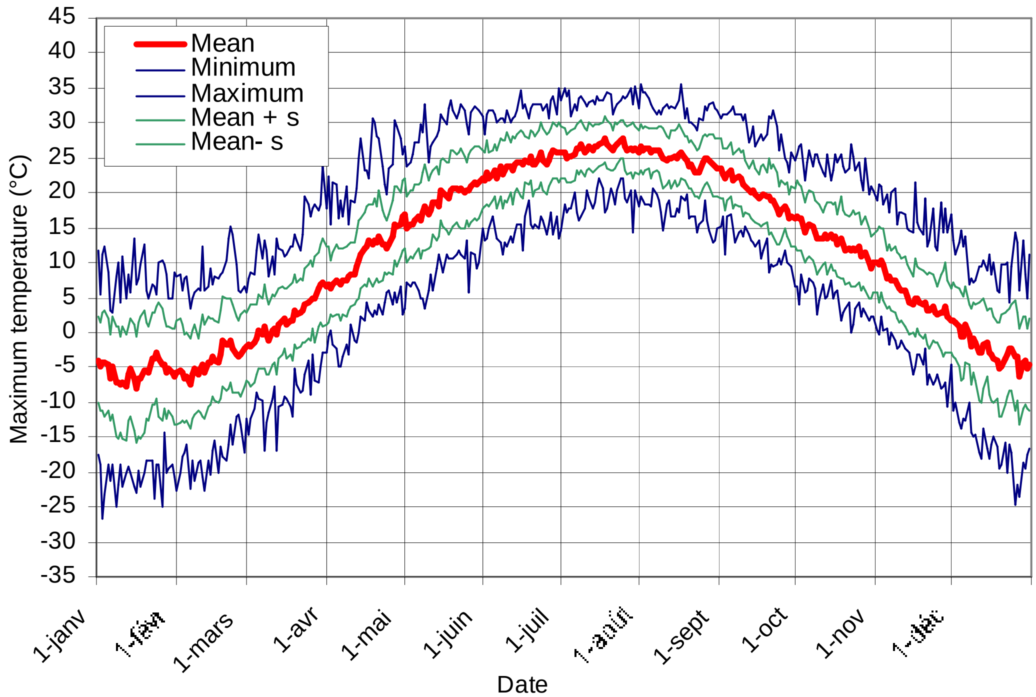


Figure 19 : Inter-annual maximum temperature at the Saint-Hubert station from 1960 to 1997 (s = standard deviation).

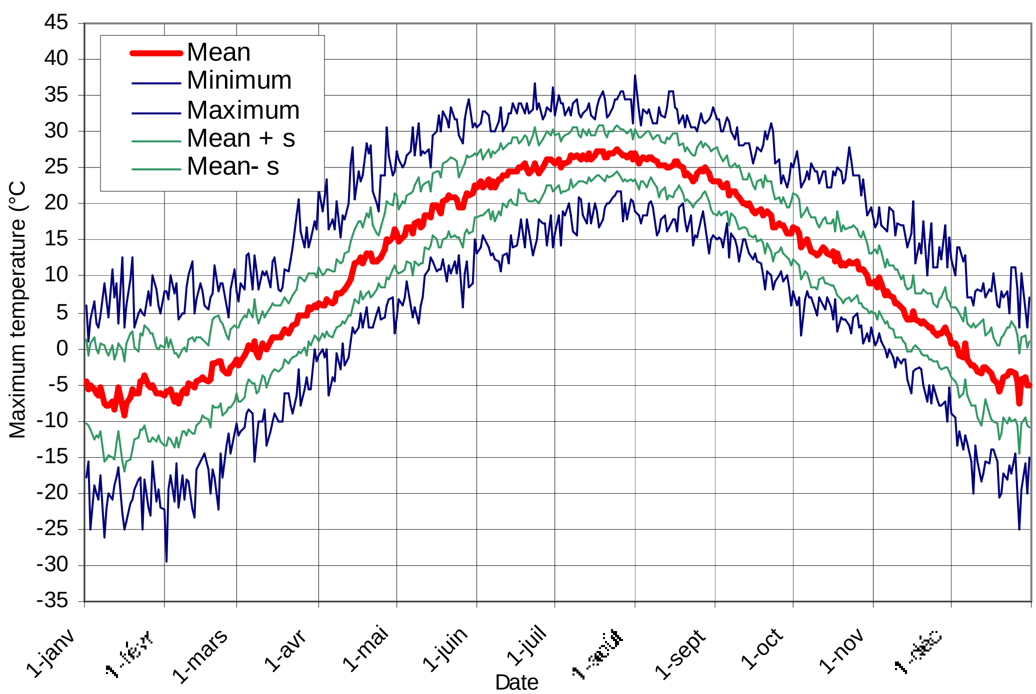


Figure 20 : Inter-annual maximum temperature at the Sorel station from 1960 to 1997 (s = standard deviation).

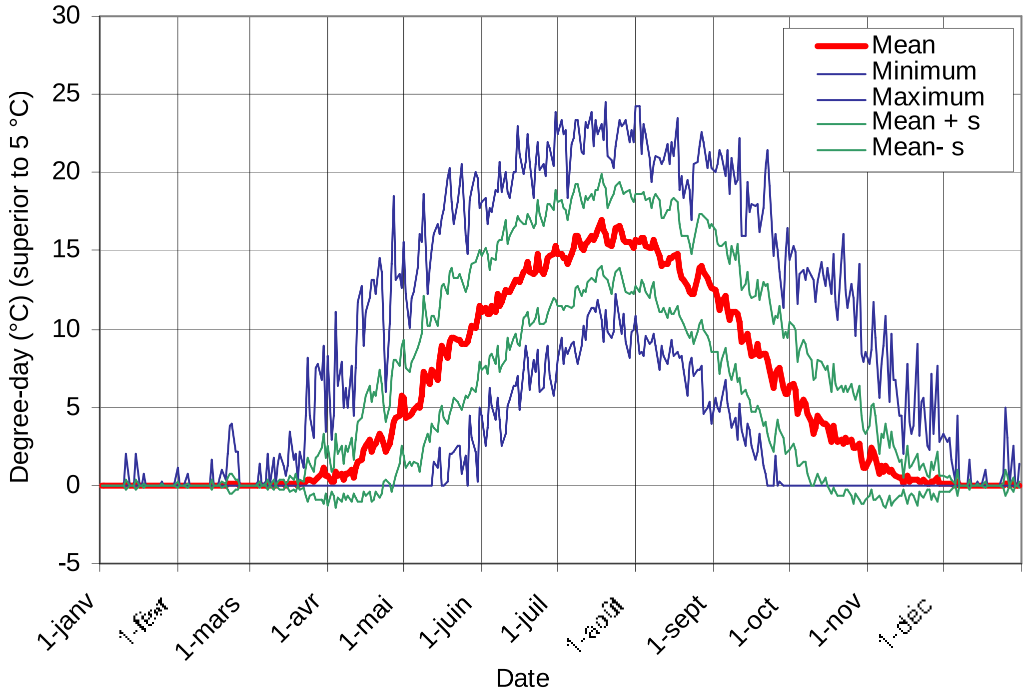


Figure 21 : Mean degree-day at the Saint-Hubert station from 1960 to 1997 (s = standard deviation).

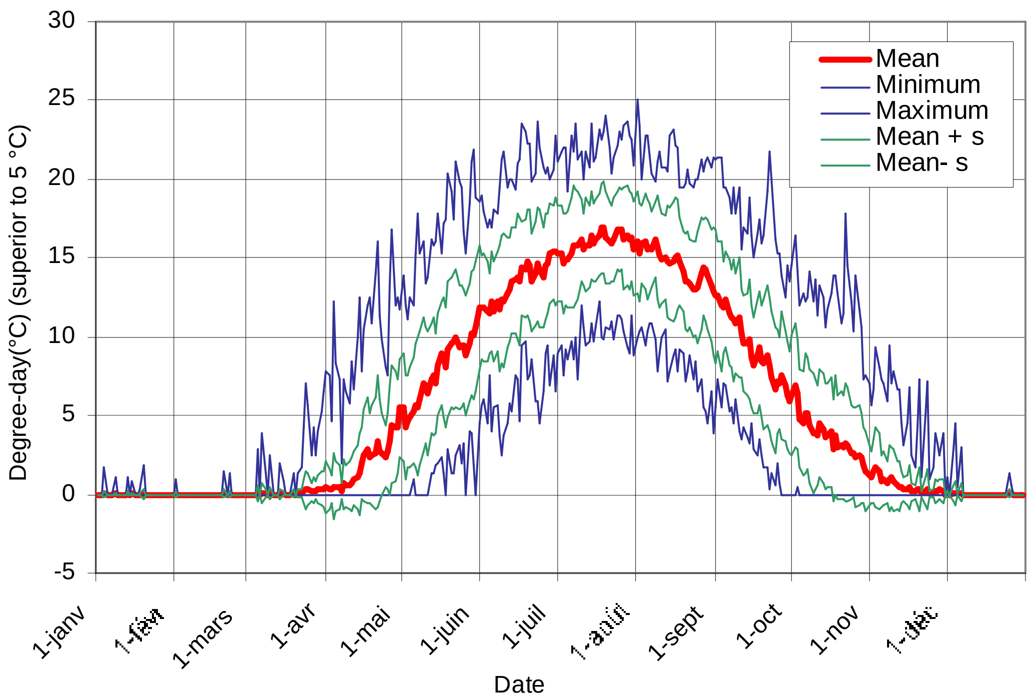


Figure 22 : Mean degree-day at the Sorel station from 1960 to 1997 (s = standard deviation).

7 Reference scenarios

The temporal variability of the discharge and level conditions in the St. Lawrence River is important. The relative discharges between the water of the Great lakes, the Ottawa River and the other tributaries, the occurrence of ice and aquatic plants, the effect of winds and tides create as many different conditions which can be simulated. However since these conditions represent an important volume of data often redundant, reference scenarios were selected to show the diversity of the environment physics, in order to represent their variability with a restricted number of conditions. With these, the currents, levels, depths, emerged/flooded areas, water masses, waves and a number of other parameters can be produced and used.

This limited number of scenarios provides calibrated and validated events, opening a developing field of analysis, such as the impacts of physical conditions on the biological components and other aspects such as erosion and sedimentation, as well as contaminant transport. These scenarios also provide for valid comparisons between the different scenarios of discharge of a given season and between seasons for similar discharges. Also, the reference scenarios have an integration effect as they allow the analysis of impacts on several fields of knowledge for a given event. The adoption and use of reference scenarios by various research teams will eventually lead to a quantification of the impacts of water level decreases and increases on the ecosystem and become a guidance for a sound management of the river.

The selection of scenarios is a long process which uses the reconstructed discharge data at Sorel and Trois-Rivières. The distribution of daily discharges was examined globally and seasonally in order to determine the most common and the extreme events. Since regulation and major dredging operations began in 1960, only the portion of the series from 1960 to 1998 was used. A recurrence analysis gave the return period of the summer low waters and spring floods. Finally, the discharges from the main inputs (Lasalle, Milles-Îles/Prairies) and the tributaries, as well as the corresponding level data are characterized to define the hydraulic parameters (limit conditions) of each scenario.

7.1 Distribution of discharges

The water masses in the Montréal / Trois-Rivières reach are very complex. For example, a discharge of 10 000 m^3/s at a given point in the river may be constituted of various proportions of water masses which may originate almost entirely from the Lachine Rapids, or be composed of a large proportion of water from the des Mille-Îles and des Prairies rivers. Because of the importance of tributaries such as the Richelieu River, the variations in the proportions of the different inputs become more and more complex toward Trois-Rivières.

Sorel, located upstream from the mouth of the Richelieu River, was chosen as discharge analysis point, simply because it is located immediately upstream from Lake Saint-Pierre. Other choices would have been as relevant. However, Sorel has the advantage of integrating the two discharge inputs dominating the hydraulics of the reach. The discharge at Sorel is made of the reconstructed discharges originating from the Lachine Rapids and the non-gauged discharges of the Montréal south shore, the Mille-Îles and des Prairies rivers discharges, as well as the discharges of the Assomption River.

The St. Lawrence discharges show short term and long term fluctuations (see section 3 : Hydrology regimen, discharge). The distribution of the frequencies observed in weekly means is presented in Figure 23, by slices of 200 m^3/s. The discharges at Sorel, as previously described, varied from 6 000 to 19 400 m^3/s between 1960 and 1998. The distribution of frequencies shows that the most frequent discharges range from 8 400 to 12 000 m^3/s and discharges below 7 000 m^3/s and above 16 400 m^3/s are extremely rare. The mean is 10 277 m^3/s, while the median is 10 031 m^3/s.

The distribution of discharges varies with the season. Figure 24 shows the duration and the variability of discharges according to different hydraulic seasons as reconstructed at Sorel. These seasons are defined by the occurrence of different types of friction affecting the flow. Winter, defined here as the season with an ice cover, was limited to the beginning of January until mid-February. It represents the period when discharge variability is the lowest. In the spring, here restricted to the period from mid-March to the beginning of June (beginning of the growth season of macrophytes), the only friction occurring is from the substrate. This is the spring flood season, the variability of discharges being at a maximum. Summer is defined as the period of maximum aquatic plant growth. This hydraulic season was limited from the first quarter of the month of

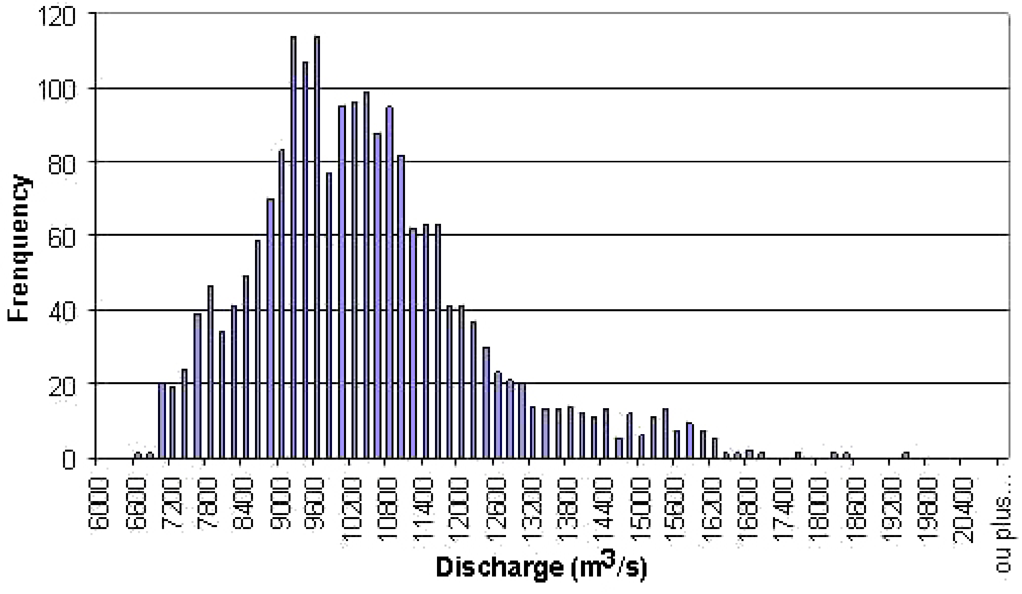


Figure 23 : Distribution of the St. Lawrence River discharges between 1960 and 1998, in weekly means by slices of 200 m^3/s.

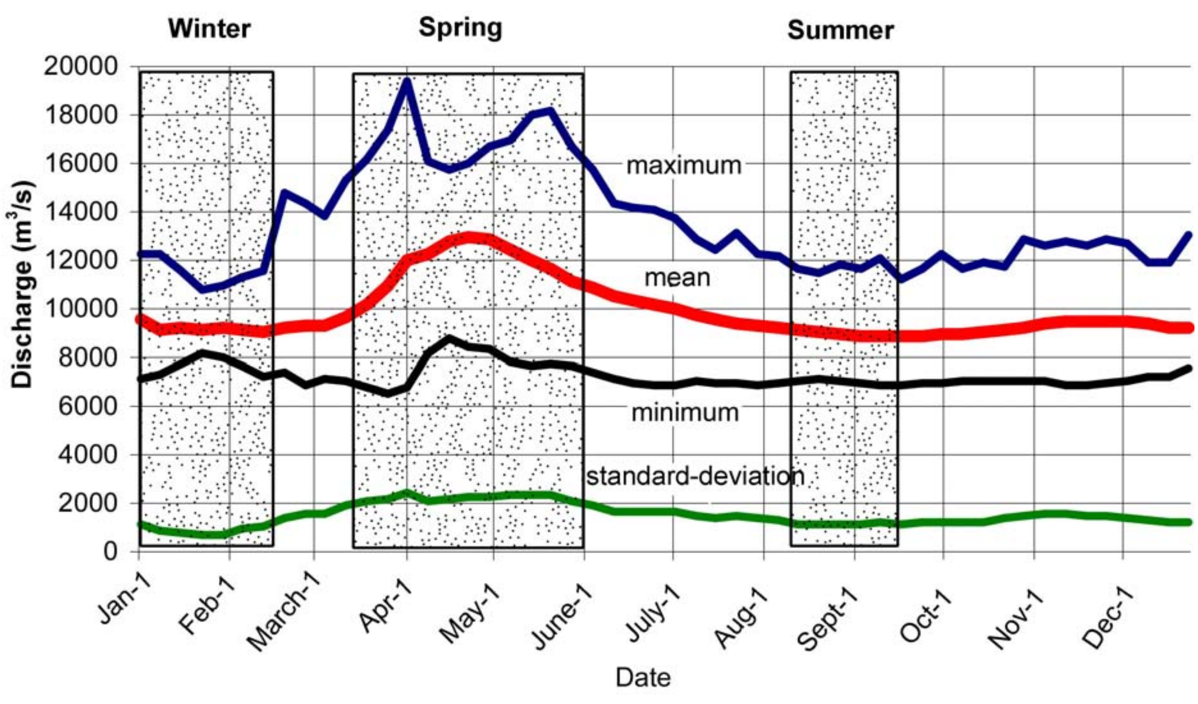


Figure 24 : Distribution of hydraulic seasons using the seasonal variation of the inter-annual mean, the minimum, the maximum and the standard deviation of the weekly discharges at Sorel between 1960 and 1998.

August to mid-September. Discharge variability is rather low.

The distribution of discharges in each hydraulic season is presented in Figure 25 by slices of 200m^3/s between 1960 and 1998. In period of ice cover, during winter, the discharges range from 7 115 m^3/s to 12 290 m^3/s. The distribution is about normal, the mean and median being similar at 9 525 m^3/s. In the spring, without ice and aquatic plants, the distribution of discharges is very wide ranging from a minimum of 6 545 m^3/s to a maximum of 19 355 m^3/s. The distribution is normal in appearance, although the high extremes are very far apart. The median is 11 885 m^3/s while the mean is 11 945 m^3/s. During maximum plant growth in summer, the discharges have a relatively low variability with extreme values of 6 865 m^3/s and 12 205 m^3/s. The mean is 9 400 m^3/s and the median is 9 366 m^3/s.

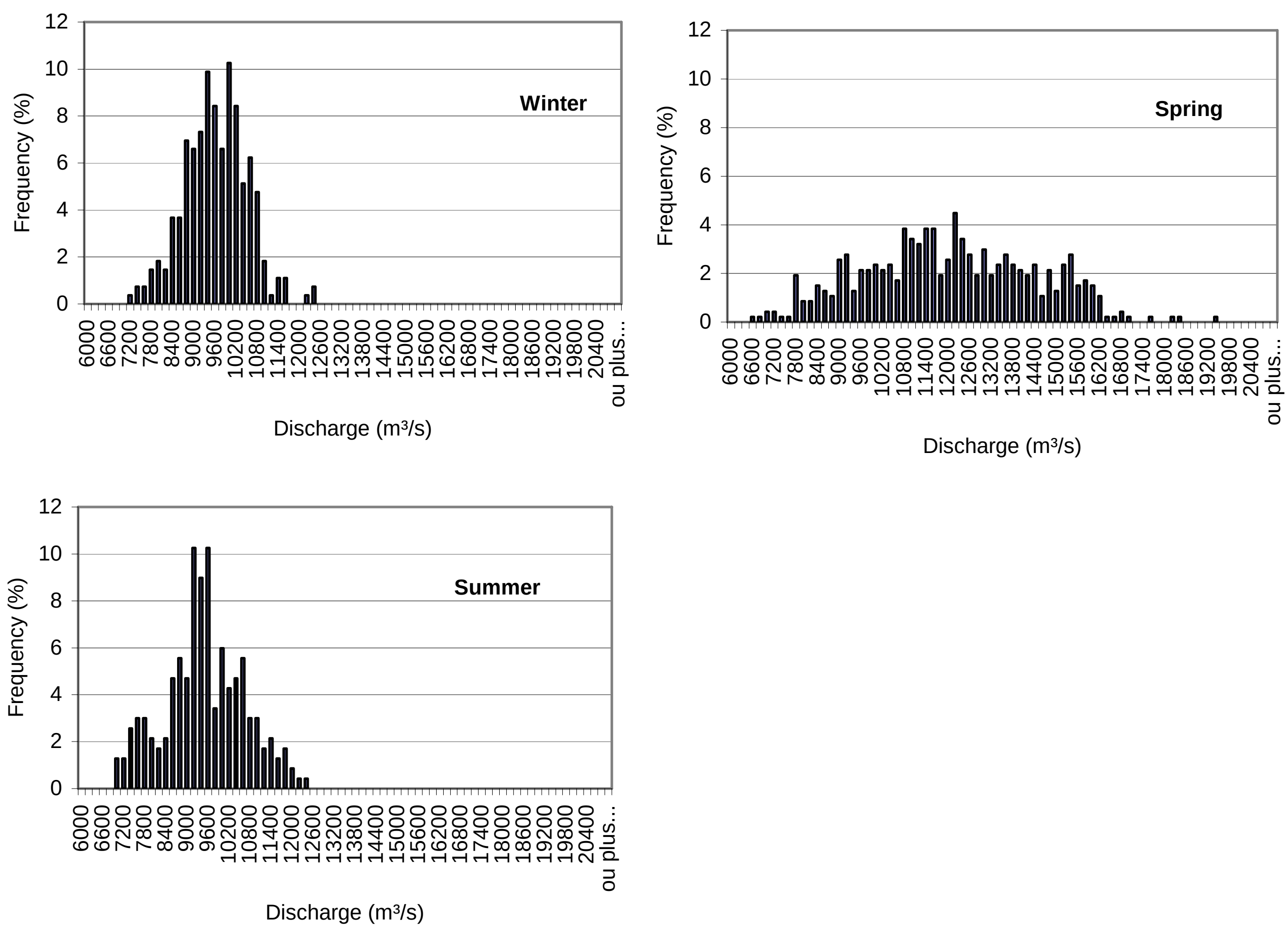


Figure 25 : Distribution of discharges within the hydraulic seasons of winter (ice : Janaury 1-February 15), spring (substrate only : March 15-June 1) and summer (macrophytes : August 7-September 15) at Sorel between 1960 and 1998.

7.2 Recurrence of discharges at low water and spring flood

A recurrence analysis was conducted for the reconstructed discharges for the period from 1960 to 1998 at Sorel and Trois-Rivières. The annual maximum (spring flood) and minimum (low water) values extracted from the weekly mean series were used and, to allow for comparisons, calculations were also made using the maximum and minimum values of the daily series. Each series of annual maximum or minimum values was characterized by a Log-Pearson Type III distribution using the HYFRAN software which now replaces the AJUSTE software (Perreault *et al.*, 1994) and includes several of the methods proposed by Bobée and Ashkar (1991). The Log-Pearson Type III distribution is recommended by the American Water Resource Council for the representation of annual maximum floods (WRC, 1967 ; Benson, 1968).

As a general rule, the floods or annual maximums occur in the spring, while the low waters or annual minimums occur in summer and winter. The maximum discharge of 19 355 m^3/s observed in the spring in the weekly discharge series at Sorel corresponds to a flood recurrence located between 100 and 500 years (Figure 26). In summer, the minimum discharge of 6 865 m^3/s observed in the weekly discharge series at Sorel corresponds to a low water recurrence located between 10 and 50 years (Figure 27). The difference between the periods of recurrence for flood and low water is probably related to the regulation of the system.

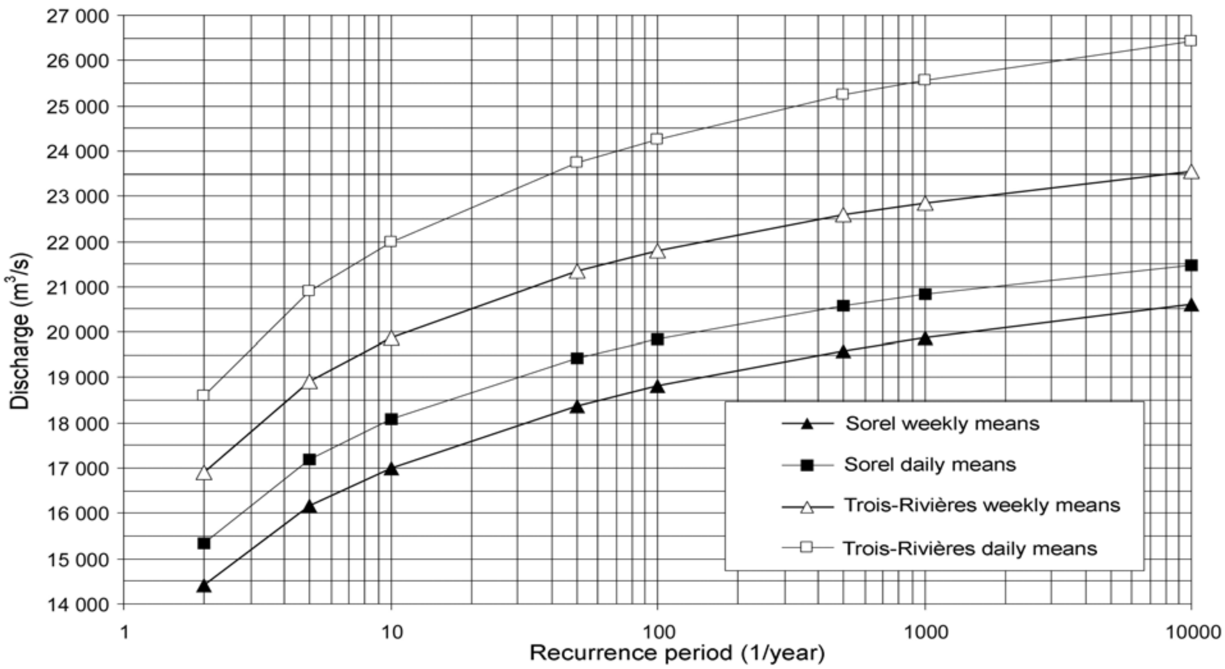


Figure 26 : Recurrence analysis of flood discharges of the St. Lawrence River between 1960 and 1998, in weekly and daily means.

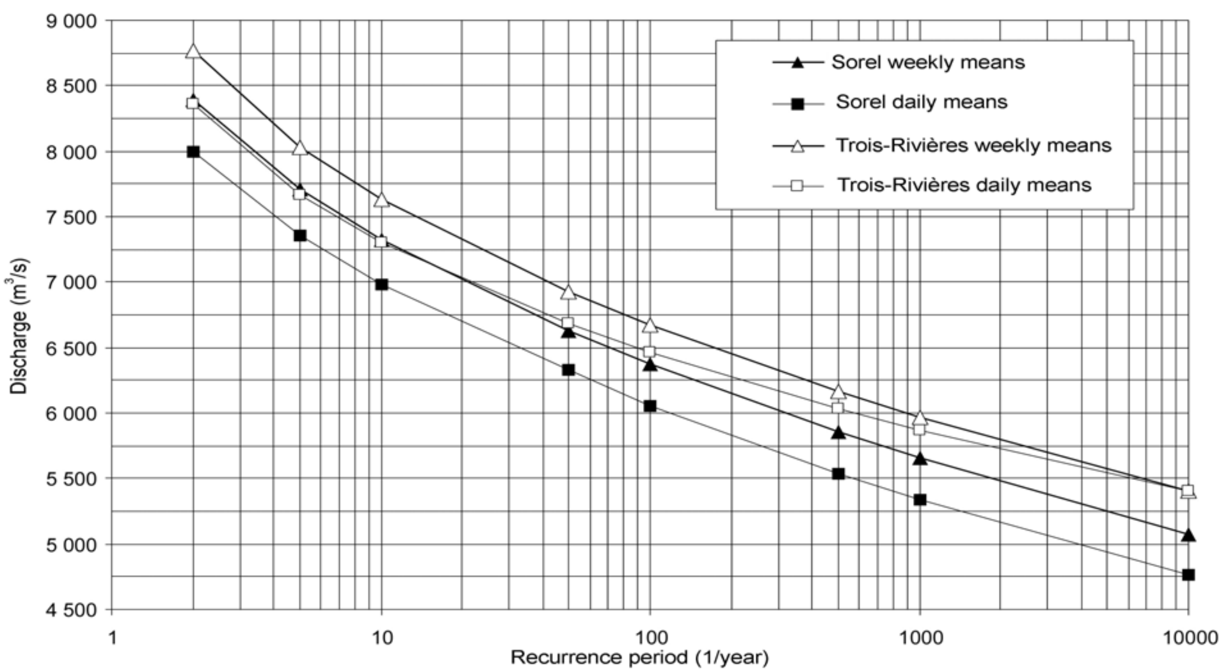


Figure 27 : Recurrence analysis of low water discharges of the St. Lawrence River between 1960 and 1998, in weekly and daily means.

7.3 Definition of the scenarios

The choice of scenarios must consider the hydrological seasons and the return periods, and must cover the range of possible conditions. In addition, since the objective of the scenarios is to simplify and highlight the hydraulic conditions, the scenarios must be restricted in number. However, they must be sufficiently numerous to observe the changes gradually and determine the critical conditions during the modeling of a given component of the ecosystem. By experience, it is accepted that changes of discharge in the order of 1 500 to 3 000 m^3/s are satisfactory. Finally, it is interesting to be able to compare hydraulic seasons with each other, and to choose similar slices of discharge for the different seasons.

The eight scenarios selected were characterized by the discharge at Sorel (Table 8). These scenarios cover the whole range of observed discharges and extend to a recurrence of nearly 1/10 000 years for floods and low waters. All the discharges are not present in each hydraulic season since certain discharges have an extremely low probability of occurrence at certain seasons. The scenarios were defined using the summer and winter means, which are close to 9 500 m^3/s (Scenario 4) and by the spring mean which is close to 12 000 m^3/s (Scenario 5). The difference of 2 500 m^3/s between the scenarios was kept until scenario 7 which represents a recurrence of 1/16 years. The extreme scenario of 20 500 m^3/s is 1 500 m^3/s higher than the weekly maximum calculated. For the low discharge scenarios, a pitch of 1500 m^3/s was selected. This pitch is lower and provides for a relatively similar resolution as larger discharges. The recurrences of low water scenarios are similar as those retained for flood discharges. The extreme scenario of 5 000 m^3/s corresponds to a very low recurrence of nearly 1/10 000 years. Although there were no similar discharges observed in the reconstructed series, it was selected in order to represent the possible conditions of a decrease of at least 20% of the water input.

The numbering of the scenarios is accompanied by a letter to identify the hydraulic season. Table 8 presents, by season, the percentage of the discharge slice observed represented by a scenario. For example, the average scenarios of the winter (4H) and the summer (4E) represent respectively 74% and 62% of the observations for the season for the discharge slice ranging from 8 750 to 10 750 m^3/s.

Table 8 : Numbering and characteristics of the discharge at Sorel for the scenarios retained according to hydraulic seasons.

Scenario	Discharge at Sorel m^3/s	Difference m^3/s	Recurrence years	Winter	Spring	Summer
8	20 500	+ 3 000	1/7000		8P (0.2%)	
7	17 500	+ 2 500	1/16		7P (2.8%)	
6	14 500	+ 2 500	1/2		6P (26.7%)	
5	12 000	+ 2 500		5H (6.2%)	**5P (38.7%)**	5E (12.4%)
4	**9 500**			**4H (74.4%)**	4P (22.4%)	**4E (62.0%)**
3	8 000	- 1 500	1/3	3H (18.7%)	3P (7.9%)	3E (22.2%)
2	6 500	- 1 500	1/70	2H (0.7%)	2P (1.3%)	2E (3.4%)
1	5 000	- 1 500	~1/10 000		1P	1E

Note : In bold : average scenario for the season and in parenthesis : percentage observed in the discharge slice by season.

7.4 Discharges and levels of the St. Lawrence and its tributaries

7.4.1 Boundary conditions - discharge

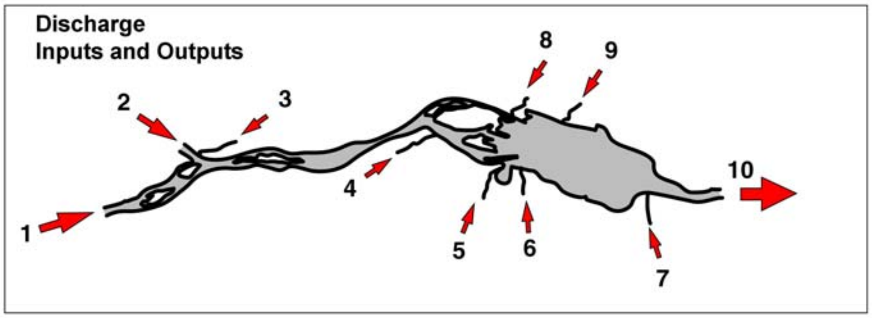
The discharge scenarios previously defined must be completed with the conditions of the tributaries water input in the system. With such a restricted number of conditions (8), it is impossible to describe all the possibilities. The conditions of the tributaries and the proportion of water originating from the des Mille-Îles/des Prairies rivers *versus* that originating from the Lachine Rapids can vary for the same discharge at Sorel. To reduce the complexity and offer an overall view, the mean conditions observed were gathered for each scenario. For example, for scenario 4 at 9 500 m^3/s at Sorel, the distribution of the discharges of the water input of each tributary for the days corresponding to a discharge of 9 500 m^3/s ±5% was constructed. Of these discharge distributions, the mean was kept to produce the scenarios. For extremely rare discharges, for which there are no data for the tributaries, discharges were extrapolated from the curves established for each tributary with the common scenarios (Scenarios 2 to 7).

The position of water inputs originating from the main tributaries and from the river's main course in the reach is presented in Figure 28. For each of the scenarios selected, the discharge conditions of all the tributaries retained are presented. The discharges at Trois-Rivières correspond, in terms of calculated recurrence, to the recurrences calculated at Sorel (see section 7.2).

7.4.2 Boundary conditions - level

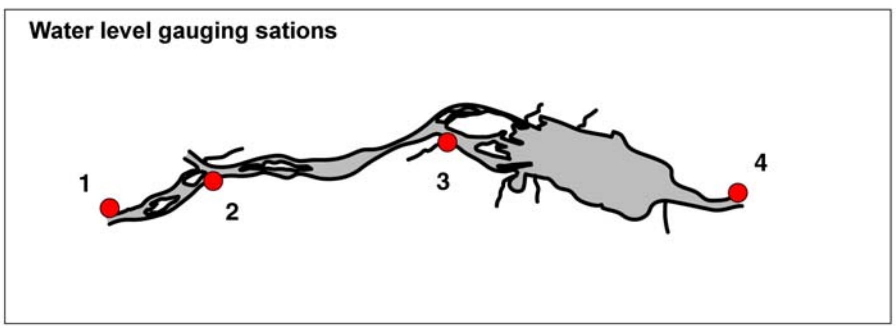
The level boundary conditions to be used for the different scenarios must vary with the season. The impact of aquatic plants and ice on the flow, as well as the discharges of the tributaries downstream, affect the level at the outlet of the reach at Trois-Rivières and in the actual reach (see section 4.3). The level conditions may change considerably within a given hydraulic season and between seasons. For example, the amount of aquatic plants reaches an annual maximum between mid-August and mid-September, but depending on the water level conditions the amount of plants changes. The situation is similar for ice. It becomes obvious that the levels at Trois-Rivières can be used as boundary conditions of the hydrodynamic simulations while the other stations are presented as indications.

The gauging stations used are presented in Figure 29 and include the Jetée #1, Varennes, Sorel and Trois-Rivières stations. The daily level data at these stations were used to show the distribution of the observations corresponding to the reference scenarios defined. The cumulated periods correspond to the hydraulic seasons defined in Figure 24. The levels corresponding to the discharges of the scenarios during the hydraulic season were kept. For example, for scenario 4 during summer, all the levels measured during the summer days (August 7-September 15) when the discharge at Sorel was 9 500 m^3/s ±1% were kept and the median of these data is presented in Figure 29. The values of certain infrequent scenarios were extrapolated in 4 cases ; the data are either missing (scenario 2) or the levels were never observed (scenario 1). The extrapolation was conducted with a second order polynomial.



Scenario		Tributaries above Sorel			Tributaries below Sorel						Total
		1	2	3	4	5	6	7	8	9	
	Sorel m³/s	Lasalle m³/s	MIP m³/s	Assomption m³/s	Richelieu m³/s	Yamaska m³/s	Saint-François m³/s	Nicolet m³/s	Maskinongé m³/s	duLoup m³/s	Trois-Rivières m³/s
8	20 500	14 531	5 374	550	1 100	410	980	380	122	107	23 554
7	17 500	13 174	3 824	502	1 044	345	850	233	119	97	20 188
6	14 500	11 396	2 772	332	898	220	572	130	105	92	16 517
5	12 000	10 102	1 750	148	615	126	330	76	43	37	13 227
4	9 500	8 304	1 142	54	326	52	155	30	16	14	10 093
3	8 000	6 997	960	43	240	38	139	24	14	14	8 469
2	6 500	5 740	728	32	148	29	128	19	8	11	6 843
1	5 000	4 572	398	30	137	28	120	17	7	10	5 319

Figure 28 : Discharge boundary conditions of the water inputs and the exit for the Montréal/Trois-Rivières reach.



Scenario	Winter				Spring				Summer			
	Jetée #1	Varennes	Sorel	Trois-Rivières	Jetée #1	Varennes	Sorel	Trois-Rivières	Jetée #1	Varennes	Sorel	Trois-Rivières
	1	2	3	4	1	2	3	4	1	2	3	4
	zc = 5.564	zc = 4.836	zc = 3.775	zc = 2.942	zc = 5.564	zc = 4.836	zc = 3.775	zc = 2.942	Zc = 5.564	zc = 4.836	zc = 3.775	zc = 2.942
8					9.82	9.06	8.01	7.24				
7					8.80	7.98	6.92	6.16				
6					7.99	7.20	6.22	5.53				
5	7.29	6.33	5.40	4.55	7.19	6.37	5.42	4.69	7.24	6.31	5.22	4.34
4	6.71	5.99	5.04	3.99	6.30	5.57	4.74	4.06	6.34	5.47	4.60	3.70
3	8.71	6.32	4.86	3.84	5.61	4.95	4.17	3.55	5.84	5.06	4.24	3.32
2	5.50	4.99	4.26	3.40	***4.95***	***4.20***	***3.56***	***2.75***	***5.21***	***4.42***	***3.60***	***2.65***
1					***4.29***	***3.48***	***2.96***	***2.52***	***4.48***	***3.93***	***2.97***	***2.29***

Note : zc= zero of charts (m). The values in italics bold are reconstructed because of the absence of observations near the real values. Datum = IGLD85.

Figure 29 : Level boundaries conditions at Trois-Rivières and reference gauging stations of the

Montréal/Trois-Rivières reach by season and scenario.

7.5 Discussion

Of the 18 reference events identified within the 8 discharge scenarios at Sorel, only the spring and summer events will be simulated for a total of 13 cases. The events during ice cover conditions will not be considered because of the absence of spatial data on ice thickness and the complexity of the phenomenon to simulate. The current interest bears mostly on the events and phenomena in the absence of ice.

7.5.1.1 On the representativeness of the scenarios

The scenarios retained represent only a portion of the complexity of the river flow, the proportion of the discharge originating from the Great Lakes versus the proportion from the Ottawa River varying greatly. Table 9 shows the variations of the discharge ratio between Lasalle and MIPA (Milles-Iles/Prairies/Assomption) and the means of the ratios observed in the hydrological series. To increase the size of the sample for each scenario, the nominative values of the discharge at Sorel (ex : Scenario 1 = 12 000 m^3/s) comprise all the discharge values corresponding to the scenario plus or minus 1% (ex : 9 880 to 12 120 m^3/s). The ratios for the very rare scenarios, such as scenarios 1 and 8, represent the ratio of the daily mean of the minimum and maximum discharge observed. In the spring, the proportion of the discharge originating from MIPA is significantly higher than in other seasons. These considerations may become important in the analyses requiring the position of the water masses.

Table 9 : Variations of the discharge ratio originating from Lasalle and MIPA (des Prairies, des Milles Iles and l'Assomption rivers) in the scenarios retained.

	Scenario discharges			**Mean ratio observed**		**Mean discharge ratio by hydrological season (observations)**							
	Sorel	Lasalle	MIPA	Lasalle (min/max)	MIPA (min/max)	Hiver (jan-mars)		Printemps (avril-mai)		Été (juin-sept)		Automne (oct-déc)	
	M^3/s	m^3/s	M^3/s			Lasalle	MIPA	Lasalle	MIPA	Lasalle	MIPA	Lasalle	MIPA
8	20500	14531	5924	73%	27%	~	~	73%	27%	~	~	~	~
7	17500	13174	4326	75% (80/69)	25% (30/19)	~	~	75%	25%	~	~	~	~
6	14500	11396	3104	78% (84/69)	21% (31/16)	~	~	78%	21%	~	~	~	~
5	12000	10102	1898	84% (89/74)	16% (25/11)	84%	16%	82%	18%	86%	14%	85%	15%
4	9500	8304	1196	86% (93/70)	14% (30/7)	86%	14%	83%	17%	89%	11%	88%	12%
3	8000	6997	1003	87% (93/75)	13% (24/7)	86%	14%	80%	20%	89%	11%	88%	12%
2	6500	5740	760	88% (92/81)	12% (18/8)	87%	13%	~	~	89%	11%	88%	12%
1	5000	4572	428	92%	8%	~	~	~	~	92%	8%	~	~

The levels presented to define the scenarios represent the median of the water levels measured. These levels originate from a sample of water levels measured at the gauging stations retained for the discharge events and correspond to the scenarios previously defined (discharge ±1%). For a same discharge event at Sorel, the water levels of the reach can vary considerably. The causes of these fluctuations are numerous : variations in the friction caused by ice, plants and possibly substrate, the effect of winds, tides and discharge of the tributaries downstream. Table 10 presents the variability of the levels within a given discharge scenario. The table gives for each station retained the median, and the maximum and minimum levels. To avoid possible aberrations or extremely rare cases in the gauging, the maximum and minimum levels represent the 90% and 10% quantile of the series.

Table 10 : Variations of the levels at the gauging stations retained for the scenarios defined by the discharge at Sorel.

Scenario	**Winter**				**Spring**				**Summer**			
	Jetée #1 **1**	Varennes **2**	Sorel **3**	Trois-Rivières **4**	Jetée #1 **1**	Varennes **2**	Sorel **3**	Trois-Rivières **4**	Jetée #1 **1**	Varennes **2**	Sorel **3**	Trois-Rivières **4**
	zc = 5.564	zc = 4.836	zc = 3.775	zc = 2.942	zc = 5.564	zc = 4.836	zc = 3.775	zc = 2.942	zc = 5.564	zc = 4.836	zc = 3.775	zc = 2.942
8					**9.82** (1)	**9.06** (1)	**8.01** (1)	**7.24** (1)				
7					**8.80** (5) 9.15 8.63	**7.98** (5) 8.41 7.73	**6.92** (5) 7.45 6.56	**6.16** (5) 6.79 5.78				
6					**7.99** (62) 8.17 7.82	**7.20** (62) 7.43 6.99	**6.22** (62) 6.42 5.96	**5.53** (62) 5.73 5.18				
5	**7.29** (6) 7.41 7.04	**6.33** (6) 6.63 6.18	**5.40** (6) 5.91 5.16	**4.55** (6) 5.06 4.40	**7.19** (98) 7.44 7.03	**6.37** (98) 6.72 6.19	**5.42** (98) 5.82 5.17	**4.69** (98) 5.14 4.37	**7.24** (13) 7.39 7.08	**6.31** (13) 6.56 6.13	**5.22** (13) 5.56 5.02	**4.34** (13) 4.81 4.09
4	**6.71** (143) 8.75 6.39	**5.99** (143) 7.14 5.69	**5.04** (143) 5.68 4.74	**3.99** (143) 4.33 3.70	**6.30** (34) 6.55 6.12	**5.57**(34) 5.93 5.30	**4.74** (34) 5.17 4.47	**4.06** (34) 4.46 3.66	**6.34** (134) 6.43 6.25	**5.47** (134) 5.61 5.39	**4.60** (134) 4.74 4.46	**3.70** (134) 3.88 3.50
3	**8.71** (24) 10.15 6.20	**6.32** (24) 7.14 5.69	**4.86** (24) 5.15 4.55	**3.84** (24) 4.21 3.57	**5.61** (13) 5.84 5.52	**4.95** (13) 5.17 4.84	**4.17** (13) 4.44 3.99	**3.55** (13) 3.94 3.31	**5.84** (31) 5.93 5.68	**5.06** (31) 5.19 4.81	**4.24** (31) 4.45 4.04	**3.32** (31) 3.62 3.02
2	**5.50 (1)**	**4.99 (1)**	**4.26 (1)**	**3.40 (1)**	*4.95*	*4.20*	*3.56*	*2.75*	*5.21*	*4.42*	*3.60*	*2.65*
1					*4.29*	*3.48*	*2.96*	*2.52*	*4.48*	*3.93*	*2.97*	*2.29*

Data in bold = median, in parenthesis () = number of samples, and the other two values correspond to the measured maximum (90% Quantile) and minimum (10% Quantile), the extremes may thus be slightly higher . Data in italics are reconstructions.

7.5.1.2 On Chart Datum

The analysis of water levels was conducted using the International Great Lakes Datum version 1985 (IGLD-85). Several studies have been conducted using Chart Datum as vertical reference which induces serious reliability problems. As opposed to IGLD-85 which is a fixed reference, Chart Datum is a sloped datum conceived for shipping and its spatial homogeneity must be verified before usage. Chart Datum level 0 in IGLD-85 for the Jetée #1, Varennes, Sorel and Trois-Rivières stations is 5.564 m, 4.836 m, 3.775 m and 2.942 m respectively. These levels correspond to low water recurrences of 4.3, 4.2, 10.5 and 6.7 years respectively. These periods of recurrence should normally be similar, which is not the case. It is possible that this observation is related to the effect of the weirs whose efficiency is greater at low level. The reversing effect of the weirs is stronger at Sorel than at the Port of Montreal and the difference in effect between the two points should be greater during low water. Notwithstanding the cause of this difference, it is important to realize that the use of Chart Datum for studies of the impact of water levels is inappropriate, this datum not being spatially homogeneous (i.e. Chart Datum level 0 does not correspond to a fixed period of recurrence on the longitudinal plan). The use of the mean sea level (MSL, geodetic datum) or the IGLD-85 as reference is recommended.

7.5.1.3 On the calculated recurrences

The recurrence periods and the reference discharges of the scenarios were calculated using the post-regulation series (post-1960). Figure 30 shows the recurrence curves calculated for the pre- and post-regulation series at Sorel. The effect of the regulation was to reduce the variability among the annual extremes and of the slope of the discharge-recurrence curve. The meeting point of the two curves corresponds to a discharge of 17 700 m^3/s and an approximate recurrence of 20 years. The flood discharges with a recurrence below 20 years are higher after regulation, while the discharges with a recurrence higher than 20 years are lower with the regulation.

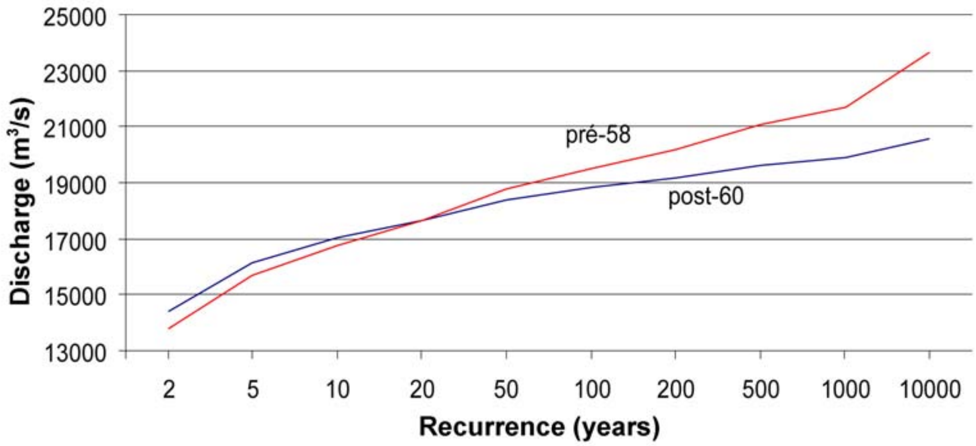


Figure 30 : Relations between discharges and their recurrence according to post- and pre-regulation series at Sorel.

8 Conclusions

The background information for modeling presented in this report summarize the information essential for the modeling of the physical factors for the Montréal/Trois-Rivières reach which will then be used to model several biological components. The reach was analyzed in terms of the evolution of infrastructures, water level, discharge and climate, to produce reference scenarios. In detail, the activities executed are :

- Preliminary sequence of interventions in the river and history of the weirs
- Reconstruction of the river discharges between Sorel and Trois-Rivières
- Analysis of the fluctuations and regulation of the discharges
- Analysis of the river water levels
- Analysis of the winds in the area
- Analysis of the air temperatures
- Period of recurrence of the discharges
- Production of reference scenarios and boundary conditions for discharges and levels

The work achieved represents a starting point for several activities. Among other things, the effort to reconstruct the discharges was limited upstream by the Lachine Rapids and by the des Prairies and Mille-Iles rivers. A next step would be to move upstream to the main inputs to the St. Lawrence River at Cornwall and Carillon. Prior to this, reliable stage-discharge relationships for the Saint-Anne and Vaudreuil channels need to be developed. These relations will serve to reconstruct discharge series for the hydraulic structures at Beauharnois and Carillon compensating for the fact that the discharge series available at these sites may contain important errors (up to 10%).

The evaluation of the impact of the regulation of the Great Lakes and the Ottawa River watershed led to an unexpected discovery. In terms of discharge at Sorel, the regulation of the Ottawa River watershed has a far greater impact than the regulation of the Great Lakes. This reality must now be taken into account in future studies on the subject.

The definition of reference scenarios for water level and discharge is a precious tool for studies carried on the impact of water levels on the various biological components in the St. Lawrence ecosystem. A total of 13 scenarios were defined (8 in the spring and 5 in summer) in order to cover all the possible hydrodynamic conditions. For each scenario, hydrodynamic simulations will be carried out and the results combined with biological data and models constituting an integrated Decision Support System (DSP). In terms of future development, the integration of the fall and spring periods must be contemplated since for the time being the question of ice is not addressed because of its complexity and the fact that in winter, part of the biological component is in dormancy.

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