THE UNIVERSITY OF WESTERN ONTARIO
DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

Water Resources Research Report

A Review of Flood Hazard Mapping Practices Across Canada

By:
James Braden
and
Slobodan P. Simonovic

Report No: 107
Date: April 2020

ISBN: (print) 978-0-7714-3143-2; (online) 978-0-7714-3144-9

A Review of Flood Hazard Mapping Practices Across Canada

By

James Braden

and

Slobodon P. Simonovic

Department of Civil and Environmental Engineering

Western University, Canada

April, 2020

Executive Summary

Flooding is currently the most common and costliest natural hazard that is occurring across Canada, threatening human life and causing infrastructure damage, social disruption and internal migration. Flood hazard maps serve as critical decision-making tools in flood mitigation, land use planning, emergency management and general public awareness. They are engineering maps that display the results of hydrologic and hydraulic investigations.

A series of major flood events were the catalyst for the federal government to initiate the Federal Damage Reduction Program (FDRP) in 1976. The main products of the FDRP were engineering maps and public information maps. The engineering maps were the basis for zoning regulations which are used to manage development in flood-prone areas. Since the end of the active mapping phase of the FDRP in 1997, provinces, territories and other levels of government have continued flood mapping for new areas or updated previous mapping using their own resources.

This situation resulted in the use of different criteria and approaches for the development of flood hazard maps. Government of Canada in 2018 established a framework to promote efforts for a national approach to flood hazard mapping for Canada. The main objective of this paper is to provide an up to date analysis and review of current approaches that are being utilized in flood hazard mapping across Canada. A review of current flood hazard mapping approaches is being completed for each province and territory using existing guidelines and case studies. An analysis has been completed for each existing approach to identify similarities between the existing approaches and assess their advantages and disadvantages.

Table of Contents

List of Figures

List of Tables

Terminology

Floodplain: An area of flat land that is located adjacent to a river that is vulnerable to flooding events.

Flood Maps: Maps that are used to identify land areas that are covered by water as a result of actual or potential flood events. Type of flood maps include Inundation Maps, Flood Hazard Maps, and Flood Risk Maps.

Inundation Maps: Maps that show the floodwater extent of a real or potential flood event. Inundation maps present the flood hazard area and are used as a management tool for emergency preparedness services.

Flood Hazard Maps: Engineering maps that display the results of hydrologic and hydraulic investigations that utilize different scenarios (flood depth, flood velocity etc.) to present the flooded areas.

Flood Risk Maps: Maps that present social, economic, environmental, and cultural consequences as a result of consequences from flood events. Flood risk maps assess the levels of risk infrastructure and other areas of land face during an actual or potential flood event.

100 Year Design Flood (1:100): A flood that has a 1% chance of being equalled or exceeded in any given year.

Flood Hazard Area: The extent of flooded land that occurs as a result of a potential or actual flood event.

Floodway: Definitions vary across provinces depending on practice. The Floodway is always the inner portion of the two zone flood risk area where flows are most damaging.

Flood Fringe: Definitions vary across provinces depending on practice. The Flood Fringe is always the outer portion of the two zone flood risk area where the flows are slower, shallower and less damaging.

1 Introduction

Flooding is a natural hazard that occurs most frequently across Canada. Impacts due to flooding include the threatening of human life, damage to infrastructure, social disruption and internal migration. Notable historical flooding events that have occurred in Canada and their damage totals trended to 2008 include; the Red River flood in 1950 and 1997, damages of $4.6 billion and $1.2 billion respectively; Alberta flooding in 2005 and 2013, damages of $519 million and $6 billion respectively; and the 1996 flooding events in Saguenay, Quebec, damages of $2.7 billion (Institute for Catastrophic Loss Reduction, 2010). Spring flooding that took place in 2019 across Ontario, Quebec and New Brunswick led to insured damages reaching a combined total of $208 million (Insurance Bureau of Canada, 2019). As a result, an approach for a national flood risk mapping framework has been promoted and encouraged to reduce future damages from flooding.

A national program with aims to reduce flood damages was announced in April of 1975 as the Flood Damage Reduction Program (FDRP) (Bruce, 1976). The program was initiated to provide clearly defined flood risk areas and then introduce appropriate measures to ensure damages are limited within those areas. The funding for the project was split equally by both, the federal and provincial governments, where the majority of the funding would be concentrated on areas with high risk and vulnerability to annual flooding damages (Natural Resources Canada, 2018). Funding invested into the program was originally planned at $20 million CAD for the initially anticipated duration of 5 years (Bruce, 1976). Over 900 communities were involved in flood mapping during the duration of the program, with a total of 320 flood risk areas designated (Government of Canada, 2010). The program lasted until 1997, when funding through the government concluded and the program was not continued. Following the conclusion of the program, provincial governments have gained responsibility for production of flood maps and have begun flood mapping for new areas or have created new maps for the purpose of updating previous maps.

As a result of the contrasting flooding conditions across Canada from province to province, provincial guidelines have varied depending on the focused needs to prevent flooding damages. Factors that have impacted the decisions towards the standards that have been imposed by provincial governments include previous history of flooding events, future vulnerability, and unique flooding challenges that exist within the province. Depending on the combination of impacts, certain provinces have taken greater initiative in producing more flood risk maps with higher standards that are made more accessible to the general public.

As of 2018, the Government of Canada has begun a framework known as The Federal Flood Mapping Guideline Series in order to promote a national approach to flood hazard mapping in Canada (Natural Resources Canada, 2018). The flood mapping series promotes the technical aspects that make up flood mapping activities, such as hydrologic and hydraulic investigation, LiDAR data acquisition, land use planning, and estimating effects related to climate change. The expectations and purpose for the framework are to provide additional guidance to provinces for more accurate implementation of flood mapping.

1.1 Literature Review

The purpose of this report is to summarize provincial guidelines that are currently being used and bring light to the contrasting methods that are currently in use. The rest of the report is organized to present the current state of flood mapping across the country. The report aims to achieve the following objectives:

1. Define the flood mapping standards and guidelines for each province
2. Specify the locations to where the flood maps are being published and/or stored
3. Identify the key hazards for each province in relation to flooding
4. Compare the current practices

Due to the purpose of this report acting as a summative comparison between provincial flood risk regulations, literature review sections have been completed for each province. Depending on the date for completed provincial legislations, guidelines or reports, the time period for the literature review extends back to 1976, start of the Flood Damage Reduction Program (Bruce, 1976). As a result of focus on governmental standards, the majority of content included has been acquired through governmental web services (included in the references), where key practices have been published, or legislations and reports that have been made available online. Provincial literature review sections focus on historical flooding events, flooding challenges, provincial mapping, mapping availability, and climate change considerations.

2 British Columbia

2.1 Historical Flooding Events

British Columbia has a lengthy history of severe flooding events that have occurred in the Fraser River basin. Flooding that occurred in the spring of 1948 in the Fraser River Delta resulted in the greatest flood event since the 1800's. Peak elevation during the flood reached 7.6 m and more than 22,000 hectares of land had been inundated (Government of Canada, 2010). The flooding caused severe infrastructure damage to rail lines and highways while also resulting in urban flooding across multiple communities. The estimated damage reached $20 million (Government of Canada, 2010), which accounts for $225 million in present day value.

Flooding events have continued to cause disruption across BC in recent years. Recent flooding events that have devastated BC include the events during the 2017 freshet flood season. High volumes of runoff were produced as a result of thawing ice and snow compounding with precipitation events (Government of BC, 2018). Flooding damages were focused in the regions of Okanagan, Kootenay and Shuswap and resulted in an estimated cost of total flood response damages of more than $73 million (Government of BC, 2018).

2.2 Flooding Challenges

The primary cause of flooding across BC has been a result of freshet flooding that occurs as a result of melting snowpack combined with precipitation events in the spring. Other causes of flooding in BC have resulted from ice jams and precipitation events. Unique flood challenges for BC include the risk of storm surge events, the threat of a tsunami, and the potential for future sea level rise. Storm surge events result in flooding across BC as a result of being located along the Pacific Ocean coastline. These events lead to an elevation in water levels and can cause compounded effects to flooding from precipitation events. Although the risk for a severe tsunami in BC is low, the Province is located near the plate boundary from the North American plate and Pacific plate resulting in the threat of a tsunami being produced in the Pacific Ocean. Finally, with climate change expecting to cause rise in sea levels across the world, BC will face sustained elevated water levels in the future which can compound with precipitation events to cause severe flooding.

2.3 Provincial Mapping

Flood mapping in BC began in 1974 as a result of having an extensive history of flooding inside the Fraser River Basin. In 1975, the Floodplain Development Control Program began as a result of an increase of funding through a country wide flood management effort from the Flood Damage Reduction Program. The program saw an increased rate of mapping from the years of 1987 to 1998 and maps were continued to be produced until the program's conclusion in 2003. Since the closure of the program, only a limited number of regions have seen an update in flood maps and 31% of communities in the Province remain without any flood maps (Parsons and BCREA, 2015).

Guidelines for flood mapping in BC are currently adopting a one zone flood design where the flood design elevations have been produced through a 200 year return period event (Ministry of Water, Land and Air Protection Province of British Columbia, 2014). Additionally, flood levels for a 20 year return period are being applied through the Health Act for the use of septic systems (Professional Engineers and Geoscientists of BC, 2017). Freeboard levels are then added on to the design elevations where the greater height of 0.3 m above the maximum instantaneous design flood level or 0.6 m above the mean daily design flood level is taken (Ministry of Water, Land and Air Protection Province of British Columbia, 2014). The maximum instantaneous design flood level is the peak flood level of the 200 year design flood at any point in time, whereas, the mean daily design flood level is the flood level above the 200 year design flood's average daily flow (Ministry of Water, Land and Air Protection Province of British Columbia, 2003). Due to the 1894 flooding in the lower Fraser River exceeding design conditions, the 1894 flood of record is used in this area for flood mapping purposes.

Efforts directed towards floodplain management have also come from outside the provincial government. The Fraser Basin Council is a local non-profit collaboration that focuses on developing initiatives based around climate change and air quality, watersheds and water resources in the Fraser River Basin. One of the many projects the Fraser Basin Council has been involved with has revolved around the production of flood maps for the Lower Fraser River. The flood maps utilize four different freshet flood events with Annual Exceedance Probabilities of 2%, 1%, 0.5%, and 0.2% as well as a historical flood map for the 1894 freshet flood event (Fraser River Council, n.d.). Depth of flooding for the given flood events are highlighted on the maps to identify the key areas at risk. The flood maps were produced for the purpose of increasing flood management strategies and improving regional flood planning.

2.4 Maps Availability

BC is currently utilizing an online interactive map software known as iMapBC that is free and available for use by the public. Figure 1 shows an example map available through the use of iMapBC. The mapping service incorporates several different layers including a historical floodplain layer. The historical floodplain layer was produced through the use of historical flood map drawings, which were completed by the provincial government during the Flood Development Control Program. Historical flood maps, produced through the use of drawings, have been uploaded for susceptible flood regions and have also been posted to the governmental website.

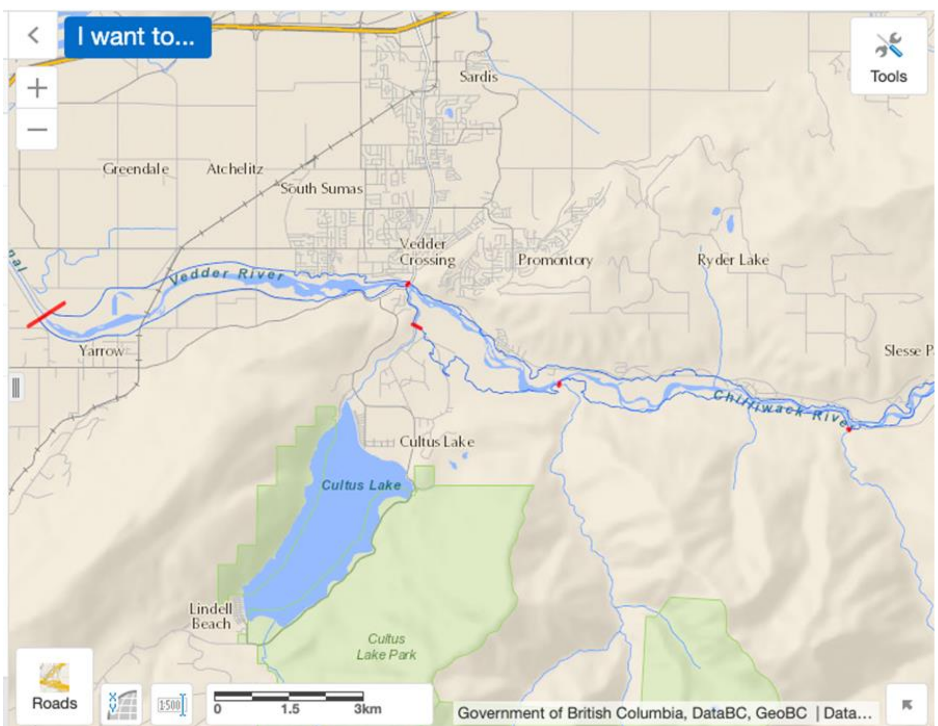

Figure 1: iMapBC (Government of British Columbia, n.d.)

The Fraser River Council have uploaded their flood maps online and free for use by the public. An example map is shown in Figure 2.

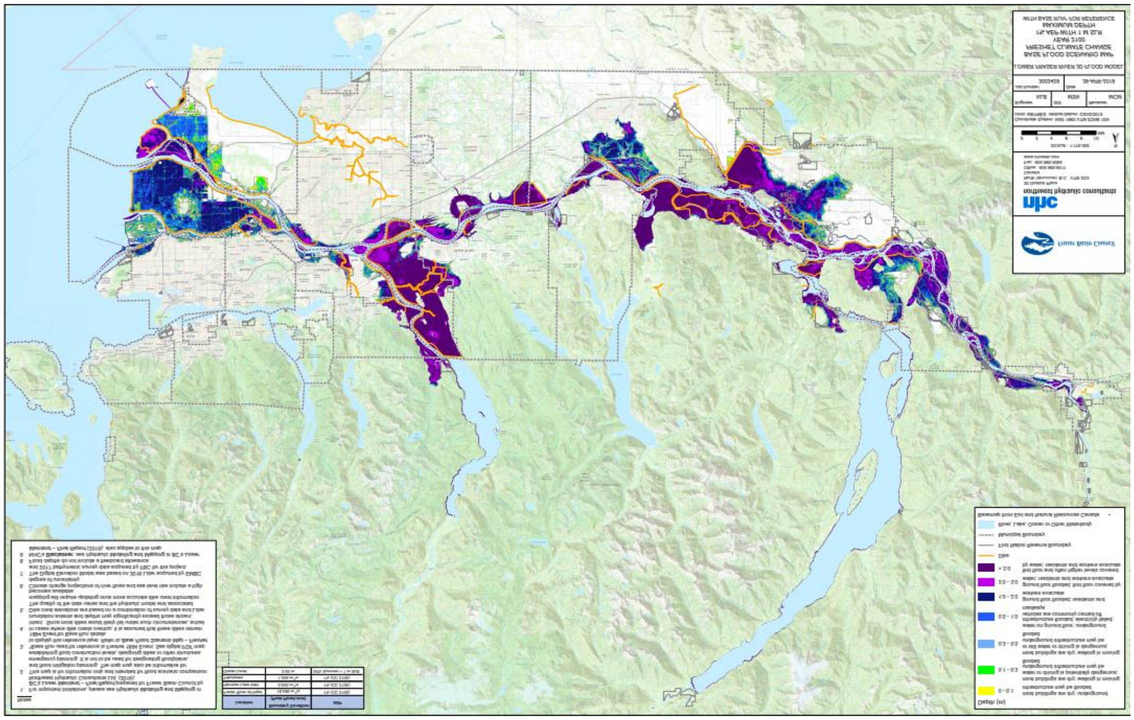

Figure 2: Fraser River Council 100 year design flood for 2100 Climate Change Scenario with 1m sea level rise (*Fraser River Council, 2019*)

2.5 Climate Change Considerations

Climate change is expected to cause significant impacts to BC of which includes a rise in sea level, an increase in storm surge events and an increase in frequency and intensity of storms. Currently BC has not incorporated any climate change scenarios into flood mapping; however, methods that can be used in guidelines for better management of mitigating the impacts of climate change for flood management are being discussed.

The Fraser River Council has included two different climate change scenarios in their collection of flood maps. The first scenario is for the year 2050 that includes a 0.5 m sea level rise added on to the flood extent of a 100 year and 500 year freshet flood event. The second scenario is for 2100 and includes a 1 m sea level rise included for the 100 year, 200 year and 500 year freshet flood events (Fraser River Council, n.d.).

3 Alberta

3.1 Historical Flooding Events

Over the past 20 years, Alberta has seen two major flood events devastate the Province. The first flood event occurred in 2005 and was caused by three intense storms that occurred within a week of each other. The flood was considered to be a 1 in 200 year occurrence and forced thousands of residents to be removed from their homes (Environment and Climate Change Canada, 2017). Total costs reached $519 million with key infrastructure damage caused to sewer networks, bridges and buildings (Institute for Catastrophic Loss Reduction, 2010).

In 2013, Calgary and neighboring communities received another major flood as a result of spring flooding. Heavy rainfall fell on a major snowpack located along the Rocky Mountains generating a large amount of runoff. Rapid and intense rainfall continued after the melting of the snowpack to provide further runoff. The flood event led to 32 communities having to declare an extensive emergency response and caused significant overland flooding (City of Calgary, n.d.). Critical infrastructure damage occurred to local drinking water facilities and totals for damage recovery from the flood event reached $6 billion (Environment and Climate Change Canada, 2017).

3.2 Flooding Challenges

The main cause of flooding across Alberta is spring flooding that results from a combination of precipitation events and melting snowpack. Snowpack melting is prominent for Alberta as a result of runoff from the Rocky Mountains feeding into river systems across the continent. This was the primary cause of the 2013 flood event that damaged the city of Calgary and neighboring communities (City of Calgary, n.d.). Other causes of flooding across Alberta are related to ice jams and intense summer precipitation events.

3.3 Provincial Mapping

Flood mapping in Alberta began in the 1970's as a result of a greater national approach for flood assessments. In 1989, a 10 year program known as the Canada-Alberta Flood Damage Reduction Program was established for the purpose of standardizing flood maps and allowing for a cost sharing system to be utilized (Government of Alberta, 2020). Before the conclusion of the program in 1999, Alberta had completed mapping for the selected communities that were chosen at the beginning of the project (Government of Alberta, 2020). Alberta has continued to produce flood maps to continue to improve their efforts in flood management since the conclusion of the program.

Current flood mapping standards for Alberta involves the use of a 100 year return period design storm and a two zone flood hazard area (Government of Alberta, n.d.), which includes a floodway and a flood fringe. The floodway is defined as the portion of the flood hazard area where water flows are deepest, fastest and most destructive. This area must meet one of the following conditions to be considered the floodway: encroachment conditions where there is a maximum in the rise of water of 0.3 m due to river flow, where there is a flood depth of 1 m, or where there is a velocity of 1 m/s (Alberta Environment Water Management Operations River Forecast Section, 2011).

Development in the floodway is discouraged. The flood fringe is defined as the hazard area of the 200 year design flood outside of the floodway where water levels are shallower with lower flow levels. Velocities in the flood fringe are less than 1m/s, while the flood depth is less than 1m (Alberta Environment Water Management Operations River Forecast Section, 2011). Development in the flood fringe is allowed with the use of flood proofing. Further infrastructure protection policies have been practiced in the Flood Risk Management Guidelines as of 2017. These development measures restricted development of vital lifeline facilities within the 1:1000 year flood level and lifeline facilities critical to the maintenance of public order within the 1:500 year flood level (Government of Alberta, 2017).

The current state of flood mapping in Calgary includes a new project established in 2015 that involves 21 flood studies (Government of Alberta, n.d.). These flood studies are focused on creating new maps and updating historical maps to better flood management. A total of 1,500 km of land will be assessed with a total of 60 municipalities and 5 First Nation communities (Government of Alberta, n.d.). Currently, 8 studies are expected to be completed by the end of spring 2020. Hydrology assessments will include several design storm conditions to allow for increased knowledge in efforts to battle flooding. The design storm conditions are expected to include return periods of 2, 5, 10, 20, 35, 50, 75, 100, 200, 350, 500, 750 and 1000-year floods.

3.4 Maps Availability

The Alberta Government is currently in use of an interactive mapping application to make flood hazard maps publicly available and free of cost. The application involves presenting areas that are considered to be part of the floodway or the flood fringe for the 100 year return period design flood. An example of the Flood Hazard Map Application can be seen in figure 3. The most recent update for the application was made on June 22nd, 2015 and includes all mapping that was completed before that date. Cross sections, produced from the use of the hydraulic modelling in HEC-RAS (Alberta Environment Water Management Operations River Forecast Section, 2011), present flood elevations at various points in mapped communities to allow the public to have an increased understanding regarding the flood mapping details. As a result of incomplete mapping from the Canada-Alberta Flood Damage Reduction Program, the application does not have complete flood mapping for the Province. With future projects involving flood assessments, the aim is to continue to update and map new areas for the application.

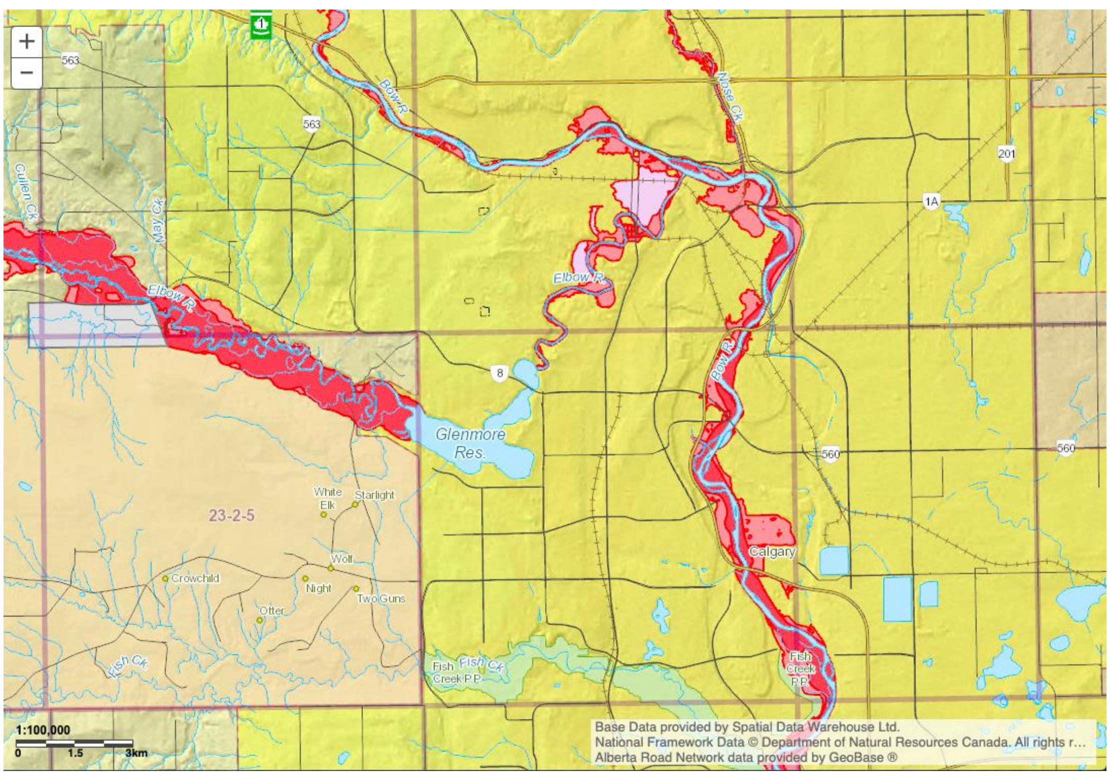

Figure 3: Flood Hazard Map Application Alberta *(Government of Alberta, 2019)*

3.5 Climate Change Considerations

Alberta has currently adopted no policies within their guidelines to incorporate future changes in flooding due to climate change. However, future assessments will involve strategies that can be implemented to address factors of climate change.

4 Saskatchewan

4.1 Historical Flooding Events

Saskatchewan has seen major flood events that date back to the 20th century. One of the most severe flood events the Province has seen occurred in 1974 as a result of the Qu'Appelle River Flood. The flood resulted from record snowfall during the winter leaving large amounts of snow cover. Once the spring temperatures arrived, Saskatchewan saw mass snowfall melting that resulted in the Qu'Appelle River, Moose Jaw River, and Thunder Creek seeing severe overflowing (Government of Canada, 2013). Farmlands, infrastructure and roads across Moose Jaw saw extensive flood damages and resulted in 1,400 people being evacuated from their homes (Government of Canada, 2013).

Recent flooding across Saskatchewan has caused a push for the need of current and updated flood maps for Saskatchewan. The 2011 spring flood event was one of these events that pushed urgency and the need for updated maps. The flood resulted from intense rainfall that lasted for 5 days combining with spring snowmelt coming from the Rocky Mountains (Water Security Agency Saskatchewan, 2013). Flooding levels varied across the Province and flow return periods ranged from a minimum of a 5 year return period to a 50 year return period in Saskatoon, while flows in the Regina region reached up to a 500 year return period (Water Security Agency Saskatchewan, 2013).

4.2 Flooding Challenges

Saskatchewan faces three main causes of flooding that include spring flooding, intense summer precipitation events, and ice jams. Spring flooding has been caused across Saskatchewan in years when large amounts of snowfall are received during the winter. When the winter temperatures extend into the spring, the soil conditions in the ground remain frozen and allow for less storage capacity. These conditions create a high degree of vulnerability for Saskatchewan in the event of an intense precipitation event. Due to limited storage capacity in the soil, water loss through infiltration is reduced and the majority of the runoff occurs as overland flow causing large flood events.

4.3 Current Standards

Saskatchewan has adopted the highest standards for design flood regulations. Guidelines for flood mapping implementation involve a two zone flood hazard area and the use of 1:500 year flood elevation (Government of Saskatchewan, 2012). The two zone flood hazard area includes the floodway, which prohibits new development, and the flood fringe, which allows for new development in situations where flood proofing is completed to an elevation of 0.5 m above the 1:500 year flood elevation (Government of Saskatchewan, 2012). Saskatchewan has continued using the Flood Damage Reduction Program (FDRP) standards when defining the floodway and flood fringe. These standards define the floodway as the area of land inundated with flood velocities equal or exceeding 1 m/s or water depths equal or exceeding 1 m (Government of Saskatchewan, 2012).

As a result of being affected by major flood events in the past decade, Saskatchewan is in process of implementing a new flood mapping project through the National Disaster Mitigation Program. The project will be completed through Saskatchewan's Water Security Agency and will focus on flood mapping for 20 "high risk" communities that have been identified (Government of Saskatchewan, 2019). Cities included in the project are Melfort, Moose Jaw, Regina, Saskatoon, Weyburn, and Yorkton, with additional towns and villages receiving flood maps as well. The project is expected to be completed by 2030, and will allow for 100 per cent of communities at risk of flood damages in Saskatchewan to receive updated and accurate flood maps (Government of Saskatchewan, 2019).

4.4 Maps Availability

Saskatchewan in the past utilized Geo Sask, an interactive online application, to make flood maps available for the public (ISC, n.d.). However, the application has been shut down since 2016 and historical flood maps produced are currently unavailable to the general public. No services or applications have been mentioned by the Saskatchewan Water Security Agency for the purpose of displaying results from future flood mapping projects.

4.5 Climate Change Considerations

Presently, Saskatchewan has not practiced any climate change strategies within floodplain mapping. The 25 Year Saskatchewan Water Security Plan document, published in 2012 (Water Security Agency Saskatchewan, 2012), notes the important impacts that Saskatchewan will face due to climatic changes. Extreme events, such as droughts and floods, will be expected to occur more frequently in the long term future.

5 Manitoba

5.1 Historical Flooding Events

Manitoba has faced severe flooding along the Red River Floodway since the 1800's (Government of Manitoba, n.d.). One of the more significant flood events that has taken place in the Province's history occurred in 1950 from April until June. The combination of heavy snowmelt during the same time period that heavy rainfall events were occurring caused the flood levels to stay above the flood stage for 51 days (Government of Manitoba, n.d.). The flooding resulted in damages of $4.65 billion trended to 2008 (Institute for Catastrophic Loss Reduction, 2010), while forcing 100,000 residence to be evacuated (Government of Manitoba, n.d.). This event was one that triggered the most comprehensive flood protection system development in Canada (one widely known component is the Red River Floodway).

Damaging flood events have continued across Manitoba with major recent flooding events taking place in 2009 and 2011. The flood event that occurred in Saskatchewan in the spring of 2011 also caused high amounts of damage in the Red River basin. Flows across the Red River peaked in Winnipeg on April 7th due to an ice jam causing increased water levels. The flows of the flood event reached 3rd highest in the Province's previous 150 years or recording flooding events (Government of Manitoba, n.d.). A total of 7,100 people were displaced from homes (Government of Manitoba, n.d.), while the flood event caused severe damage to farmlands and infrastructure.

5.2 Flooding Challenges

The majority of flood events that occur in Manitoba are a result of spring freshet conditions. These conditions are caused originally by long winters that have produced large amounts of snowfall and caused freezing within the ground. When spring temperatures begin to warm, the snowpack starts to melt and in the events of intense spring storms, severe flooding can occur across Manitoba. Manitoba has additionally seen flood events where ice jams have created compounding effects on current flow levels to raise the severity of the flood. One of the unique challenges for the Red River basin in Manitoba is the northern direction of river flow. When temperatures in the southern part of the basin begin to rise and start the spring melt that increases flow through the river channel, the northern part is still under ice. This causes the river to overflow its banks and cause serious flooding.

5.3 Current Standards

Since the Flood Damage Reduction Program mapping program in the 1970’s, Manitoba has not produced any updated or new flood maps (National Research Council Canada, 2017). The historical maps have implemented a design flood with a return period of 100 years and incorporated a two zone flood hazard area (Babaei and National Research Council Canada, 2017). The flood hazard area is composed of the floodway, which occurs where there is a flood depth of greater than 1 m (Babaei and National Research Council Canada, 2017), and the flood fringe, which is the remaining flooded area from the 100 year design flood. Manitoba has used Designated Flood Areas, which are located along the Red River Valley South of Winnipeg and Lower Red River North of Winnipeg to ensure safe development of infrastructure. Flood protection levels must be applied for developing infrastructure in these areas.

Manitoba has been making changes regarding the guidelines for flood mapping, as they have recently increased the design flood to a 200 year return period event (Babaei and National Research Council Canada, 2017). This has been due to recent flooding events that have been greater than the 100 year return period flood that was originally used for historical mapping. The design flood is also expected to prepare the Province for precipitation changes related to climate change for the future. At the moment, Manitoba has not applied the new standards for any currently used maps. As a result of recent funding from the Natural Disaster Mitigation Program, Manitoba has announced a new project that would involve applying the new 200 year return period for the watersheds including the Lower Assiniboine River, Souris River, and Whitemud River (Babaei and National Research Council Canada, 2017). The flood maps will also incorporate new technology methods through use of LiDAR elevation data and modern hydrotechnical tools to increase the accuracy for flood mapping in Manitoba.

As a result of heavy and frequent flooding along the Red River, Canada and Manitoba invested $628 million in a floodway expansion project in 2005 (Manitoba Infrastructure, n.d.). The project increased the capacity of the floodway from a 160 year to a 700 year return period design flood by increasing the flow capacity from 1700 cubic metres per second to 3963 cubic metres per second (Manitoba Infrastructure, n.d.). Figure 4a represents the impact of the 700 year flood event prior to changes in the floodway, while figure 4b represents the impact following the expansion.

5.4 Maps Availability

Manitoba infrastructure currently is in possession of the historical maps produced through the Flood Damage Reduction Program. However, due to fears of misinterpretation and misuse, they have not been made available to the public online. There has been no confirmation to where future flood mapping projects will be made available or if they will be made available for the public.

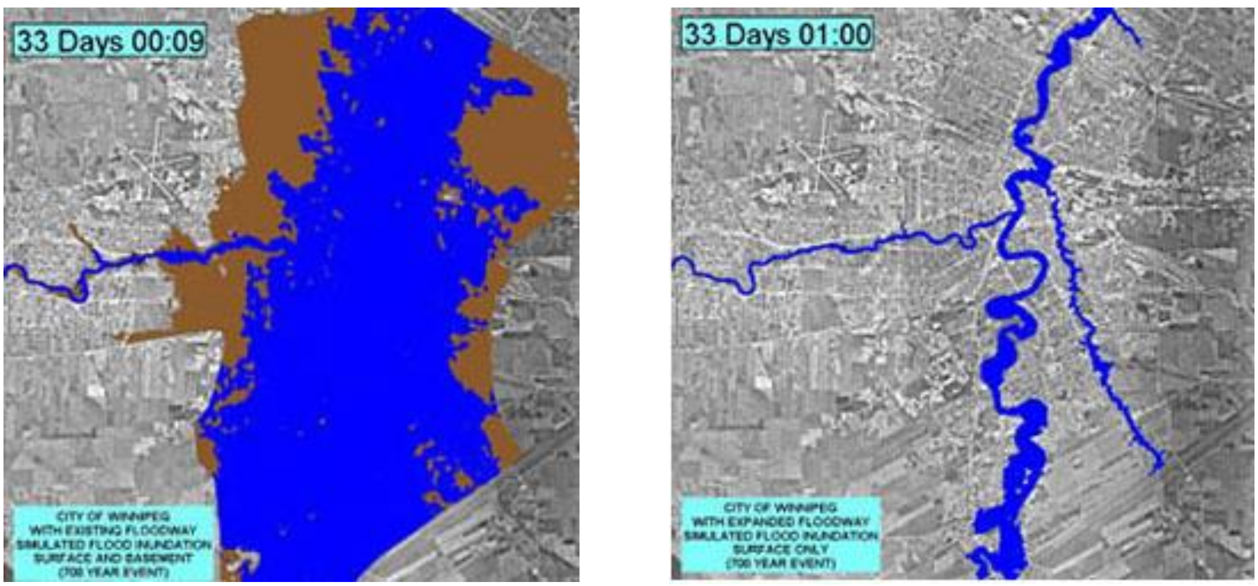

Figure 4a and 4b: Illustrates the impact of a 700 year flood event before (4a) and after (4b) the expansion of the Red River Floodway in Winnipeg *(Manitoba Infrastructure, n.d.)*

5.5 Climate Change Considerations

As a result of current estimated impacts related to climate change not being accurate nor having a high degree of confidence, no climate change considerations have been proposed for flood mapping across Manitoba. Manitoba is currently evaluating methods that can be appropriately implemented in flood mapping to allow for future climatic conditions. Methods include expansion in the number of meteorological stations, continual development of IDF curves and the new use of a 200 year return period storm (Babaei and National Research Council Canada, 2017).

6 Ontario

6.1 Historical Flooding Events

Hurricane Hazel was one of the costliest flood events in Ontario's history and due to the large amount of precipitation the storm brought, Ontario is still using the event in flood mapping where applicable. The hurricane, which occurred in October of 1954, brought in large amounts of intense rainfall during the span of two days that led to a high area of land across Ontario being flooded (Government of Canada, 2010). The event worsened due to prior rainfall before the event causing high amounts of moisture to be available in the soil, which led to increased runoff. The impacts of the event included over 1800 people homeless, 81 deaths and an estimated $100 million worth of damage (Government of Canada, 2010).

Ontario has seen frequent flood events over recent years, which include the 2019 flood events across Ontario. Due to compounding impacts from heavy rain combining with snow melt during the spring season, high amounts of runoff were produced. Over the past few years, Lake Ontario had also been receiving high levels of water that prevented further storage to increase the vulnerability for a damaging flood event. As a result, Ontario insurance damages reached $74 million and flooding of 2,000 homes (Insurance Bureau of Canada, 2019).

6.2 Flooding Challenges

Flooding challenges across Ontario primarily occur during the spring snowmelt season and can be made more extensive when intense precipitation events simultaneously occur. With the intensity from precipitation events expected to increase as a result of climate change, this challenge will only worsen in the future. Other challenges are due to ice jams that have caused increased flows in fluvial channels and the flooding of shorelines along the Great Lakes.

6.3 Current Standards

Ontario has developed a unique situation with regard to the authority responsible for flood management. Rather than one authority in charge of Ontario, the Province is divided into 36 Conservation Authorities, where each conservation authority is established on a watershed basis and works with their specific municipalities and governments to aid and assist flood management responsibilities. The conservation authorities have been responsible for producing approximately 22,000 km of mapping for flood prone areas that includes 90% of rivers and creeks across the Province (Conservation Ontario, n.d.). However, due to conservation authorities having the responsibility for their own watershed, components of flood mapping have been highly variable across Ontario with respect to mapping availability for the public, zone concept employed, and the number of maps produced.

Flood standards for river systems have been developed within the River and Stream Systems: Flooding Hazard Limit Guideline published by the Ontario Ministry of Natural Resources. The flooding hazard limit is considered to be the greater of:

I. *The flood resulting from a rainfall actually experienced during a major storm such as the Hurricane Hazel storm (1954) or the Timmins storm (1961), transposed over a specific watershed and combined with the local conditions, where evidence suggests that the storm event could have potentially occurred over watersheds in the general area*

II. *The 100 year flood; or*

III. *A flood which is greater than i) or ii) which was actually experienced on a particular watershed or portion thereof, for example as a result of ice jams and which has been approved as the standard for that specific area by the Minister of Natural resources* (Ontario Ministry of Natural Resources, 2002)

The guidelines allow for a one zone concept or a two zone concept to be employed within flood mapping. The one zone concept uses the floodway as the entirety of the floodplain and both prohibits and restricts any new development within the floodplain (Ontario Ministry of Natural Resources, 2002). The two zone concept allows for a floodway and flood fringe to exist within the floodplain. The floodway is defined as the inner portion of the floodplain, which represents the area of the flood that is most at risk to damage due to high depths and/or velocities. The extent of the floodway includes areas where flood depth is in excess of 1 m and/or flow velocities are above 1 m/s (Ontario Ministry of Natural Resources, 2002). New development within the floodway is prohibited and restricted. The flood fringe is defined as the outer portions of the flooding hazard limit and allow for conditional development should the development be protected to the flooding standards (Ontario Ministry of Natural Resources, 2002). Table 1 below summarizes the flood standards employed within each conservative authority.

Table 1: Summary of Conservation Authorities Standards

Conservation Authority (CA)	Flood Standard	URL
Mattagami Region CA	Maximum of 100 year flood event or Timmins Flood event standard	https://www.ontario.ca/laws/regulation/060165
North Bay – Mattawa CA	100 year flood event for Chippewa Creek and its tributaries below the North Bay Escarpment, Parks Creek, the Mattawa River in the town of Mattawa and the La Vase River Timmins Flood event standard used for rest of CA	https://www.ontario.ca/laws/regulation/060177/v1
Nickel District CA	Maximum of 100 year flood event or Timmins Flood event standard Wanapitei Lake uses maximum flood allowance elevation of 267.95m	https://www.ontario.ca/laws/regulation/060156
Essex Region CA	March 1985 Flood event used for main and east branch of the Ruscom River, and its tributaries within the Town of Lakeshore and Kingsville March 1985 Flood event used for main and north branch of Canard River in the Town of LaSalle, Concessions I and II, and on main branch of the Canard River in the Town of Amherstburg, Concessions I, II, III, and IV 100 Year Flood Standard used for rest of CA	https://www.ontario.ca/laws/regulation/060158
Lower Thames Valley CA	1937 Flood event standard on the River Thames – equivalent to 250 year flood or 100 Year Flood level plus wave uprush	https://www.ontario.ca/laws/regulation/060152
St. Clair Region CA	100 year flood event for Perch Creek 100 year flood plus wave uprush for Lake Huron, Lake St. Clair and St. Clair River in the Great Lakes-St. Lawrence River System Hurricane Hazel Flood event standard used for rest of CA (approx. 250 year return period)	https://www.ontario.ca/laws/regulation/060171
Ausable Bayfield CA	Maximum of Hurricane Hazel Flood event standard (approx. 250 year return period), 100 year flood event, and 100 year flood level plus wave uprush	https://www.ontario.ca/laws/regulation/060147

Conservation Authority (CA)	Flood Standard	URL
Upper Thames River CA	1937 flood event standard on the River Thames – equivalent to 250 year flood	https://www.ontario.ca/laws/regulation/060157
Kettle Creek CA	Maximum of Hurricane Hazel Flood event standard (approx. 250 year return period), 100 year flood event, and 100 year flood level plus wave uprush for Lake Erie	https://www.ontario.ca/laws/regulation/060181
Catfish Creek CA	Maximum of Hurricane Hazel Flood event standard (approx. 250 year return period), 100 year flood event, and 100 year flood level plus wave uprush for Lake Erie	https://www.ontario.ca/laws/regulation/060146
Long Point Region CA	Maximum of 100 year flood event, or 100 year flood level plus wave uprush for Lake Erie	https://www.ontario.ca/laws/regulation/060178
Maitland Valley CA	Maximum of Hurricane Hazel Flood event standard (approx. 250 year return period), 100 year flood event, and 100 year flood level plus wave uprush for Lake Huron	https://www.ontario.ca/laws/regulation/r06164
Grand River CA	Maximum of Hurricane Hazel Flood event standard (approx. 250 year return period), 100 year flood event, and 100 year flood level plus wave uprush for Lake Erie	https://www.ontario.ca/laws/regulation/060150
Niagara Peninsula CA	Hurricane Hazel Flood event standard (approx. 250 year return period) applies to the watersheds associated with Shriner's Creek, Ten Mile Creek, and Beaverdams Creek 100 year flood event standard plus wave uprush applies to Lake Ontario and Lake Erie 100 year flood event standard applies to rest of CA	https://www.ontario.ca/laws/regulation/060155
Hamilton Region CA	100 year flood event standard plus wave uprush applies to Lake Ontario 100 year flood level applies to Hamilton Harbour 100 year flood level applies to Watercourses WCO, WCI, WC2, 3, 4, 5.0, 5.1, 6.0, 6.1, 6.2, 6.3, 6.4, 7.0, 7.1, 7.2, 7.3, 8.0, 9.0, 10.0, 10.1, 10.2, 11.0 and 12.0 as indicated on Map Figure 1 of Project 98040-A Hurricane Hazel Flood event standard applies to rest of CA (approx. 250 year return period)	https://www.ontario.ca/laws/regulation/060161
Halton Region CA	Maximum of Hurricane Hazel Flood event standard (approx. 250 year return period), 100 year flood event, and 100 year flood level plus wave uprush for Lake Ontario and Hamilton Harbour	https://www.ontario.ca/laws/regulation/060162
Credit Valley CA	Maximum of Hurricane Hazel Flood event standard (approx. 250 year return period), 100 year flood event,	https://www.ontario.ca/laws/regulation/060160

Conservation Authority (CA)	Flood Standard	URL
	and 100 year flood level plus wave uprush for Lake Ontario	
Saugeen Valley CA	Maximum of Hurricane Hazel Flood event standard (approx. 250 year return period), 100 year flood event, and 100 year flood level plus wave uprush for Lake Huron	https://www.ontario.ca/laws/regulation/060169
Grey Sauble CA	100 year flood event standard plus wave uprush applies to Lake Huron and Georgian Bay 100 year flood event applies to Sauble River Watershed Timmins Flood event standard applies to rest of CA	https://www.ontario.ca/laws/regulation/060151
Nottawasaga Valley CA	Maximum of Timmins Flood event standard, 100 year flood event, and 100 year flood level plus wave uprush for Lake Ontario and Lake Erie	https://www.ontario.ca/laws/regulation/060172/v1
Toronto and Region CA	Maximum of Hurricane Hazel Flood event standard (approx. 250 year return period), 100 year flood event, and 100 year flood level plus wave uprush for Lake Ontario	https://www.ontario.ca/laws/regulation/r06166
Lake Simcoe Region CA	100 year flood event standard applies to Bunker's Creek and Sophia Creek Timmins Flood event standard applies to Talbot River and the Trent-Severn waterway 100 year flood level plus wave uprush applied to Lake Simcoe Hurricane Hazel Flood event standard applies to rest of CA (approx. 250 year return period)	https://www.ontario.ca/laws/regulation/060179
Kawartha Region CA	Maximum of Timmins Flood event standard and 100 year flood event	https://www.ontario.ca/laws/regulation/060182
Central Lake Ontario CA	100 year flood event standard applies to Pringle Creek and Darlington Creek 100 year flood level plus wave uprush applies to Lake Ontario Hurricane Hazel Flood event standard applies to rest of CA (approx. 250 year return period)	https://www.ontario.ca/laws/regulation/060042
Otonabee Conservation	Water surface elevations govern for the following lakes: Rice Lake – 187.90m Stony Lake – 235.95m Clear Lake – 235.96m Lovesick Lake – 242.16m Deer Bay – 244.31m	https://www.ontario.ca/laws/regulation/060167

Conservation Authority (CA)	Flood Standard	URL
	Buckhorn Lake – 247.12m Chemong Lake – 247.12m Pigeon Lake – 247.12m Katchiwanooka Lake – 233.68m Lower Buckhorn Lake – 244.31m Timmins Flood event standard applies to rest of CA	
Ganaraska Region CA	Maximum of Hurricane Hazel Flood event standard (approx. 250 year return period), 100 year flood event, and 100 year flood level plus wave uprush for Lake Ontario	https://www.ontario.ca/laws/regulation/R06168
Crowe Valley CA	Maximum of Hurricane Hazel Flood event standard (approx. 250 year return period), 100 year flood event, and Timmins Flood event standard	https://www.ontario.ca/laws/regulation/060159
Lower Trent Region CA	Water surface elevations govern for the following lakes and dams: Rice Lake – 187.9m Below Dam #1 (Trenton) – 77.2m Below Dam #2 (Sidney) – 81.3m Below Dam #3 (Glen Miller) – 87.7m Below Dam #4 (Batawa) – 95.7m Below Dam #5 (Trent) – 101.7m Below Dam #6 (Frankford) – 107.9m Below Dam #7 (Glen Ross) – 113.5m Below Dam #8 (Meyers) – 117.9m Below Dam #9 (Hagues Reach) – 128.1m Below Dam #10 (Ranney Falls) – 143.4m Below Dam #11 (Campbellford) – 148.3m Below Dam #12 (Crowe Bay) – 154.3m Below Dam #13 (Healy Falls) – 175.5m Below Dam #14 (Hastings) – 186.7m 100 year flood level plus wave uprush applies to Lake Ontario Timmins Flood event standard applies to rest of CA	https://www.ontario.ca/laws/regulation/060163
Quinte CA	100 year flood event standard and 100 year flood level plus wave uprush for Lake Ontario	https://www.ontario.ca/laws/regulation/090319/v1
Cataraqui Region CA	100 year flood event standard and 100 year flood level plus wave uprush for Lake Ontario and the St. Lawrence River	https://www.ontario.ca/laws/regulation/060148
Mississippi Valley CA	100 year flood event standard	https://www.ontario.ca/laws/regulation/060153

Conservation Authority (CA)	Flood Standard	URL
Rideau Valley CA	100 year flood event standard	https://www.ontario.ca/laws/regulation/r06174
South Nation River CA	100 year flood event standard and 100 year flood level plus wave uprush for the St. Lawrence River	https://www.ontario.ca/laws/regulation/r06170
Raisin Region CA	100 year flood event standard and 100 year flood level plus wave uprush allowance	https://www.ontario.ca/laws/regulation/060175
Sault Ste Marie Region CA	Maximum of Timmins Flood event standard, 100 year flood event standard and 100 year flood level plus wave uprush for Lake Superior and the Upper and Lower St. Mary's River	https://www.ontario.ca/laws/regulation/060176
Lakehead Region CA	100 year flood event standard applies to the main channel of the Kaministiquia River 100 year flood level plus wave uprush applies to Lake Superior Timmins Flood event standard applies to rest of CA	https://www.ontario.ca/laws/regulation/r06180

6.4 Maps Availability

As a result of conservation authorities being responsible for decisions made within flood mapping, mapping availability is highly variable within the Province. Flood mapping availability has ranged from the use of interactive web services or flood map drawings. The Toronto Regional Conservation Authority and Upper Thames River Conservation Authority have employed an interactive web tool that allows the public to identify the flood regulated areas within the watershed, while other authorities, such as the Cataraqui Region Conservation Authority, have published flood map drawings presenting the extent of the general regulated area. An example of one of the Toronto and Region Conservation Authority flood maps can be seen in figure 5.

6.5 Climate Change Considerations

Climate change impacts have not been required by guidelines for the purpose of implementation within flood mapping and flood management for Ontario.

Figure 5: TRCA Interactive Flood Map *(https://trca.ca/conservation/flood-risk-management/flood-plain-map-viewer/)*

7 Quebec

7.1 Historical Flooding Events

Quebec has commonly experienced flooding events during the spring snowmelt season. The 1974 flood event was one such event that resulted from high intensity storms resulting during the same time period that temperatures were increasing and causing snowmelt runoff (Government of Canada, 2010). As a result, the sewer systems were unable to account for the additional runoff and drastic flooding occurred. Impacts due to the flood included the damage of 5000 homes and forcing 7000 people to be evacuated (Government of Canada, 2010). Damage costs reached a total of $60 million (Government of Canada, 2010), which is equivalent to $332 million in present day value.

Recent flooding events that have taken place in 2017 and 2019 have caused Quebec to increase their efforts in managing flooding events. The severity of the two events has caused Quebec to review floodplain policies in efforts of further mitigation of flood events for the future. The 2019 flood event resulted from high amounts of precipitation occurring across Ontario and Quebec during the spring snowmelt season. Due to the Great Lakes and the St Lawrence River acting as a chain of lakes and outlet channels (Fisheries and Oceans Canada, 2019), the impact of the flood levels were made greater as a result of increased flows travelling along the St Lawrence River into Quebec leading to high flows that floodways across Quebec were not able to accommodate for. The flood left 9,800 homes flooded and $127 million worth of damage (Insurance Bureau of Canada, 2019).

7.2 Flooding Challenges

Quebec faces three main flooding challenges that include spring snowmelt, ice jams, and high intensity precipitation events. Two of the most recent flooding events that have occurred in the Province have resulted from high intensity precipitation events occurring during the same time period that spring snowmelt was occurring. The compounding effects led to a greater degree of flooding and caused increased amounts of damage for the two events.

7.3 Current Standards

Guidelines for flood mapping for Quebec were published in 2005 through The Protection Policy for Lakeshores, Riverbanks, Littoral Zones and Floodplains Environment Quality Act. Article 2.1 states that the flood map is composed of two zones: the high velocity zone and the low velocity zone. The high velocity zone is defined as the area of the flood map that floods as a result of a 20 year flood event (Gouvernement du Québec, 2005). Any development within the zone is prohibited. The low velocity zone is the area of the flood map that floods as a result of a 100 year return period. Development of structures in the low velocity zone are prohibited unless flood proofing methods are employed to prevent the risk of damage (Gouvernement du Québec, 2005). Flood proofing measures include no ground floor lower than the level of the 100 year flood elevation, no opening lower than the 100 year flood elevation and drains that have a non-return backup valve. In the event where a part of the structure is built below the 100 year flood elevation level, a study must be completed to prove the resistance to flooding (Gouvernement du Québec, 2005).

Due to spring flooding in 2017 and 2019, Quebec has initiated a draft in preparation of a new act involving the management of floodplains. The purpose of the draft was due to inconsistencies in implementation of previous guidelines that have been used by the Province. The final version of the draft was published on the 15th of July, 2019 and places a freeze on any construction or repairs to infrastructure that is located within the "Zone d'intervention spéciale" (Special Intervention Area). The "Zone d'intervention spéciale" area is composed of the maximum flood level from either the 20 year flood elevation level or the flood levels from the 2017 and 2019 flooding events (Gouvernement du Québec, 2019). Along with the draft, an online web application was produced through the government to identify and distinguish the 20 year flood elevation level.

7.4 Maps Availability

As of July 2019, Quebec has utilized an online web application to promote better management of development in flood prone areas. The web application presents the Special Intervention Area using GIS ESRI base maps. A total of 776 municipalities have been mapped across Quebec including communities that were impacted by the recent spring flooding events. The map is known as the “Zone d’intervention spéciale” and it presents the area of land flooded by the 2017 and 2019 flooding events. (Gouvernement du Québec, 2019). An example map section from the “Zone d’intervention spéciale” can be seen in figure 6.

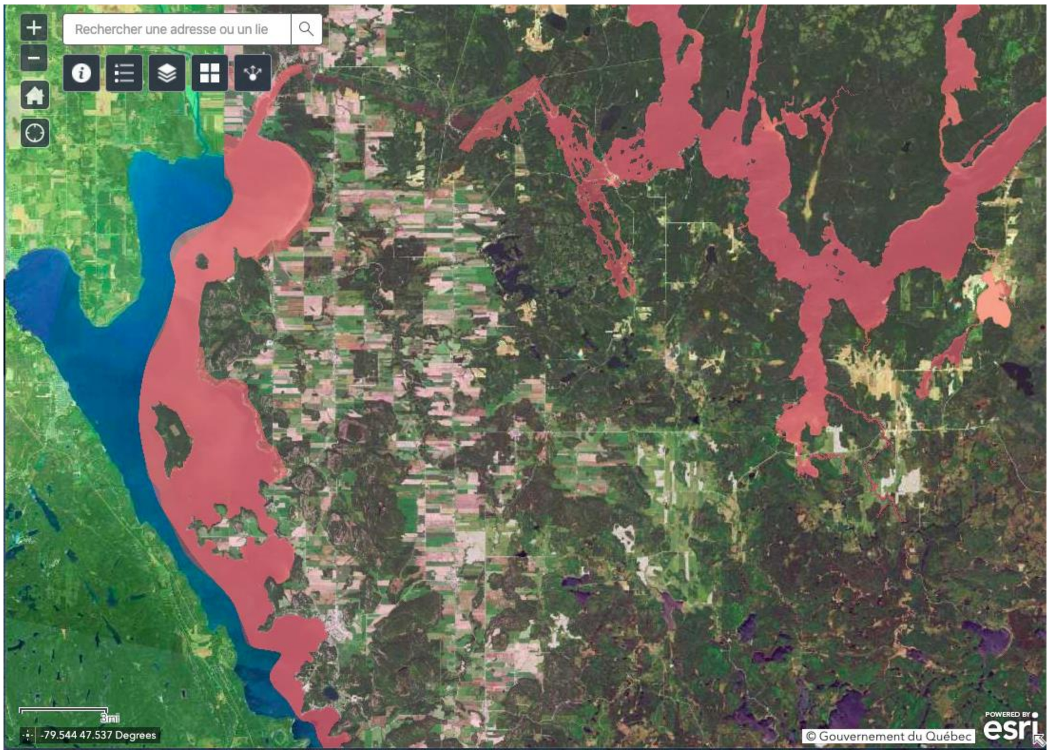

Figure 6: “Zone d’intervention spéciale” *(Gouvernement du Québec, 2019)*

7.5 Climate Change Considerations

The updated flood maps, produced in July 2019, have not considered climate change.

8 New Brunswick

8.1 Historical Flooding Events

New Brunswick has experienced flooding over the past 15 years with isolated events in Fredericton and Saint John. The flood event that took place in Fredericton in 2008 resulted from compounding impacts through spring snowmelt and intense precipitation storms. Record snowfall occurred during the winter season that provided an additional source of runoff that went on to melt during the high intensity storm events in the spring (Government of New Brunswick, n.d.). As a result, the Saint John River received high flows and severe flooding that resulted in 1000 people being evacuated and 2000 locals impacted by the flooding (Government of New Brunswick, n.d.). The final impacts of the flood event included damages that exceeded $23 million and a total of 631 properties damaged as a direct cause of the flooding (Government of New Brunswick, n.d.).

The recent flooding event that occurred in 2018 in the Lower Saint John River has pushed the government to initiate additional and updated flood protection studies. The flooding resulted from record low temperatures in April which led to additional snowfall across the Province. Once temperatures had begun to increase at the end of April, precipitation events combined with the rapid snowmelt to produce high levels of flow across the Lower Saint John River. The flooding led to the river being above the flood stage for 14 days (Boisvert and Government of New Brunswick, 2020).

8.2 Flooding Challenges

New Brunswick faces a range of challenges related to both coastal and inland flooding. The challenges include spring snowmelt, intense precipitation events, ice jams, storm surge, and sea level rise. Historical spring flooding events have resulted from a combination of intense precipitation events occurring during the spring snowmelt season to produce high levels of flows through river channels. Coastal flooding impacts have resulted from both current storm surge events produced along the Atlantic Coast and future impacts of sea level rise along the coast.

8.3 Current Standards

Flood Management in New Brunswick dates back to the Flood Damage Reduction Program that lasted in the Province from 1976 until 2000. Over the past 10 years, New Brunswick has switched their focus to producing coastal flood hazard maps as a result of future concerns regarding sea level rise. This has left the production of new fluvial flood maps to be ignored over the past 17 years, leaving the Province with historical flood maps that are now outdated and need to be updated with the use of new technology.

Fluvial flood mapping guidelines for New Brunswick involves a two zone flood hazard area composed of the floodway and flood risk area. The floodway is defined as the area inundated via a 20 year return period and permits any development of infrastructure (Government of New Brunswick, n.d.). The flood risk area is defined as the area of land inundated via a 100 year return period (Government of New Brunswick, n.d.). Development is allowed within the flood risk area as long as the infrastructure does not reduce the flood water storage capacity of the area. The flood frequencies employed for the two zones does not consider the impact of ice jam flooding as the complexities of ice jams are extensive and do not allow for accurate representation in flood mapping (Government of New Brunswick, n.d.).

The New Brunswick government has begun the process for a new Inland Flood Hazard Mapping Project, which is expected to be finalized by the late 2020's. The program was initiated through an agreement with Public Safety Canada and initial priorities for the project involve updating historical maps from the Flood Damage Reduction Program, before expanding to new areas (Boisvert, 2020; Government of New Brunswick, 2020).

8.4 Maps Availability

The New Brunswick government has been in use of an online application to distribute important geographical information to local communities. Within the database, a flood information viewer is included and accommodated with a topographic base map. The flood maps highlight areas that are projected to be impacted by the design floods for a 20 year and 100 year return period as well as the inclusion of two historic flood events from the years of 1973 (Fredericton) and 2008. Historical flood map drawings are also available on the New Brunswick Government website through the use of a separate web application known as the Flood Map Index (http://elg-egl.maps.arcgis.com/apps/PanelsLegend/index.html?appid=30b97c1830b84fbd8e581a6d05243bb9). An example for the historical flood map drawing of the Lower Marsh Creek can be seen in figure 7. The application allows the user to select a designated zone on the map to open the flood map drawing.

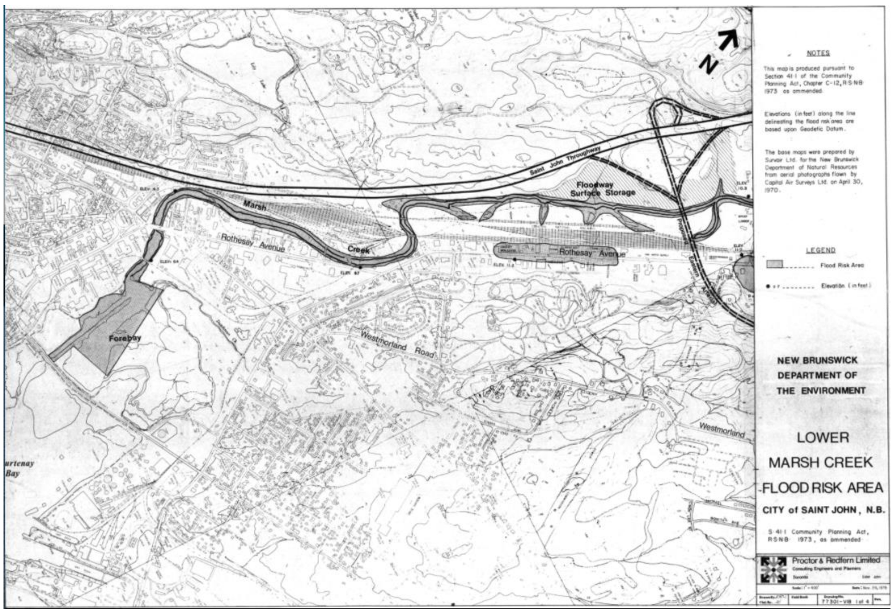

Figure 7: Lower Marsh Creek Flood Risk Area (*Government of New Brunswick, 1979)*

8.5 Climate Change Considerations

Currently no climate change considerations have been considered in flood mapping across New Brunswick. With climate change expecting to cause a rise in sea level along the Atlantic coast, future coastal flooding projects should utilize future projections of sea level rise to produce new and updated coastal flooding maps.

9 Nova Scotia

9.1 Historical Flooding Events

Nova Scotia has experienced frequent flooding events through intense precipitation events, which have included tropical storms and hurricanes. Hurricane Juan in 2003 arrived in Nova Scotia as a category 2 hurricane on September 29th (Environment and Climate Change Canada, 2015). The hurricane was sustained with winds gusts over 185 km/h producing significant waves that were recorded up to 9 m (Environment and Climate Change Canada, 2015). The hurricane resulted in $200 million worth of damage and caused a total of 8 deaths (Environment and Climate Change Canada, 2015). Hurricane Dorian, in 2018, was the most recent flood event caused by a hurricane to go through the Province. Although Dorian reached Nova Scotia on September 8th near the end of its life cycle, the hurricane caused extensive damage to infrastructure and left hundreds of residents without electricity (Environment and Climate Change Canada, 2015). Severe overland flooding followed, causing extensive damage to both, roads and infrastructure.

9.2 Flooding Challenges

Flooding challenges in Nova Scotia range from spring snowmelt, precipitation events, ice jams, sea level rise and storm surge events. One of the unique challenges Nova Scotia faces is due to the potential for hurricanes and tropical storms to cause intense and large precipitation events. In the event of precipitation events combining during the time period that spring snowmelt occurs has caused additional fluvial flooding events across the Province.

9.3 Current Standards

Under the Flood Damage Reduction Program, Nova Scotia focused on preparation of flood maps for 5 designated areas: East River, Little Sackville River, Sackville River, Salmon and North Rivers, and West and Rights Rivers and Brierly Brook (Government of Nova Scotia, 2013). The guidelines that were employed for the 5 regions involved a two zone flood risk area composed of the floodway and flood fringe. The floodway is defined as the inner portion of the flood risk area where the risk of flooding is on average once in 20 years. Development within this area is restricted only for uses such as roads, open spaces, parking lots and temporary uses (Government of Nova

Scotia, 2013). The flood fringe is defined as the outer portion of the flood risk area where the risk of flooding is on average once in 100 years. Development, so long that flood proof measures are employed, may be permitted except for residential institutions or any use associated with the warehousing or production of hazardous materials (Government of Nova Scotia, 2013).

In consequence of the previous flood maps becoming outdated, the CBCL Limited has produced a new set of flood maps for the flood hazard area along the Sackville and Little Sackville Rivers. The flood maps follow the same guidelines previously employed and are currently in use by the City of Halifax for municipal planning regulations. The flood maps were produced in 2017 allowing appropriate updates to be utilized in reference to river channel changes, development of land and technology updates (Halifax Regional Municipality, 2019).

9.4 Mapping Availability

Flood maps produced through the Flood Damage Reduction Program are available through Geomatics Nova Scotia and can be accessed through contacting the centre (geoinfo@novascotia.ca). The City of Halifax has produced an online web application that utilizes a satellite base map to identify the areas that are projected to be impacted by design floods of a 20 year return period and 100 year return period produced in 2017. Shown in figure 8 is the Sackville Region flood map produced by the City of Halifax.

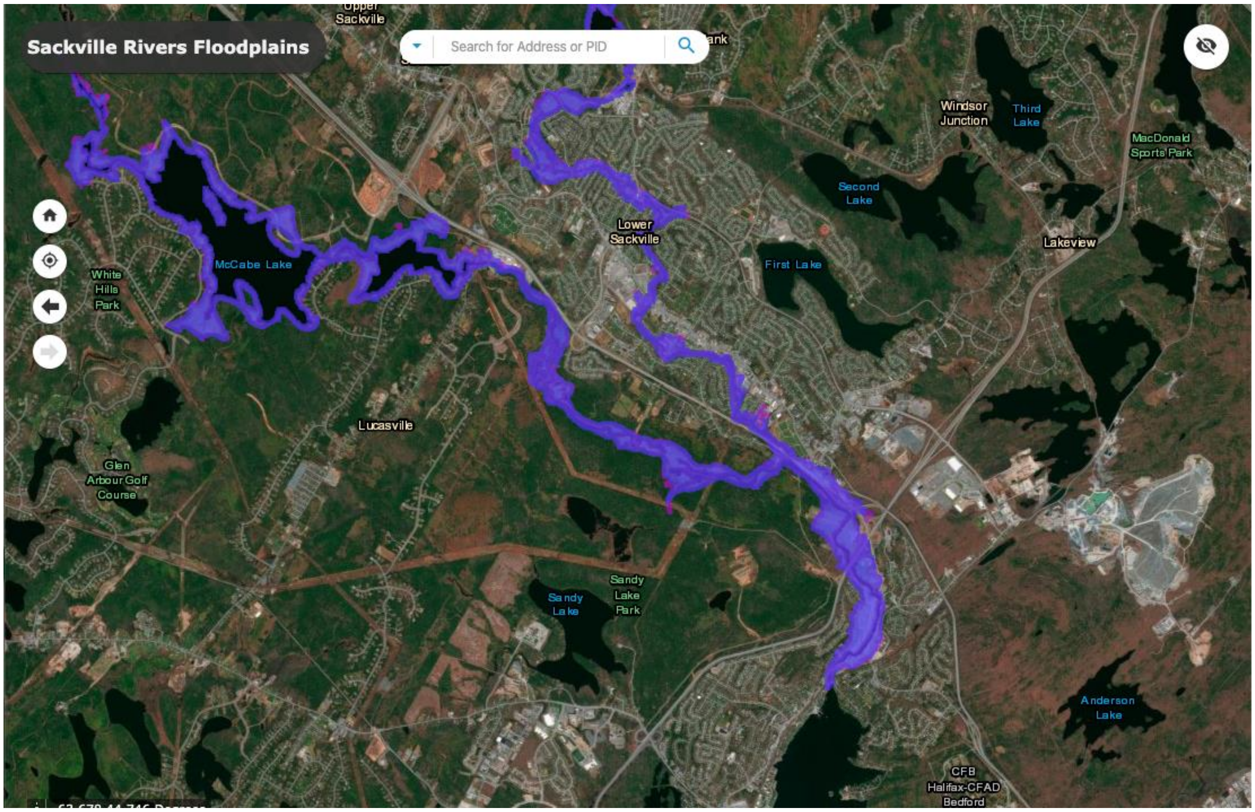

Figure 8: City of Halifax Flood Map for Sackville Region *(City of Halifax, 2017)*

9.5 Climate Change Considerations

Flood mapping that was completed under the Flood Damage Reduction Program involved no considerations of climate change impacts in relation to flooding. A future flood mapping project will be utilizing impacts of climate change into their flood mapping procedures. Impacts of climate change that are being considered involve precipitation changes, sea level rise, and storm surge changes. The scenarios are still currently in the stage of testing.

10 Prince Edward Island

10.1 Historical Flooding Events

Prince Edward Island has received limited flooding events over its history. One of the Province's major flood events occurred in 1962 as a result of compounding impacts from a large precipitation event occurring over local snowpack (Government of Canada, 2010). Extensive flooding followed and caused damages to infrastructures and roadways, leaving an estimated damage total of $600,000 (Government of Canada, 2010), which is equivalent to $5.2 million in present day value.

10.2 Flooding Challenges

Prince Edward Island currently has major challenges with regards to coastal flooding and coastal erosion. With sea level rise expected to cause severe problems along the Atlantic Coast, coastal flooding is one of the main challenges the Province faces currently, and will continue facing in the future. Other flooding challenges are related to spring meltf, ice jams, storm surges and intense storms.

10.3 Current Standards

As a result of being the only island Province in Canada, Prince Edward Island focuses its attention on coastal flooding and coastal erosion. Prince Edward Island has limited guidelines in place with regards to fluvial flooding. Within the Watercourse, Wetland, and Buffer Zone Activity Guideline, all watercourses include a buffer zone with area of 15 m where certain activities are not to be engaged (Prince Edward Island Department of Communities, Land and Environment, 2016). These activities include:

- *Drain, pump, dredge, excavate or remove soil, water, mud, sand, gravel, stones, rubbish, rocks, aggregate or material or objects of any kind*
- *Dump or infill, or deposit soil, water, mud, sand, gravel, stones, rubbish, rocks, aggregate or material or objects of any kind*
- *Construct or place, repair or replace, demolish or remove, buildings or structures or obstructions of any kind*
- *Operation of heavy equipment on the sediment bed, beach or bank of a watercourse; exception involves motor vehicle on a beach for activities to due with legal harvesting of a*

fishery resource or the legal removal of beach material (Prince Edward Island Department of Communities, Land and Environment, 2016)

In the event of a new subdivision or development application, a Coastal Erosion and Flood Risk Assessment is completed by the provincial government to ensure plans are performed safely.

The Atlantic Climate Adaptation Solutions Association (ACASA) project is a partnership among the provincial governments of Newfoundland and Labrador, Nova Scotia, Prince Edward Island, and New Brunswick. They have prepared projects and documents that have addressed impacts of climate change that include inland flood mapping, coastal flood mapping, erosion assessments and more. One such project involved the production of flood maps for four at risk communities in Prince Edward Island. The included communities were Mount Stewart, North Rustico, Souris and Souris West, and Victoria. The result of the project included flood maps using a combination of sea level projections for 2050 and 2100 as well as storm surge return periods of 1 in 10 year, 1 in 25 year, 1 in 50 year, and 1 in 100 year (Atlantic Climate Adaptation Solutions Association, 2012).

10.4 Maps Availability

Flood maps are not available through the provincial government for Prince Edward Island. ACASA has made their flood maps available through their online website to allow the municipality and public to understand and identify areas that are at risk (Atlantic Climate Adaptation Solutions Association, 2012).

10.5 Climate Change Considerations

Prince Edward Island has not implemented any climate change considerations within flood mapping guidelines. However, implemented within the ACASA flood maps, future sea level rise projections have been included within the maps for the years of 2050 and 2100 (Atlantic Climate Adaptation Solutions Association, 2012). The projections have been applied for each community with site specific projections acquired.

11 Newfoundland and Labrador

11.1 Historical Flooding Events

Due to Newfoundland and Labrador being located along the Atlantic coast, the Province faces flooding events from tropical storms and hurricanes, with one such historical event being Hurricane Igor. Hurricane Igor reached Newfoundland and Labrador as a category 1 hurricane on September 21^{st} in 2010 (Government of Newfoundland and Labrador, 2010). The storm resulted in large amounts of rainfall that caused the storm to reach the third wettest storm in Canadian history. Total damages recorded in the Province reached $200 million, where $72 million worth of damages resulted directly from flood damages (Government of Newfoundland and Labrador, 2010).

11.2 Flooding Challenges

Common flooding challenges in Newfoundland and Labrador include: ice jams, sea level rise, storm surge, intense storms, and spring snowmelt. One of the unique challenges the province faces are tropical storms that follow a trajectory along the Atlantic coast. These storms have involved large winds and produced high amounts of rainfall that lead to overland and fluvial flooding.

11.3 Current Standards

Flood mapping guidelines and studies began in Newfoundland and Labrador in 1981 after the Province became involved in the Flood Damage Reduction Program, which lasted until 1993. The Province identified 37 communities where the communities required flood mapping and improved implementations of floodplain management policies (Government of Newfoundland and Labrador, 2014).

In 2009, the Province implemented a new three zone flood hazard area that involves a floodway, floodway fringe and climate change zone (Government of Newfoundland and Labrador, 2014). The floodway is considered the most frequent flooding area based off of a 1 in 20 year return period. The floodway fringe is defined as the less frequent flood area based off of a 1 in 100 year return period. The most recent zone incorporated into the flood hazard area is the climate change zone, which is based off an extension of the floodway fringe, aimed at presenting the area most likely to be impacted under effects of climate change. Development related to temporary alterations, non-structural uses, structures related to use of water resources, and hydraulic structures are permitted; however, the majority of development categories involve flood proofing conditions to allow for development. Residential areas are not permitted within the floodway, while institutional development is not permitted within any zone.

11.4 Maps Availability

Province of Newfoundland and Labrador has published reports and flood maps within the Flood Risk Mapping Studies section of the provincial government website to allow the public to have access to relevant studies (Government of Newfoundland and Labrador Municipal Affairs and Environment, n.d.). Reports published included hydrotechnical studies, mapping projects and other mapping studies that involved flood risk management. Figure 9 illustrates a flood map example for Corner Brook using the 2050 Maximum IDF relationship as the climate change projection.

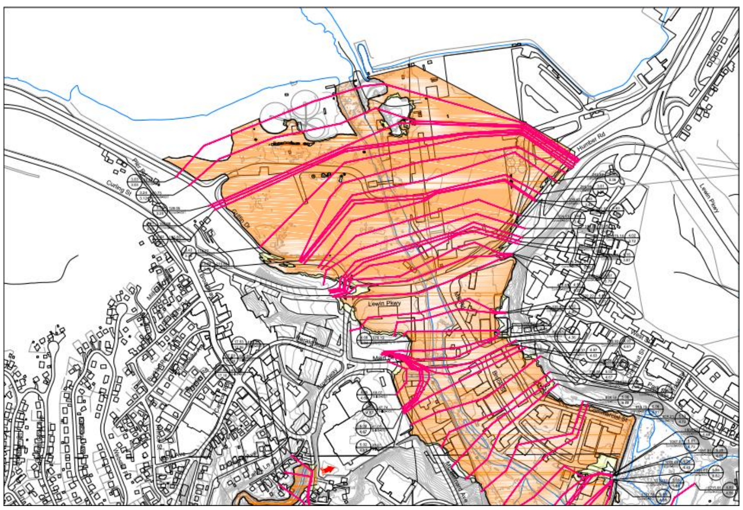

Figure 9: 1:20 and 1:100 Annual Exceedance Probability Climate Change Flood lines using the 2050 Maximum IDF Relationship for Corner Brook *(Government of Newfoundland and Labrador, 2013)*

11.5 Climate Change Considerations

As of 2009, Newfoundland and Labrador has implemented a new template for the purpose of flood risk mapping that incorporates impacts of climate change. Flood mapping practices in the Province now involve identifying precipitation changes under different climate models, such as Gander CGCM2, Gander HadCM3, and St Johns CGCM2, for the use of design storms (Meteorological Service of Canada Atlantic Region, 2008). In 2010, the climate change flood zone was incorporated into flood mapping, making Newfoundland and Labrador the first Province to apply a three zone floodplain.

12 Yukon

12.1 Flooding Challenges

Ice jams have become a primary cause of flooding and have been occurring during both the spring breakup and winter freeze up seasons. The city of Whitehorse has experienced minor flooding annually due to ice jams commonly disrupting fluvial flows (Government of Canada, 2010). Other challenges include intense summer storms, which lead to large amounts of rainfall, and the potential for sea level rise, which will increase the risk of coastal flooding. An example of flooding, resulting from the spring break up, can be seen in figure 10.

Figure 10: Spring 2019 Flooding in Whitehorse *(Canadian Broadcasting Corporation, 2019)*

12.2 Current Standards

As a result of limited flood mapping in the Territories' history, no published flood mapping standards have been produced from the provincial government. The fear for future flooding damages has pushed the provincial government and Yukon Water to establish a new Flood Risk Mapping project. The approach involves using updated LiDAR surveying for 13 communities and was originally expected to be completed between 2014 and 2015 (Yukon Water, n.d.); however, the project is yet to be completed and Yukon Water has provided no recent updates for the project timeline or any guidelines to be included within the mapping. Yukon's Emergency Measures Organization has proposed an additional project involving the development of a tool for flood risk assessments that can be utilized for the Territory. The project involves developing an online tool for identification of areas in two selected communities that are vulnerable and exposed to flood hazards (Yukon College, n.d.). The timeline of the project was originally expected to conclude in September of 2017; however, no new updates have been provided by the government.

12.3 Maps Availability

Currently, no flood maps are available to the public. One of the future projects, proposed by the provincial government, involves the development of a tool for flood risk assessments that is expected to include an online map viewer. The map viewer will allow users to identify hazard and exposure areas in relation to projected flood events.

12.4 Climate Change Considerations

Yukon has proposed no climate change considerations within flood mapping

13 Northwest Territories

13.1 Historical Flooding Events

The largest historical flood, in terms of economic damage, that took place in the Northwest Territories occurred in Aklavik in May of 2006 (Government of Canada, 2010). Ice melt from the Peel Channel caused extensive flooding in the Mackenzie River delta. Infrastructure damages from the flood reached an estimated $3.5 million, while 300 people were evacuated from their homes (Government of Canada, 2010).

13.2 Flooding Challenges

The Northwest Territories face a range of flooding challenges that include intense storms, storm surges, ice jams, and coastal flooding from current sea level rising. Storm surges have caused major flooding in the community of Tuktoyaktuk during the late summer and fall seasons (Government of Canada, 2010), while ice jams are frequently experienced in the spring breakup period. Future projections for climatic conditions present challenges related to coastal flooding from sea level rising and will increase the need for accurate flood assessments.

13.3 Current Standards

The Northwest Territories began a partnership with ATLAS that involves the production of flood maps. The flood maps use a two zone flood area composed of a floodway and flood fringe. The floodway is composed from the flood mapping guidelines used within the Flood Damage Reduction Program and flood risk mapping completed in the 1980s (use of a 100 year design flood for land inundated by a flood depth of 1m), while the flood fringe is defined as the flood risk area and shows all areas where the elevation is under 1 m higher than the flooded event (ATLAS, 2017).

13.4 Maps Availability

ATLAS has utilized an interactive web service that allows for identification of the floodway and flood fringe. Due to limited mapping, few communities' flood hazard areas are available and have been mapped. Shown in figure 11 is an example of one of the sections from the interactive flood map for the community of Fort Simpson.

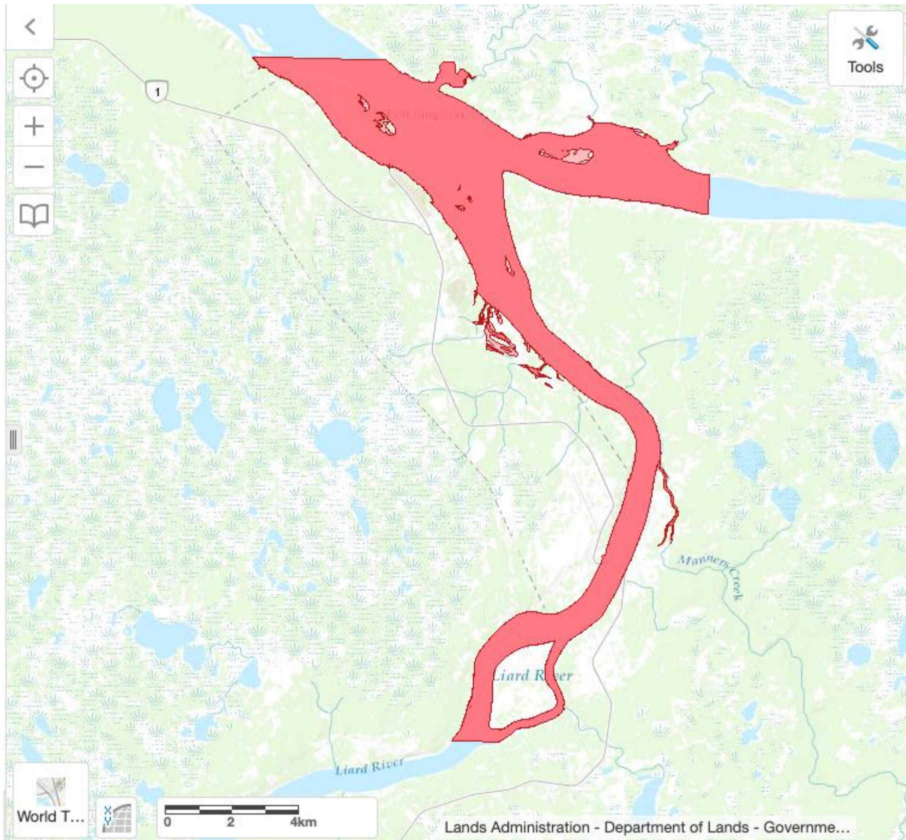

Figure 11: ATLAS Interactive Flood Map for Fort Simpson *(ATLAS, 2017)*

13.5 Climate Change Considerations

No climate change considerations have been made for the current project by ATLAS.

14 Nunavut

14.1 Flooding Challenges

Nunavut faces similar challenges to the other two territories through floods being produced by precipitation events, spring snowmelt, and ice jams. One of the ongoing challenges that the Territory faces currently and in the future is the risk of sea level rise, which has led to increasing rates of coastal flooding events.

14.2 Current Standards

As a result of Nunavut being established as a Canadian Territory at the conclusion of the Flood Damage Reduction Project, the Territory has no available flood maps to identify flood hazards. Climate change implications have caused Nunavut to develop coastal mapping assessments for risk adaptation.

14.3 Maps Availability

The government has not released any flood maps for the public.

14.4 Climate Change Considerations

Climate change factors are currently being considered for coastal flooding risks.

15 Discussion

With provincial governments responsible for their own flood hazard areas production within their provincial guidelines and legislations, varying protection levels of flood zone management have been identified. Table 2 summarizes the existing standards and regulations across the country.

Table 2: Summary of Flood Mapping Practices for Each Province

Province	Design Flood	Flood Hazard Area	Climate Change Considerations
British Columbia	200 Year	One Zone	No Considerations
Alberta	100 Year	Two Zone	No Considerations
Saskatchewan	500 Year	Two Zone	No Considerations
Manitoba	200 Year	Two Zone	Evaluating methods
Ontario	100 Year or Historic Regional Flood	One or Two Zone	No Considerations
Quebec	100 Year (Low Velocity Zone) 20 Year (High Velocity Zone)	Two Zone	No Considerations
New Brunswick	20 Year (Floodway) 100 Year (Flood Fringe)	Two Zone	No Considerations
Nova Scotia	20 Year (Floodway) 100 Year (Flood Fringe)	Two Zone	No Considerations
Prince Edward Island	25m Buffer Zone	NA	Sea Level Projections included in ACASA maps

Province	Design Flood	Flood Hazard Area	Climate Change Considerations
Newfoundland and Labrador	20 Year (Floodway) 100 Year (Flood Fringe)	Three Zone	Climate Change Flood Zone Climate Change Scenarios
Yukon	NA	NA	NA
Northwest Territories	100 Year	Two Zone	No Considerations
Nunavut	NA	NA	NA

One of the key technical aspects for the production of flood hazard areas involves the design flood period that is to be utilized. Many provinces have continued to use the standard 100 year design flood, used in the Flood Damage Reduction Program. Included within this practice are the Atlantic Provinces, Quebec, and Alberta. British Columbia and Manitoba are in the next tier and utilize a 200 year design flood to provide for climate uncertainties and as a result of increased flood events, while Saskatchewan is practicing the use of a 500 year design flood. Due to historical flood events that have surpassed the 100 year design flood in use, Ontario has allowed for the maximum of the two events to best execute flood management practices across the 36 conservation authorities.

The next key difference was the design of the flood hazard area within each province to manage effective flood development strategies. A two zone flood hazard approach is the most common method employed, with New Brunswick, Nova Scotia, Quebec, Alberta, Saskatchewan, and Manitoba currently in use of this approach. The two main components of this type of flood hazard zone involves the floodway and the flood fringe, which had been previously utilized within the Flood Damage Reduction Program. Slight differences within the two zone flood hazard area involve Quebec referring to their two zones as the Low Velocity Zone and the High Velocity Zone. Another difference within the two zone flood hazard area involves the discrepancies between the classifications of the floodway versus flood fringe. This discrepancy is a result of provinces involving the floodway as the water level for a 20 year design flood versus the floodway consisting of the area of the flood zone where the flood depth is greater than 1 m or the flood velocity greater than 1 m/s. The use of a floodway and flood fringe has allowed provincial governments to more effectively identify areas that will be more vulnerable to damage by flood events. The most common use has been development being restricted within the floodway, while permitted within the flood fringe so long that flood proofing measures have been implemented. British Columbia is in use of a one zone flood hazard area where the entirety of the design flood is classified within the flood zone, while Conservation Authorities across Ontario are still given the option to use a one zone area or a two zone area. Newfoundland and Labrador has recently included climate change considerations by progressing to a three zone flood hazard approach. The three zones include the floodway, flood fringe, and also includes the climate change flood zone to incorporate projected changes that will happen within the flood zone in the future. The only province that has not practiced flood management with zoning techniques is Prince Edward Island who have employed a 15 m buffer zone that is applied to all river streams and coastal zones within the province. The buffer zone allows for identification of areas that prevent future development.

The availability of maps for public access identifying areas that are located within the flood hazard zones is also widely variable. One of the more popular current techniques being employed is the use of an interactive online web service that allows for anyone to use and monitor areas that are included within the flood hazard area. This availability then ranges towards historical flood map drawings to no maps presently available. Quebec is the most recent province to include an online interactive web service that was provided following the 2017 and 2019 flood events.

For the purpose of locating the guidelines online, Table 3 summarizes the main source information for each province.

Table 3: Summary of Source Information for Each Province

Province	Source URL for Guidelines
British Columbia	https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/integrated-flood-hazard-mgmt/flood_hazard_area_land_use_guidelines_2017.pdf
Alberta	https://www.alberta.ca/flood-hazard-mapping.aspx or contact for further guidelines: aep.flood@gov.ab.ca
Saskatchewan	https://pubsaskdev.blob.core.windows.net/pubsask-prod/70924/P13-2R3.pdf
Manitoba	https://nrc-publications.canada.ca/eng/view/fulltext/?id=00442140-e349-4911-908e-0e091aff5f8c
Ontario	http://www.renaud.ca/public/Environmental-Regulations/MNR%20Technical%20Guide%20Flooding%20Hazard%20Limit.pdf
Quebec	https://www.cehq.gouv.qc.ca/zones-inond/zone-intervention-speciale.htm
New Brunswick	https://www2.gnb.ca/content/gnb/en/departments/elg/environment/content/flood/flood_maps/understanding.html
Nova Scotia	https://novascotia.ca/just/regulations/regs/mgstmt.htm
Prince Edward Island	https://www.princeedwardisland.ca/sites/default/files/publications/watercourse_wetland_and_buffer_zone_activity_guidelines_dec_2016.pdf
Newfoundland and Labrador	https://www.mae.gov.nl.ca/waterres/regulations/policies/flood_plain.html
Yukon	NA
Northwest Territories	http://www.geomatics.gov.nt.ca/site_docs/Documents/ATLAS_Map_Viewer_User_Manual_Version_1-0.pdf
Nunavut	NA

References

Introduction

Government of Canada. (2010). *Floods*. Retrieved March 14, 2020 from https://www.canada.ca/en/environment-climate-change/services/water-overview/quantity/floods.html

Insurance Bureau of Canada. (2019). *Eastern Canada Spring Flooding Caused Close to $208 million in Insured Damage*. Retrieved March 14, 2020 from http://www.ibc.ca/on/resources/media-centre/media-releases/eastern-canada-spring-flooding-caused-close-to-208-million-in-insured-damage

Institute for Catastrophic Loss Reduction. (n.d.). *Flood Mapping in Canada*.

J.P. Bruce (1976) *THE NATIONAL FLOOD DAMAGE REDUCTION PROGRAM* , Canadian Water Resources Journal, 1:1, 5-14, DOI: 10.4296/cwrj0101005

Natural Resources Canada. (2018). *Federal Flood Mapping Framework*. Available online at: http://ftp.geogratis.gc.ca/pub/nrcan_rncan/publications/ess_sst/308/308128/gip_112_v2_0_en.pdf [accessed 17/03/2020]

BC

Fraser River Council. (n.d.). *Lower Mainland Flood Management Strategy: Regional Flood Maps*. Retrieved February 22, 2020 from https://www.fraserbasin.bc.ca/Regional_Flood_Maps.html

Fraser River Council. (2019). Year 2100 1% AEP (100-year) freshet flood with 1m sea level rise. Retrieved April 5, 2020 from https://www.fraserbasin.bc.ca/_Library/LMFMS_Maps/Base_Freshet_CC2100_1AEP_1mSLR_MaxDepth_Web.pdf

Government of British Columbia. (2018). *Addressing the New Normal: 21st Century Disaster Management in British Columbia*. Available online at: https://www2.gov.bc.ca/assets/gov/public-safety-and-emergency-services/emergency-preparedness-response-recovery/embc/bc-flood-and-wildfire-review-addressing-the-new-normal-21st-century-disaster-management-in-bc-web.pdf [accessed 17/03/2020]

Government of British Columbia. (n.d.). *iMapBC*. Retrieved March 30, 2020 from https://maps.gov.bc.ca/ess/hm/imap4m/

Government of Canada. (2010) *Flooding events in Canada: British Columbia*. Retrieved February 20, 2020 from https://www.canada.ca/en/environment-climate-change/services/water-overview/quantity/floods/events-british-columbia.html#sub1

Ministry of Water, Land and Air Protection Province of British Columbia. (2003). *Dike Design and Construction Guide*. Available online at: http://www.env.gov.bc.ca/wsd/public_safety/flood/pdfs_word/dike_des_cons_guide_july-2011.pdf [accessed 01/04/2020]

Ministry of Water, Land and Air Protection Province of British Columbia. (2004). *Flood Hazard Area Land Use Management Guidelines*. Available online at: https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/integrated-flood-hazard-mgmt/flood_hazard_area_land_use_guidelines_2017.pdf [accessed 20/2/2020]

Parsons, C.; BC Real Estate Association (BCREA). (2015). *BC Floodplain Map Inventory Report*. Available online at: https://pdf4pro.com/download/bc-floodplain-map-inventory-report-123476.html [accessed 20/2/2020]

Professional Engineers and Geoscientists of BC. (2017). *Flood Mapping in BC: APEGBC Professional Practical Guidelines*. Available online at: https://www.egbc.ca/getmedia/8748e1cf-3a80-458d-8f73-94d6460f310f/APEGBC-Guidelines-for-Flood-Mapping-in-BC.pdf.aspx [accessed 21/02/2020]

Alberta

Alberta Environment Water Management Operations River Forecast Section (2011). *Flood Hazard Identification Program Guidelines*

City of Calgary. (n.d.). *The Flood of 2013*. Retrieved February 23, 2020 from https://www.calgary.ca/UEP/Water/Pages/Flood-Info/Flooding-History-Calgary.aspx

Environment and Climate Change Canada. (2017). *Top ten weather stories for 2005: story one.* Retrieved February 23, 2020 from https://ec.gc.ca/meteo-weather/default.asp?lang=En&n=A4DD5AB5-1

Environment and Climate Change Canada. (2017). *Canada's top 10 weather stories of 2013. Retrieved April 2nd from* https://www.ec.gc.ca/meteo-weather/default.asp?lang=En&n=5BA5EAFC-1&offset=2&toc=hide

Government of Alberta. (n.d.). *Flood Hazard Identification Program*. Retrieved February 23, 2020 from https://www.alberta.ca/flood-hazard-identification-program-overview.aspx

Government of Alberta. (2019). *Flood Hazard Map Application*. Retrieved April 5, 2020 from https://maps.alberta.ca/FloodHazard/

Government of Alberta. (n.d.). *Flood Hazard Mapping*. Retrieved February 23, 2020 from https://www.alberta.ca/flood-hazard-mapping.aspx

Government of Alberta. (2017). *FLOOD RISK MANAGEMENT GUIDELINES FOR LOCATION OF NEW FACILITIES FUNDED BY ALBERTA INFRASTRUCTURE*. Available online at: https://www.alberta.ca/assets/documents/tr/tr-floodriskmgmt.pdf [accessed 23/02/2020]

Institute for Catastrophic Loss. (2010). *Making Flood Insurable for Canadian Homeowners.*

Saskatchewan

Government of Canada. (2013). *Flooding events in Canada: Prairie Provinces.* Retrieved February 26, 2020 from https://www.canada.ca/en/environment-climate-change/services/water-overview/quantity/floods/events-prairie-provinces.html#AB

Government of Saskatchewan. (2019). *High Risk Communities to Receive Flood Mapping*. Retrieved February 27, 2020 from https://www.saskatchewan.ca/government/news-and-media/2019/august/12/flood-mapping

Government of Saskatchewan. (2012). *The Statement of Provincial Interest Regulations – P-13.2 Reg 3*. Available online at: https://pubsaskdev.blob.core.windows.net/pubsask-prod/70924/P13-2R3.pdf. [accessed 27/02/2020]

ISC. (n.d.). *GeoSask.* Retrieved April 2, 2020 from https://www.isc.ca/Pages/Content%20Gallery/GeoSask.aspx

Water Security Agency Saskatchewan. (2012). *25 Year Saskatchewan Water Security Plan. Available online at:*

https://www.wsask.ca/Global/About%20WSA/25%20Year%20Water%20Security%20Plan/WSA_25YearReportweb.pdf [accessed 02/04/2020]

Water Security Agency Saskatchewan. (2013). *2011 Emergency Flood Damage Reduction Program Review*. Available online at: https://www.wsask.ca/Global/About%20WSA/Publications/2011%20EFDRP%20Report/2011%20EFDRP%20Report.pdf [accessed 15/03/2020]

Manitoba

Babaei, H.; National Research Council Canada. (2017). *Flood hazard maps in Manitoba: present status and future provincial plans with respect to climate change.* Available online at: https://nrc-publications.canada.ca/eng/view/fulltext/?id=00442140-e349-4911-908e-0e091aff5f8c. [accessed 02/03/2020]

Government of Manitoba. (n.d.). *Manitoba Flood Facts*. Retrieved March 1, 2020 from https://www.gov.mb.ca/flooding/history/index.html

Ontario

Conservation Ontario. (n.d.). *Floodplain Mapping Ensures Public Safety and Prevents the Costly Impacts of Flooding and Erosion.* Retrieved March 3, 2020 from https://conservationontario.ca/conservation-authorities/flood-erosion-management/floodplain-mapping/

Government of Canada. (2010). *Flooding events in Canada: Ontario*. Retrieved March 2, 2020 from https://www.canada.ca/en/environment-climate-change/services/water-overview/quantity/floods/events-ontario.html

Insurance Bureau of Canada. (2019). *Eastern Canada Spring Flooding Caused Close to $208 million in Insured Damage*. Retrieved March 14, 2020 from http://www.ibc.ca/on/resources/media-centre/media-releases/eastern-canada-spring-flooding-caused-close-to-208-million-in-insured-damage

Ontario Ministry of Natural Resources. (2002). *River and Stream Systems: Flooding Hazard Limit.* Available online at: http://www.renaud.ca/public/Environmental-Regulations/MNR%20Technical%20Guide%20Flooding%20Hazard%20Limit.pdf [accessed 03/03/2020]

Quebec

Fisheries and Oceans Canada. (2019). *The Great Lakes-St. Lawrence River System*. Retrieved April 5, 2020 from https://www.waterlevels.gc.ca/C&A/glsystem-eng.html

Gouvernement du Québec. (2005). *Protection Policy for Lakeshores, Riverbanks, Littoral Zones and Floodplains*. Available online at: http://legisquebec.gouv.qc.ca/en/ShowDoc/cr/Q-2,%20r.%2035 [accessed 05/03/2020]

Gouvernement du Québec. (2019). *ZIS ANNEXE 2*. Retrieved April 6, 2020 from https://www.cehq.gouv.qc.ca/zones-inond/carte-esri-czi/index.html

Gouvernement du Québec. (2019). *Zone d'intervention spéciale.* Retrieved March 6, 2020 from https://www.cehq.gouv.qc.ca/zones-inond/zone-intervention-speciale.htm

Government of Canada. (2010). *Flooding events in Canada: Quebec*. Retrieved March 4, 2020 from https://www.canada.ca/en/environment-climate-change/services/water-overview/quantity/floods/events-quebec.html

Insurance Bureau of Canada. (2019). *Eastern Canada Spring Flooding Caused Close to $208 million in Insured Damage*. Retrieved March 14, 2020

from http://www.ibc.ca/on/resources/media-centre/media-releases/eastern-canada-spring-flooding-caused-close-to-208-million-in-insured-damage**New Brunswick**

Boisvert, J.; Government of New Brunswick. (2020, January). *New Brunswick Flooding-Forecasting and Mapping.* Presentation presented at the NRCAN Flood Mapping Workshop, Saint John, NB

Government of New Brunswick. (n.d.). *Flood Details - 2008-04-23 - 2008-05-02*. Retrieved March 8, 2020 from https://www.elgegl.gnb.ca/0001/en/Flood/Details/304

Government of New Brunswick. (1979). *Lower Marsh Creek Flood Risk Area*. Retrieved April 5, 2020 from https://www.elgegl.gnb.ca/floodriskmaps/SaintJohn/MARSHCREEK.jpg

Government of New Brunswick. (n.d.). *Understanding New Brunswick's Flood Maps.* Retrieved March 9, 2020 from https://www2.gnb.ca/content/gnb/en/departments/elg/environment/content/flood/flood_maps/understanding.html

Nova Scotia

Environment and Climate Change Canada. (2015). *Hurricane Juan Storm Summary*. Retrieved March 10, 2020 from https://www.ec.gc.ca/ouragans-hurricanes/default.asp?lang=en&n=B1A7B85A-1

Government of Nova Scotia. (2013). *Statements of Provincial Interest made under Section 193 and subsections 194(2) and (5) of the Municipal Government Act*. Available online at: https://novascotia.ca/just/regulations/regs/mgstmt.htm [accessed 10/03/2020]

Halifax Regional Municipality. (2019). *Sackville Floodplains.* Retrieved March 10, 2020 from https://www.halifax.ca/about-halifax/regional-community-planning/sackville-floodplains

Halifax Regional Municipality. (2017.) *Sackville River Floodplains*. Retrieved April 8, 2020 from https://www.arcgis.com/apps/webappviewer/index.html?id=54adf80df5d94459a8ea08554997fa07

Prince Edward Island

Atlantic Climate Adaptation Solutions Association. (2012). *Flood Risk Mapping for Community Assessment in PEI.* Retrieved March 11, 2020 from https://atlanticadaptation.ca/en/islandora/object/acasa%3A627

Government of Canada. (2010). *Flooding Events in Canada: Atlantic Provinces.* Retrieved March 11, 2020 from https://www.canada.ca/en/environment-climate-change/services/water-overview/quantity/floods/events-atlantic-provinces.html#PEI

Prince Edward Island Department of Communities, Land and Environment. (2016). *Watercourse, Wetland and Buffer Zone Activity Guidelines*. Available online at: https://www.princeedwardisland.ca/sites/default/files/publications/watercourse_wetland_and_buffer_zone_activity_guidelines_dec_2016.pdf [accessed 11/03/2020]

Newfoundland and Labrador

Government of Newfoundland and Labrador. (2010). *Hurricane Igor [map]*. Retrieved March 12, 2020 from https://www.stats.gov.nl.ca/Maps/PDFs/HurricaneIgor.pdf

Government of Newfoundland and Labrador. (2013). *Hydrotechnical Study of Corner Brook and Goulds\Petty Harbour*. Retrieved April 6, 2020 from https://www.mae.gov.nl.ca/waterres/flooding/corner_brook_stream/20%20_100_Climate Change_Floodlines.pdf

Government of Newfoundland and Labrador. (2014). *Policy for Flood Plain Management.* Retrieved March 12, 2020 from https://www.mae.gov.nl.ca/waterres/regulations/policies/flood_plain.html

Government of Newfoundland and Labrador Municipal Affairs and Environment. (n.d.). *Flood Risk Mapping Studies*. Retrieved April 10, 2020 from https://www.mae.gov.nl.ca/waterres/flooding/frm.html

Meteorological Service of Canada Atlantic Region. (2008). *Climate Change Scenarios for Atlantic Canada Utilizing a Statistical Downscaling Model Based on Two Global Climate Models.* Available online at: https://www.gpa.gov.nl.ca/gs/attachments/RFPFloodRisk/RFPFloodRisk-2.pdf [accessed 12/03/2020]

Yukon

Canadian Broadcasting Corporation. (2019). *Record-breaking temperatures hit Yukon with a splash*. Retrieved April 8, 2020 from https://www.cbc.ca/news/canada/north/yukon-temperatures-spring-flooding-1.5063491

Government of Canada. (2010). *Flooding Events in Canada: Yukon.* Retrieved March 13, 2020 from https://www.canada.ca/en/environment-climate-change/services/water-overview/quantity/floods/events-yukon.html

Yukon College. (n.d.). *Developing a Tool for Flood Risk Assessments in Yukon Communities.* Retrieved March 13, 2020 from https://www.yukoncollege.yk.ca/research/our-research/northern-climate-exchange/projects/developing-a-tool-for-flood-risk-assessment-in-yukon-communities

Yukon Water. (n.d.). *Flood Risk Mapping.* Retrieved March 13, 2020 from http://yukonwater.ca/docs/default-source/resources/flood_risk_mapping.pdf?status=Temp&sfvrsn=0.4855619966983795

Northwest Territories

ATLAS. (2017). *ATLAS Interactive Map Viewer*. Retrieved April 5, 2020 from https://www.maps.geomatics.gov.nt.ca/HTML5Viewer_Prod/index.html?viewer=ATLAS

ATLAS. (2017). *Atlas Map Viewer User Manual*. Available online at: http://www.geomatics.gov.nt.ca/site_docs/Documents/ATLAS_Map_Viewer_User_Manual_Version_1-0.pdf [accessed 13/03/2020]

Government of Canada. (2010). *Flooding Events in Canada: Northwest Territories.* Retrieved March 13, 2020 from https://www.canada.ca/en/environment-climate-change/services/water-overview/quantity/floods/northwest-territories.html

Appendix – A: List of Previous Reports In The Series

ISSN: (Print) 1913-3200; (online) 1913-3219
In addition to 78 previous reports (No. 01 – No. 78) prior to 2012

Samiran Das and Slobodan P. Simonovic (2012). Assessment of Uncertainty in Flood Flows under Climate Change. Water Resources Research Report no. 079, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 67 pages. ISBN: (print) 978-0-7714-2960-6; (online) 978-0-7714-2961-3.

Rubaiya Sarwar, Sarah E. Irwin, Leanna King and Slobodan P. Simonovic (2012). Assessment of Climatic Vulnerability in the Upper Thames River basin: Downscaling with SDSM. Water Resources Research Report no. 080, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 65 pages. ISBN: (print) 978-0-7714-2962-0; (online) 978-0-7714-2963-7.

Sarah E. Irwin, Rubaiya Sarwar, Leanna King and Slobodan P. Simonovic (2012). Assessment of Climatic Vulnerability in the Upper Thames River basin: Downscaling with LARS-WG. Water Resources Research Report no. 081, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 80 pages. ISBN: (print) 978-0-7714-2964-4; (online) 978-0-7714-2965-1.

Samiran Das and Slobodan P. Simonovic (2012). Guidelines for Flood Frequency Estimation under Climate Change. Water Resources Research Report no. 082, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 44 pages. ISBN: (print) 978-0-7714-2973-6; (online) 978-0-7714-2974-3.

Angela Peck and Slobodan P. Simonovic (2013). Coastal Cities at Risk (CCaR): Generic System Dynamics Simulation Models for Use with City Resilience Simulator. Water Resources Research Report no. 083, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 55 pages. ISBN: (print) 978-0-7714-3024-4; (online) 978-0-7714-3025-1.

Roshan Srivastav and Slobodan P. Simonovic (2014). Generic Framework for Computation of Spatial Dynamic Resilience. Water Resources Research Report no. 085, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 81 pages. ISBN: (print) 978-0-7714-3067-1; (online) 978-0-7714-3068-8.

Angela Peck and Slobodan P. Simonovic (2014). Coupling System Dynamics with Geographic Information Systems: CCaR Project Report. Water Resources Research Report no. 086, Facility

for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 60 pages. ISBN: (print) 978-0-7714-3069-5; (online) 978-0-7714-3070-1.

Sarah Irwin, Roshan Srivastav and Slobodan P. Simonovic (2014). Instruction for Watershed Delineation in an ArcGIS Environment for Regionalization Studies. Water Resources Research Report no. 087, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 45 pages. ISBN: (print) 978-0-7714-3071-8; (online) 978-0-7714-3072-5.

Andre Schardong, Roshan K. Srivastav and Slobodan P. Simonovic (2014). Computerized Tool for the Development of Intensity-Duration-Frequency Curves under a Changing Climate: Users Manual v.1. Water Resources Research Report no. 088, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 68 pages. ISBN: (print) 978-0-7714-3085-5; (online) 978-0-7714-3086-2.

Roshan K. Srivastav, Andre Schardong and Slobodan P. Simonovic (2014). Computerized Tool for the Development of Intensity-Duration-Frequency Curves under a Changing Climate: Technical Manual v.1. Water Resources Research Report no. 089, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 62 pages. ISBN: (print) 978-0-7714-3087-9; (online) 978-0-7714-3088-6.

Roshan K. Srivastav and Slobodan P. Simonovic (2014). Simulation of Dynamic Resilience: A Railway Case Study. Water Resources Research Report no. 090, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 91 pages. ISBN: (print) 978-0-7714-3089-3; (online) 978-0-7714-3090-9.

Nick Agam and Slobodan P. Simonovic (2015). Development of Inundation Maps for the Vancouver Coastline Incorporating the Effects of Sea Level Rise and Extreme Events. Water Resources Research Report no. 091, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 107 pages. ISBN: (print) 978-0-7714-3092-3; (online) 978-0-7714-3094-7.

Sarah Irwin, Roshan K. Srivastav and Slobodan P. Simonovic (2015). Instructions for Operating the Proposed Regionalization Tool "Cluster-FCM" Using Fuzzy C-Means Clustering and L-Moment Statistics. Water Resources Research Report no. 092, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 54 pages. ISBN: (print) 978-0-7714-3101-2; (online) 978-0-7714-3102-9.

Bogdan Pavlovic and Slobodan P. Simonovic (2016). Automated Control Flaw Generation Procedure: Cheakamus Dam Case Study. Water Resources Research Report no. 093, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 78 pages. ISBN: (print) 978-0-7714-3113-5; (online) 978-0-7714-3114-2.

Sarah Irwin, Slobodan P. Simonovic and Niru Nirupama (2016). Introduction to ResilSIM: A Decision Support Tool for Estimating Disaster Resilience to Hydro-Meteorological Events. Water Resources Research Report no. 094, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 66 pages. ISBN: (print) 978-0-7714-3115-9; (online) 978-0-7714-3116-6.

Tommy Kokas, Slobodan P. Simonovic (2016). Flood Risk Management in Canadian Urban Environments: A Comprehensive Framework for Water Resources Modeling and Decision-Making. Water Resources Research Report no. 095. Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 66 pages. ISBN: (print) 978-0-7714-3117-3; (online) 978-0-7714-3118-0.

Jingjing Kong and Slobodan P. Simonovic (2016). Interdependent Infrastructure Network Resilience Model with Joint Restoration Strategy. Water Resources Research Report no. 096, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 83 pages. ISBN: (print) 978-0-7714-3132-6; (online) 978-0-7714-3133-3.

Sohom Mandal, Patrick A. Breach and Slobodan P. Simonovic (2017). Tools for Downscaling Climate Variables: A Technical Manual. Water Resources Research Report no. 097, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 95 pages. ISBN: (print) 978-0-7714-3135-7; (online) 978-0-7714-3136-4.

R Arunkumar and Slobodan P. Simonovic (2017). General Methodology for Developing a CFD Model for Studying Spillway Hydraulics using ANSYS Fluent. Water Resources Research Report no. 098, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 39 pages. ISBN: (print) 978-0-7714-3148-7; (online) 978-0-7714-3149-4.

Andre Schardong, Slobodan P. Simonovic and Dan Sandink (2017). Computerized Tool for the Development of Intensity-Duration-Frequency Curves Under a Changing Climate: Technical Manual v.2.1. Water Resources Research Report no. 099, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 52 pages. ISBN: (print) 978-0-7714-3150-0; (online) 978-0-7714-3151-7.

Andre Schardong, Slobodan P. Simonovic and Dan Sandink (2017). Computerized Tool for the Development of Intensity-Duration-Frequency Curves Under a Changing Climate: User's Manual v.2.1. Water Resources Research Report no. 100, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 52 pages. ISBN: (print) 978-0-7714-3152-4; (online) 978-0-7714-3153-1.

Ayushi Gaur, Abhishek Gaur and Slobodan P. Simonovic (2017). Modelling of High Resolution Flow from GCM Simulated Runoff using a Mesoscale Hydrodynamic Model: CAMA-FLOOD. Water Resources Research Report no. 101, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 44 pages. ISBN: (print) 978-0-7714-3154-8; (online) 978-0-7714-3155-5.

Jingjing Kong and Slobodan P. Simonovic (2017). Multi-hazard resilience model of an interdependent infrastructure system. Water Resources Research Report no. 102, Facility for Intelligent Decision Support. Department of Civil and Environmental Engineering, London, Ontario, Canada, 99 pages. ISBN: (print) 978-0-7714-3158-6; (online) 978-0-7714-3159-3.

Andre Schardong, Slobodan P. Simonovic and Dan Sandink (2018). Computerized Tool for the Development of Intensity-Duration-Frequency Curves Under a Changing Climate: Technical Manual v.3. Water Resources Research Report no. 103, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 67 pages. ISBN: 978-0-7714-3107-4.

Andre Schardong, Slobodan P. Simonovic and Dan Sandink (2018). Computerized Tool for the Development of Intensity-Duration-Frequency Curves Under a Changing Climate: User's Manual v.3. Water Resources Research Report no. 104, Facility for Intelligent Decision Support, Department of Civil and Environmental Engineering, London, Ontario, Canada, 80 pages. ISBN: 978-0-7714-3108-1.