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ORIGINAL PAPER

The 1996 Saguenay Flood event and its impacts

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Abstract
Major natural disasters have different impacts on our lives. There are the direct consequences of the event, but when the situation is under control and the damages under repair, it is time to review what we can improve to minimize the consequences of a future event. The present paper reviews the direct consequences of a natural flood that occurred in the province of Quebec and its impact on our approach to evaluate the risk of such an event and minimize the risks in the future. The paper is divided into two parts. The first part is an overview of the 1996 Saguenay Flood caused by a three-day intense rainstorm over the Saguenay and North Shore areas in Quebec, including a description of the area, the characteristics of this event and the main direct consequences of the flood, particularly on the reservoirs located in this area. The second part is a short discussion about the impact of this particular event on the legislative framework in the province of Quebec and on the dam safety aspect in Canada.

Keywords 1996 Saguenay Flood · Rivers · Dams · Consequences · Commission Nicolet

1 Introduction

In July 1996, a three-day intense rainstorm over the Saguenay and North Shore areas in Quebec caused severe floods, which in turn caused several dam failures. Extensive damages resulted, which were evaluated in the range of one billion dollars, and ten loss of lives occurred. It has been estimated that the rainstorm over the Saguenay area had a frequency of about one in 1000 years.

Lessons were learnt from this disaster which highlighted the need for implementing consistent and systematic dam safety measures, including systematic design criteria for spillway capacity and dam construction, and clear reservoir operating rules.

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Fig. 1 Saguenay area (Image from Google Earth)

A dam safety law was passed in year (2002) in the Province of Quebec; it was prepared and discussed in collaboration with representatives of the dam industry—dam owners, regulators and consulting engineers—and in collaboration with the Canadian Dam Association, which is a Canada-wide organization promoting dam safety and preparing Dam Safety Guidelines. In the various Canadian provinces, these guidelines serve as basis for the dam safety laws and regulations adopted.

2 Description of the 1996 Saguenay Flood

2.1 The Saguenay area

The so-called Saguenay area is located in the north-eastern part of the province of Quebec; it is the valley and surrounding areas of the Saguenay River, which is the outlet of Lake Saint-Jean (see Fig. 1). Economic development started in the early twentieth century, attracted by the abundant hydraulic resources which made it possible to develop particularly pulp and paper industrial activities. The rivers provided "highways" for wood transportation and power for paper mills. Later on, hydropower was also used for aluminium production. The major cities in 1996 were Chicoutimi, Jonquière and La Baie; in the year 2000, they were merged into a city named Saguenay.

The main south bank tributaries of the Saguenay River are the Aux Sables and Chicoutimi Rivers (they are both outlets of Lake Kenogami, which is the largest lake in the Saguenay area), and the rivers Du Moulin, À Mars, Ha! Ha!,[1] Saint-Jean and Éternité. On the north bank, the tributaries are the rivers Des Aulnaies, Shipshaw, Valin and

[1] Exclamation points are integral parts of the name of this river.

Fig. 2 Lake Kenogami area (Image from Google Earth)

Sainte-Marguerite. Hydraulic structures (dams, control structures, power plants) have been erected on the main rivers (the Saguenay itself, Aux Sables, Chicoutimi, Ha! Ha! and Shipshaw) and around Lake Kenogami.

Structures on Lake Kenogami are owned and operated by the Government of Quebec; they consist of two control structures, namely Portage des Roches and Pibrac which control, respectively, the outflow to Chicoutimi and Aux Sables Rivers (see Fig. 2). Lake Kenogami is contained by 13 structures of various sizes: concrete gravity dams, embankment dykes and mixed structures; their crest levels vary between el. 165.67 and 167.41 m.

There are four hydroelectric developments on the Chicoutimi River; they were built between 1923 and 1958, and they are owned by Hydro-Quebec, Elkem Metal and Abitibi Price.[2] The maximum outflow at Portage des Roches, which controls the flows in the Chicoutimi River, is 1820 m^3/s; however, the maximum outflow capacities on the four downstream projects are not consistent: they vary between 540 and 1080 m^3/s.

There are also four hydroelectric developments on the Aux Sables River which are owned by Abitibi Price and the city of Jonquière. The maximum outflow at Pibrac, which controls the flows in the Aux Sables River, is about 990 m^3/s; however, the maximum outflow capacities on the four downstream projects are not consistent: they vary between 400 and 770 m^3/s.

Hydraulic developments on the Ha! Ha! River (see Fig. 3) are owned and operated by a pulp and paper company, the Stone Consolidated Company, (See Footnote 2) and they were built for the purpose of providing water for their plant at La Baie. The developments consist of a regulating reservoir on Lake Ha! Ha!, which is located some 40 km upstream of the river outlet. The structures around Lake Ha! Ha! consisted of a concrete dam and two- to three-metre-high earthfill dykes. Outflow from the lake was controlled

[2] Now known as Abitibi-Consolidated.

Fig. 3 River Ha! Ha! area (Image from Google Earth)

by a four-bay outlet structure. A second structure, a small gravity structure close to river outlet, created a small pond for daily regulation at the water intake to the paper mill.

On the north bank of the Saguenay River, the Shipshaw River is the only river with extensive hydraulic developments, including regulating reservoirs and power plants. These developments experienced higher than normal inflow during the 1996 storm event and water levels exceeded extreme levels in all of them; however, no overtopping of the containing structures occurred.

The area is well covered by a network of hydrometeorological stations. One of them—Chicoutimi—had more than 120 years of record at the time of the storm. The records at most of these stations were accessible in real time either via satellite or telephone. The climate of this area is typical of north-eastern North America. Precipitation is distributed throughout the year, with a weak peak in summer/autumn and a minimum in winter. Average annual precipitation in the area varies between 900 and 1000 mm, and the average July rainfall is between 100 and 120 mm.

Perrier and Slivitzky (1999) have carried out a study of the large summer/autumn storms in the Saguenay area over the period 1924 to 1999. They found that large storms in this area are generated by the following mechanisms:

- An important and sustained warm and humid air inflow from the USA, the Gulf of Mexico or the Caribbean;
- A mechanism—usually a cyclonic depression—that causes rapid raising and condensation of that warm, humid air;
- A mechanism that temporarily slows down, blocks or deviates the trajectory of the depression, forcing it to spill its water on the same area for a period of several hours. This blockage is usually induced by the relative movements of the high-pressure zones in the vicinity of the cyclonic depression.

The hydraulic regime of the rivers under such a climate consists of a large spring flood where river flow is the combination of run-off from spring rainstorms and melting of the snow accumulated during the winter season. Flow in summer and autumn generally fluctuates around the average annual flow, with peak magnitudes depending on the intensity of the summer/autumn storms. Winter flows are characterized by a steady recession, due to the absence/reduction of liquid inflow.

River flow information on the main river system of the area, Lake Kenogami drainage area, is available since 1912. The highest flood peak observed before 1996 was 997 m^3/s; the 1996 flood peak was evaluated as 2360 m^3/s (Commission Nicolet 1997),[3] which is for practical purpose equal to the 1000 years flood (evaluated as 2390 m^3/s—Commission Nicolet).

2.2 Typical reservoir operation

The general purpose of reservoir operation is to maintain controlled inflow to the hydroelectric plants or the paper mills. Typical reservoir operation is governed by the hydraulic regime: reservoirs are generally drawn down at the end of winter; they are rapidly filled with the spring inflow and maintained close to the maximum level in summer/autumn, leaving a certain margin to enable storing as much as possible of the excess water from large storms. In winter, reservoirs are slowly drained down to compensate for the low natural inflow.

New social constraints for reservoir operation have emerged during the second half of last century. Lakes and rivers are more and more used for recreation activities, and an ever-growing number of summer houses are built around the lakes and along the river banks. Summer houses' owners insist of maintaining lake (reservoir) levels within strict limits from the end of spring to the middle of autumn, and river users want to strictly limit the magnitude and rate of variation of the flow release from the control structures. The effect of these constraints is to jeopardize the efficiency of the reservoirs to control the outflow in case of a sudden abnormal event.

2.3 The July 1996 rainstorm event

During the first two weeks of July 1996, rainfall occurred 3 days out of four over South Quebec totalling between 100 and 150 mm over the area, i.e. about the average rainfall of the month. As a result, the soil of all watersheds in the Saguenay area was saturated by the middle of July.

On July 18, a depression extended its warm front from Lake Superior to Maine in USA, attracting air masses from the south. Humidity inflow to the north was considerable, with dew points between 22 and 27 °C. The depression intensified on July 19, releasing a considerable amount of rain over South Quebec. On July 19 and 20, the relative intensities and movements of the Hudson Bay and Bermuda anticyclones temporarily blocked the progression of the depression; which, in the process, released an additional 100 mm of rainfall over the Saguenay and Quebec North Shore areas. In addition, more humidity to the Saguenay area came from north-west winds which blew over Lake Saint-Jean and gathered

[3] The Scientific and Technical Commission on Dam Management is mainly referred in Quebec as "Commission Nicolet".

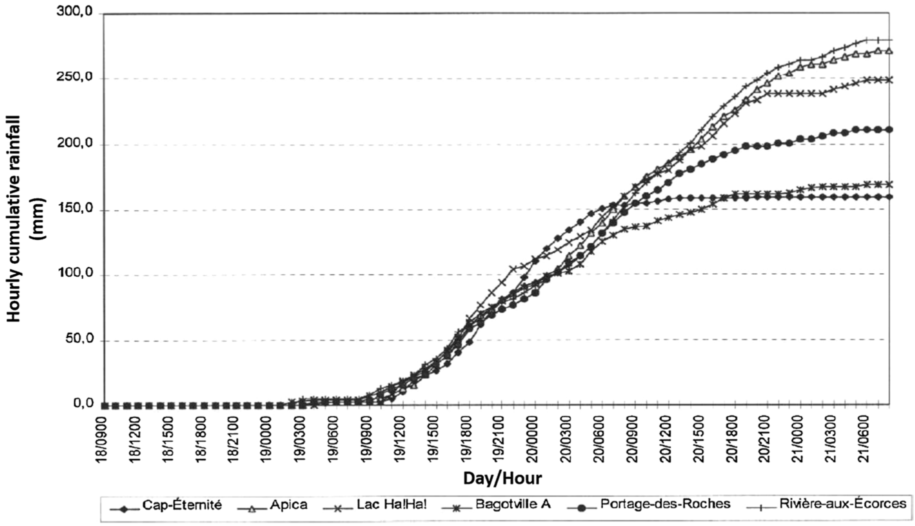

Fig. 4 Cumulated rainfall at meteorological stations in the Saguenay area [ref Perrier and Slivitzki (1999), data from Environment Canada 1997)]

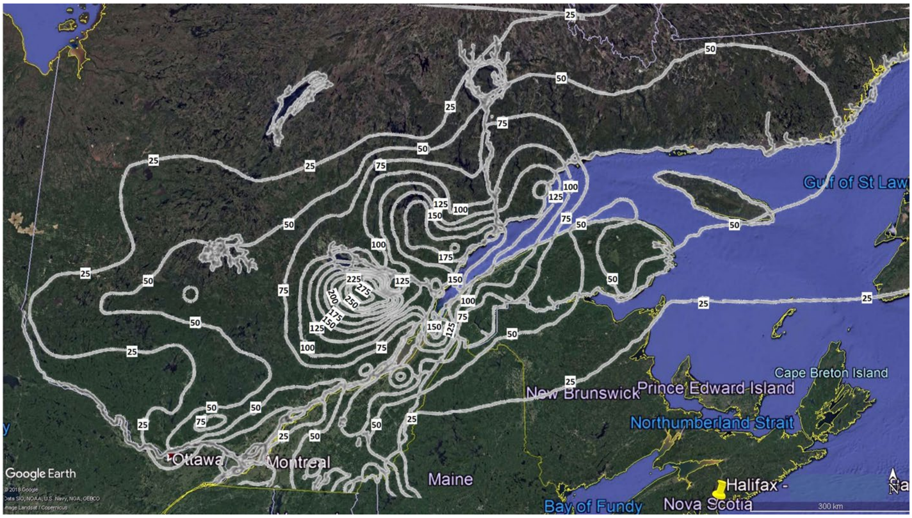

Fig. 5 Isohyets of the total July 18–21 rainfall over South Quebec—This map shows that the Saguenay area was the centre of that storm [data from Environment Canada (1997)]

more humidity from this large neighbouring water body. Forecasts of exceptionally high rain were published as soon as Thursday, July 18 at noon, i.e. 24 h before the beginning of the storm. Other forecasts until July 20 confirmed the duration and the severity of the storm.

Environment Canada (1997) carried out an exhaustive compilation of the meteorological data gathered over the entire area during the storm. Significant results from that study are presented in Figs. 4 and 5 which show the cumulated rainfall versus time at meteorological stations in the area and the map of the total rainfall between 18 and 21 July 1996.

This rainstorm caused large floods in all the rivers of the area. The return period of the flood on the basin of Lake Kenogami was estimated close to 1000 years (Environment Canada). No hydrologic records were available to estimate the return period of the floods on the smaller rivers of the area; however, it can be estimated—based on the rainfall conditions—that they were in excess of 100 years.

The regulating reservoirs in the area, Lake Kenogami and Lake Ha! Ha!, were quickly filled up to their normal maximum level, and efficient flood control would have required exceptional and drastic measures to be applied without delay, i.e. encroaching on the normal freeboard and releasing outflows larger than maximum normal.

For Lake Kenogami, however, efficient operation of the outlets (Portage des Roches and Pibrac control structures) was hampered because of conflicting criteria:

- No encroachment on the summer freeboard was tolerated in order to protect dwellings around the lake;
- Low limits for normal maximum outflow were imposed to avoid flooding along the banks of the Aux Sables and Chicoutimi Rivers and to avoid excessive velocities.

Outflow capacities at the downstream structures on both rivers were lower than the capacity of the corresponding head structures on Lake Kenogami. This inconsistency resulted in delaying the opening of outflow structures from the lake, knowing that it could result in overtopping the downstream structures. The crest level of the lower structures around Lake Kenogami was quickly reached, and large overflow occurred over these structures, causing severe damages in the downstream low-lying areas.

This overflow at the downstream structures on the Aux Sables and Chicoutimi Rivers caused the failure of the embankment structures at these sites. In the city of Chicoutimi, the overflow on the Abitibi Price concrete dam caused severe damages to a residential district where all commercial and residential buildings were destroyed or strongly damaged, although a small house in that district resisted unharmed against the raging flows. It was nicknamed “La petite maison blanche”[4], and it was adopted as the symbol of the resistance of the population against the wrath of the unleashed natural disaster. A picture of that house is shown in Fig. 6.

At the Lake Ha! Ha! dam, no clear instructions were provided for reservoir operation in case of an extreme summer flood. The operator was therefore facing the following dilemma, either:

(a) Release large outflow in order to keep the reservoir below the crest level of the containing structures; this would have resulted in severe flooding of the downstream villages of Ferland and Boileau; or
(b) Maintain outflow low enough to protect the villages downstream; this could result in spilling over the embankment dykes and possibly cause their failure.

[4] The Little White House.

Fig. 6 “La Petite Maison Blanche” (“Le musée de la petite maison blanche—S. Genest”)

The reservoir level reached the crest of the dykes in the middle of the night, between Friday and Saturday. At that time, there was no possibility to quickly get instructions from qualified persons.

The lowest dyke around Lake Ha! Ha! eventually collapsed as it was only three metres high; moreover, it was built on overburden which rapidly got washed away; the actual breach depth reached 14 m, causing a major dam failure. The sudden flow increase in the river severely flooded the villages of Ferland and Boileau and part of the city of La Baie and destroyed the intake structure of the Stone Consolidated Company. The 40 km river reach, from the lake to the mouth, was dramatically reshaped with deep erosions and huge material deposits. The complete study and modelling of the consequences of that dam failure were carried out by INRS-EAU (1997).

The damages which resulted from the intense rains, the floods and the dam failures were extensive, and the event is now known under the name of the “Deluge of the Saguenay”. The total cost was estimated at about one billion dollars, and there were ten life losses.

A pretty exhaustive list of the damages is provided in the report of the Commission Nicolet (1997). The damages consisted mainly of the destruction of houses, buildings, hydraulic projects, roads, bridges and production loss at the various plants.

They were also extensive environmental damages, mainly the destruction of river beds and spilling of contaminants into the river systems from submerged industrial and commercial facilities.

The ten losses of life resulted from traffic accidents caused by the heavy rains and persons buried in their homes due to landslides. It is noteworthy that although the large dam failure at Lake Ha! Ha! occurred in the middle of the night, with no warning time and with a large number of persons at risk, no loss of life was caused by that specific disaster.

3 Consequences of the Saguenay Flood on legislation and guidelines in Quebec and Canada

The control of water by dams is an important contribution of the economic activity in Quebec and more generally in Canada. Dams contribute to hydroelectric generation, water supply to cities and industries, flood control, irrigation, etc. There are more than 15,000 dams in Canada; 6000 of them located in Quebec, and 1150 of them are considered as large dams[5] according to ICOLD classification

3.1 Quebec

In the province of Quebec, one of the main consequences of the 1996 Saguenay Flood was to highlight the risks related to large floods, including the risks of dam failure. This led to the review of the legislation and regulations in force to make sure the population and infrastructures are adequately protected.

In 1996, activities related to dam safety, dam construction and dam operation were covered as subsections of a multitude of laws, some of them dating as far back as the nineteenth century. Some of these laws were conflicting or outdated. The absence of an appropriate supervisory regime did not guarantee the safety of the population and the properties against the risks related to the operation of dams and water-retaining structures (Paquet and Martel 2013). The 1996 flood event brought to light the false sense of safety associated with the presence of dams and their ability to control floods and to reduce downstream damages.

Following the "Saguenay deluge", the Government of Quebec set up the Commission Nicolet and gave it the mandate to study the actions taken by private and public dam managers before, during and after the flood (Commission Nicolet 1997) and to set out appropriate recommendations. Among those recommendations was the improvement of dam construction and monitoring standards by the Quebec Government and the creation of a directory of all the dams in the province of Quebec. The report also recommended the identification of risk areas created by a potential dam failure and causing a sudden unexpected large flood.

Based on the recommendations of the report, a legislative framework (Dam Safety Act) and dam safety regulations were implemented in April 2002 (Government of Quebec 2002). The main objectives of the law were to increase dam safety and to protect people and property from the risks associated with the presence of dams. Some of the basic principles of this legislation were directly motivated by the experience of the Saguenay disaster, i.e. (a) make sure that the emergency outflow capacity at any structure is at least equal to

[5] The International Commission on Large Dams (ICOLD) defines a large dam as "a dam with a height of 15 m or greater from lowest foundation to crest or a dam between 5 and 15 m impounding more than 3 million cubic metres".

the outflow capacity of the structures located upstream; and (b) make sure that clear operating rules in case of emergency are specified to the dam operators.

The law establishes a method to assign a classification for each dam. Based on that classification, minimum dam safety criteria (design flood, design earthquake, minimum freeboard, etc.) and minimum dam monitoring criteria are specified. The classification of each dam must be reviewed at least every 10 years.

The classification of a dam (including associated structures) is based on its main characteristics and on the expected consequences following its failure (Government of Quebec 2002). Similar hybrid approaches (taking into account the system's characteristics and the possible consequences of the dam failure) are in use in other countries such as Brazil, China and Portugal (ICOLD 2015).

3.2 Canada

The 1996 Saguenay Flood together with the 1997 Red River flood (in Manitoba) prompted the review and update of existing Dam Safety Guidelines and dam safety legislation (in provinces where such legislation already existed) on a Canada-wide basis.

In Canada, dam safety is under provincial jurisdiction; however, an independent organization called Canadian Dam Association (CDA)[6] deals with the promotion of dam safety, including the preparation of Dam Safety Guidelines. It was founded in 1989, and its members are volunteers; they represent activities involved in the dam industry—dam owners, regulators and consulting engineers. The first CDA Dam Safety Guidelines were released in (1995). These guidelines were updated and revised in 1999, 2007 and 2013, partly as a response to the Saguenay and Red River floods.

4 Conclusion

The 1996 flood in Saguenay constitutes a landmark event for the region as much in terms of the extent of the damage caused as in terms of the improvements that had to be made to certain infrastructures. It is also a landmark in terms of environmental damage caused by a single event. Furthermore, it prompted the people of the region, of the province of Quebec and of Canada in general to be more aware of the need for a legislative framework and rules to ensure the safety of the dams.

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[6] The Canadian Dam Association (CDA) resulted from the merger in 1997 of the Canadian Dam Safety Association (CDSA), founded in 1989, and CANCOLD, which dated as far back as the 1930s.

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