McGill University

Department of Bioresource Engineering

Integrated Water Resources Management (IWRM) Program

BREE 631: IWRM INTERNSHIP PROJECT

Hydrological Analysis of the Historical May 2017 Flooding Event in Montreal and Surrounding Areas

By

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perfectly controlled in the Ottawa River system in the past. The study further concluded that apart from the wet and warm winter that was experienced which contributed directly to the flooding event in Montreal, the inflow forecasting model used by the Ottawa River Regulation and Planning Board (ORRPB) as a guide to the decision-making process to assists in the release of flows from each control facility and to maintain flood control did not work for the wet and warm winter which rapidly transitioned into a wet spring, as record historical flows were recorded at the outflow of the Ottawa River which directly influenced flooding of Montreal and surrounding areas.

1.0 Introduction

Extreme events such as flooding is not a new phenomenon worldwide. Records show that the last flooding event in Montreal and surrounding areas of comparable nature to the May 2017 flooding event was experienced in 1976. Anthropogenic changes in our river systems such as the construction of reservoirs, land development and ment r human ttlement, etc., ve
led to both positive and negative outcomes as it relates to water resources and flood management in our river systems.

The St Lawrence River links the Atlantic Ocean with the Great Lakes and is one of the world's

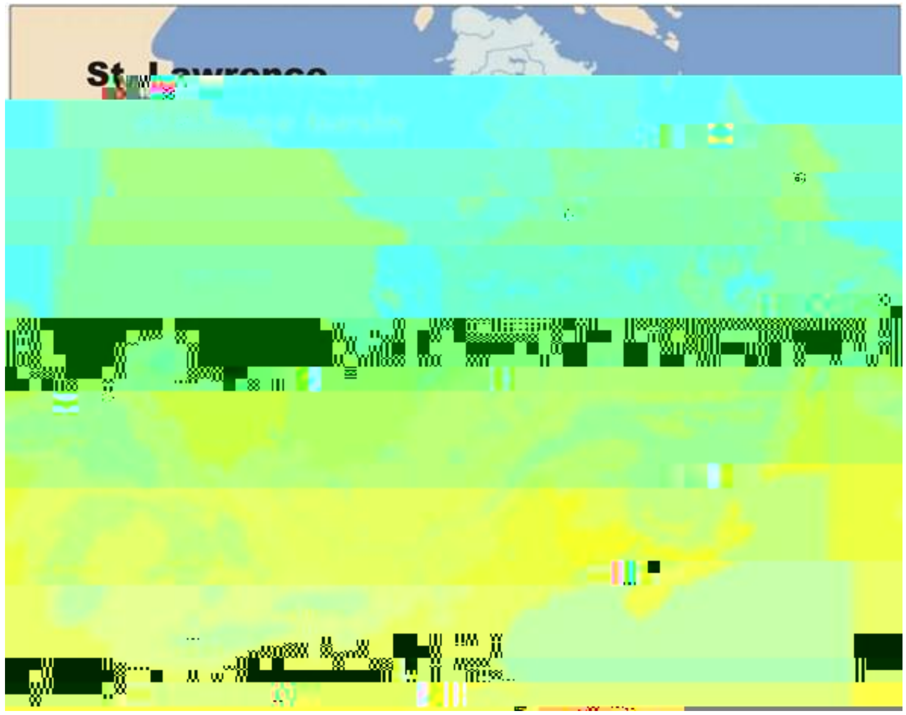

Figure 1- Map Showing the St Lawrence Hydrographic System and Drainage Basins. (Source: Environment Canada, 2017)

The entire basin has varying land use and cover, with 55% being forested, 20% cropland (with little or no irrigation), 22% urban, and 3% other types of land cover (Revenga 1998). This hydrographic system comprises of Lake Michigan, Lake Superior, Lake Huron, Lake Erie, Lake Ontario and the main stem of the St Lawrence River.

This study focuses on the analysis of the physical hydrology of the Lake Ontario - St Lawrence River Basin (LOSLR). This basin includes the lower Niagara River, Lake Ontario and the St. Lawrence River basin. International waters shared by the Lake Ontario St Lawrence River basin extends from the lower Niagara River downstream from the Niagara Falls, through Lake Ontario and the upper St Lawrence River to just downstream from the Moses Saunders Dam near the towns of Massena, New York and Cornwall, Ontario; from there the St Lawrence River flows through the Canadian province of Quebec near the cities of Montreal and Trois Rivieres, until it discharges into the Gulf of the St Lawrence (fig. 1). The LOSLR basin supplies drinking water for some 8.6 million people and supports a very complex aquatic, wetland and coastal eco-systems that are affected by water flow and fluctuations.

The St Lawrence River starts at the outflow of Lake Ontario and is the main drainage outlet for Lake Ontario. A difference of even a half of a meter in Lake Ontario water levels can aggravate

Figure 3- Map Showing the direction of River Flows surrounding Montreal (

Land use and land cover for this basin represents: 86% being forest, 10% surface waters, 2% urban, and 2% agriculture (Revenga 1998). The Ottawa River watershed has 30 storage reservoirs which has a holding capacity of more than 14 billion cubic meters of water. Table 1 shows the thirteen principle reservoirs with their respective holding capacities.

The mean annual discharge of the Ottawa River is 1942 m^3/s with maximum historical flows as high as 8190 m^3/s and minimum flows of 306 m^3/s over the past Fifty-Two (52) years (1964 – 2016), (ORRPB 2017).

Table 1- Principle Reservoirs in the Ottawa River

NO.	RIVER	RESERVOIR	CAPACITY*
1	Outaouais	Dozois	1,863
2		Rapid VII	371
3		Quinze	1,308
4		Timiskaming	1,217
5		Des Joachims	229
6	Montreal	Lady Evelyn	308
7	Kipawa	Kipawa	673
8	Madawaska	Bark Lake	374
9	Gatineau	Cabonga	1,565
10		Baskatong	3,049
11	Lievre	Mitchinamecus	554
12		Kiamika	379
13		Poisson Blanc	625

*Capacity measured in millions of cubic meters
(Source: ORRPB 2017)

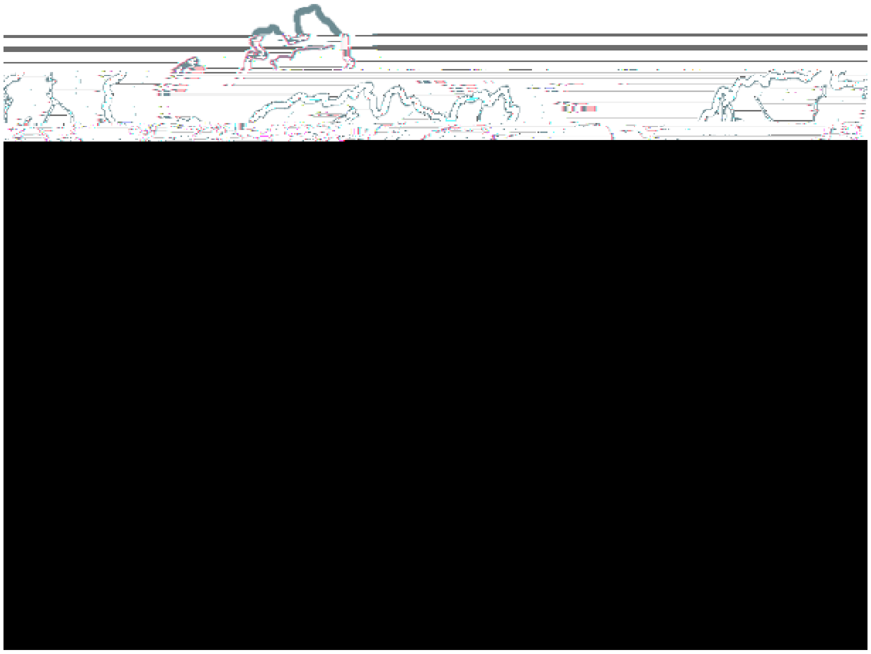

Figure 4 - Map of Ottawa River Basin Showing the 13 Main Reservoirs (ORRPB 2017)

2.1.2 Water Use

The Ottawa River in the early years was used mainly for navigational purposes, hence the first reservoirs were built in aid of augmenting low flows during dry years and to some level provide flood control measures, however with rapid urbanization in the 20^{th} century and changes in need of the basin's population there has been a change in uses of the River (ORRPB 2017). Presently the greatest use of water in this river basin is for hydroelectric power generation, domestic water supply and effluent dilution, recreational boating and to a lesser extent log driving. According to the Ottawa River Regulation Planning Board there are 43 hydroelectric generating stations in the Ottawa River Basin with a combined capacity of some 3,500 Megawatts representing an electrical value of about $1 million per day which is very important to the economies of both Quebec and Ontario.

2.1.3 Climate

The climate within this basin is like many parts of the Canadian Shield and St Lawrence lowlands and can be classified as humid continental with mesoscale local effects caused by the Great Lakes and Hudson Bay (Farvolden R.N. 1988).

The basin experiences an average total precipitation of 880 mm of which 445mm leaves as runoff (Ontario Water Resources Commission and Quebec Water Board 1971).

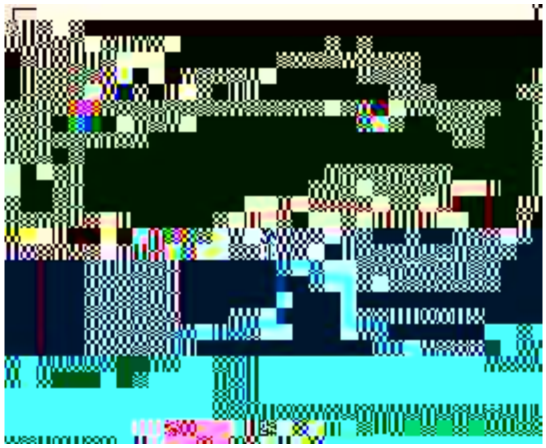

Figure 5- Mean monthly air temperature, precipitation and runoff for the Ottawa River Basin (James H. Thorp 2005).

Figure 2 illustrates that there is an increase in surface runoff for the months of April and May which represent the peak of the spring snow melt period where the soil is saturated (Ottawa River Heritage Designation Committee 2005). As precipitation rates increases for the summer months there is a decrease in surface runoff due to increased potential abstraction (soil moisture retention) caused by increased evapotranspiration and reservoir storage.

2.1.4 Flooding in the Basin

The Ottawa River system experiences the same general pattern of flow as shown for the surface runoff in figure 5, with low flows in the fall and a sudden increase in flows during the spring snowmelt period with floods in April to early May (Ottawa River Heritage Designation Committee 2005).

Due to the basin's size, shape and topography and highly varied meteorological conditions, the basin produces two distinct flood peaks, about three weeks apart (fig. 6). At Carillon, the first peak originates from unregulated flows from its southern tributaries and the second peak from a combination of high flows from tributaries of the north shore together with flows from headwater areas, and is partially regulated (Ottawa River Heritage Designation Committee 2005). It is further stated by the Ottawa River Designation Committee 2005, that the second peak which is usually the larger peak can be detrimental with a heavy snowpack, a late thaw, above normal rains, or a combination of these abnormalities causing flooding of downstream areas from Carillon such as Rigaud, Laval and Montreal (fig. 3).

2.2.2

Figure 7- Mean monthly air temperature, precipitation and runoff for the St Lawrence River basin (James H. Thorp 2005).

2.2.4 Flooding in the Basin

Figure 6 illustrates that water levels on the lake and St Lawrence River are determined largely by natural factors such as precipitation, evaporation and runoff. The International Joint Commission (IJC)

Figure 8ς Sketch Illustrating the Hydrology of Lake Ontario. (Source: IJC, 2017) the threshold level on Lake St. Louis also rises, allowing more water to be released from Lake Ontario (Tables 2 & 3).

Table 2 - Corresponding F Limit levels for Lac St Louis corresponding to Lake Ontario Levels for limiting lower St Lawrence flooding damages. (International Joint Commission 2014)

Lake Ontario Level (m)	**Lac St Louis Level @ Pointe Claire (m)**
<75.3	22.10
≥75.3 to ≤75.37	22.20
≥75.37 to ≤75.5	22.33

the Ottawa River and its tributaries, particularly in the Montreal Region, and at the same time maintain the interests of the various users particularly in hydro-electric energy production (ORRPB 2017).

During an approaching flood, strategies will be assessed and revised as necessary each day to minimize the flooding in the whole basin (ORRPB 2017). The board uses an inflow forecasting model that simulates the hydrology of the watershed as a guide to the decision-making process to assists the operators in the release of flows from each control facility to maintain flood control while having the least effect on the various other uses in the basin. Results from this model is used to keep the public informed on flows and levels, and their expected variations.

4.0 Data Collection and Methods

A large part of the study consisted in performing a thorough search for historical available climate, water levels and flow data for gauging stations surrounding the Montreal area. To analyze the magnitude of the recent May 2017 flooding event in Montreal and surrounding areas these gauging stations were selected based on the most complete and long-duration hydrological series (table 4). Gauging stations at Pointe Fortune (Carillon), Lac de Deux Montagnes, Ste Anne de Bellevue and lac St Louis (fig.9) were chosen for river flows and level data with corresponding local meteorological stations within proximity of the gauging stations (table 4). Environment Canada online historical database had 2 meteorological stations for the Ste Anne de Bellevue area, Ste Anne de Bellevue 1 was chosen for analysis since there was available daily climate data for the period 1994 to 2017; the other station named Ste Anne de Bellevue had available weather data for period 1969 to 1992 which was not necessary for this study. The hydrological variables selected for analysis in the study includes, annual maximum water levels and flows, annual mean levels and flows, monthly mean levels and flows and daily maximum levels and flows. Climatic variables selected include temperature and precipitation for different time series.

Data obtained for this study were obtained from Environment Canada online databank (Environment Canada 2017), Hydro Quebec and Quebec’s Ministry of Environment online databank (Quebec Government 2017).

Ottawa CDA RCS	6105978	45.38°N – 75.72°W	79.2	2000 - 2017	2000 - 2017	Climate	Env. Canada
Gauging Station	**Number**	**Location**	**Basin (Km^2)**	**Period**		**Data**	**Source**
Ste Anne de Bellevue	020A033	45.40°N – 73.95°W	N/a	1978 - 2017		Level	Env. Canada
Saint Louis (LAC) a Pointe - Claire	02OA039	45.43°N – 73.82°W	N/a	1915-2017		Level	Env. Canada
Lac de Deux Montagnes	043108	45.49°N – 73.98°W	146,548	1986-2017		Level	Mini.63 3

To calculate the estimates of exceedance probabilities associated with historic observations, the Weibull plotting position formula is used as shown below:

(1)

Where:

p_{est} - Is the estimated probability of occurrence (multiplied by 100 gives the percentage probability)

r - Is the rank given to a specific row in the data series. The highest discharge or water level has a rank of 1, the second highest 2 etc.

N – Number of values in the series.

4.1.1 Statistical Return Period

Assuming that X is a random variable which has a cumulative distribution function $F_x(x)$. The probability that X is less than equal to a given event x_p is given as:

Figure 10 - Flood

Figure 15 Showing daily variation in Temperature for weather Station, Rigaud.

This warm winter weather continued in February with more days above freezing point compounded with snowfall. Since the temperatures were above 0°C for the days with almost maximum daily historical precipitation, the snowfall melted and made its way into the rivers and streams.

Figure 18 Comparison of Average daily 2017 precipitation compared to the daily historical maximums for Rigaud

5.2 Historical Recorded Water Levels

Figure 19 shows us that t

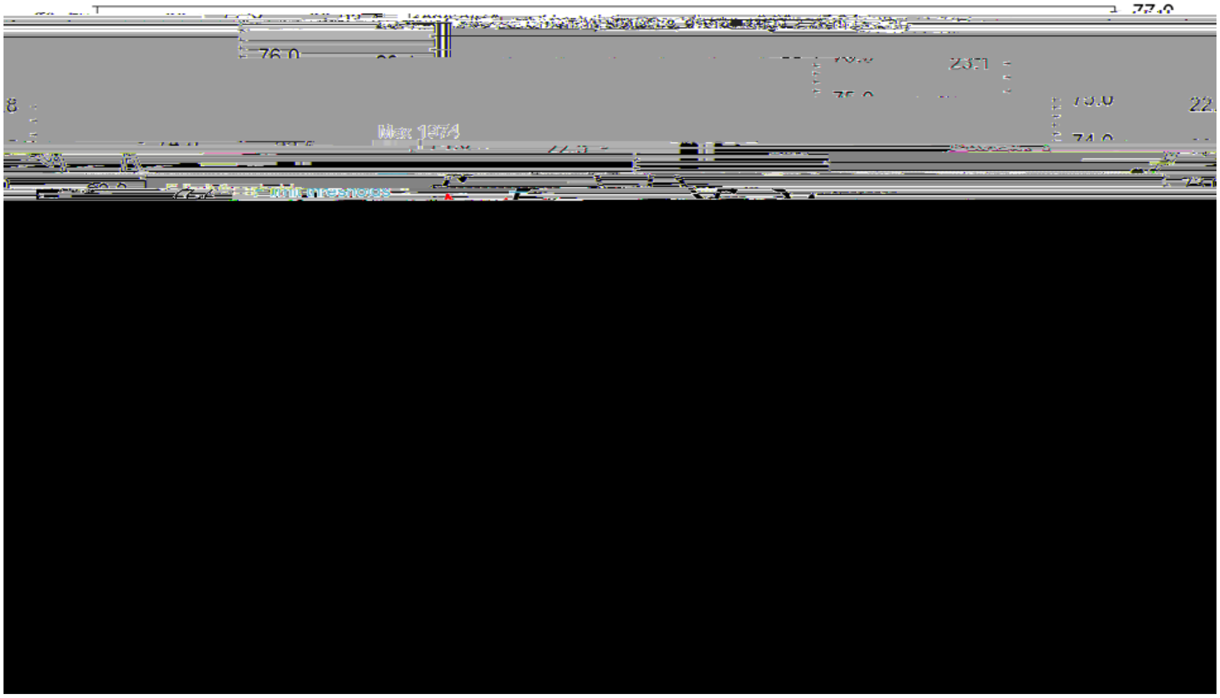

Figure 1919 Flood Hydrograph for Lac St Louis at Pointe Claire (IJC 2017)

To prevent further increase in water levels at Lac St Louis and causing further damage, the International Lake Ontario – St Lawrence Board reduced outflows from Lake Ontario in accordance with Plan 2014 (table 2). The International Joint Commission reported that the total inflow into Lake Ontario for the month of April 2017 was the second highest recorded since the year 1900.

Figure 20 shows that the upper H14 criterion was reached on April 28, 2017. Criterion H14 is a rule which is part of Plan 2014, that when exceeded, the board is authorized to follow an alternative strategy and release outflows to mitigate the effects of flooding that may affect riparians along the shorelines of the entire river system (IJC 2017).

Figure 21   Flood Hydrograph of Ottawa River at Carillon (Jan. 1 to July 31, 2017)

If the two hydrographs in figures 21 and 22 were to be compared the discharge of the Ottawa River and the rate of rise and fall of Lac de Deux Montagnes are comparable having similar peaks and trends. The water level in this lake also peaked on May 8^{th}, 2017 to a maximum level of 24.77m which is above the 100-year return level of 24.4m.

Figure 202

Figure 23 - Flood Hydrograph for Ste Anne de Bellevue (April 1 to May 31, 2017)

Figure 214 - Flood Hydrograph for Pointe Claire (April 1 to May 31, 2017)

To better understand the flows of water surrounding Montreal, figures 23 and 24 where compared with the hydrograph for Lac de Deux Montagnes to see a trend in water levels. The peak flood levels Lac de Deux Montagnes were recorded on May 8th, 2017 with a level of 24.77m whereas the peaks at Ste Anne de Bellevue and Pointe Claire for the same day were recorded as 22.739m and 22.58m respectively. This shows that the flows from the Ottawa River directly affects the levels of Lac de Deux Montagnes and Lac St Louis which validates the flow diagram as shown earlier in figure 3 of this report.

Table 4 shows us that the total precipitation of 422.2mm was experienced before the peak water level at Lac de Deux Montagnes which is way above the average total accumulated precipitation of 275mm for that time of the year (fig. 7). It further shows us that for the period 2010 to 2016, the year 2006 was the wettest year with a total accumulated precipitation of 1335.9 mm and 2012 was the driest with 926.6mm of total accumulated precipitation.

The flood hydrographs for these years were analyzed with the daily hydrograph for 2017 along with the year 2011 and there was not much difference with the flood peaks experienced for the wet and dry years

The F limit threshold level as stipulated by Plan 2014 of 22.1m

Great Lakes Connection.

Lake Ontario - St Lawrence River Plan 2014.

Lake Ontario Outflow Strategy.

Ottawa River Basin, Water Quality and its control in the Ottawa River.