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Assessment of Canadian Floodplain Mapping and Supporting Datasets for Codes and Standards

Technical Report - UNCLASSIFIED
OCRE-TR-2017-026

Document Version 1.4

M.N. Khaliq
A. Attar

Ottawa, ON

October 05, 2017





National Research Council
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Ocean, Coastal and River
Engineering

Génie océanique, côtier et fluvial

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Executive Summary

The National Research Council–Construction (NRC–Construction) Portfolio was awarded the Climate Resilient Core Public Infrastructure (CR-CPI) project by the government of Canada to bring resilience into buildings and CPI against recurrent floods and projected climate change by updating national codes and standards and developing related guidelines.

Public Safety of Canada’s records reveal that over the last decade, Canada has seen a notable increase in flooding, resulting in billions of dollars of damages. Therefore, the impact of floods on buildings and CPI was identified as a primary area of study within the CR-CPI project. Climate change is expected to exacerbate the severity of flooding, which in turn will worsen the impact of floods on buildings and CPI. In fact, all reports of the Intergovernmental Panel on Climate Change indicate that storminess will intensify in the future as large amounts of precipitation over shorter periods will occur more frequently in many parts of the world. This includes Canada, where the impacts of climate change may even be more severe. As a result, the impact of climate change has also been identified as another major research area within the CR-CPI project.

Protecting Canadians from natural disasters, such as floods, has been the focus of the Canadian government for the last several decades. In 1976 the federal government started a nation-wide flood protection program, the Flood Damage Reduction Program (FDRP), to protect Canadian communities and their assets from flood hazards. This program was federally administered and implemented on a cost sharing basis between the provinces/territories and the federal government. The provinces and territories entered into bilateral agreements at different times, except for Prince Edward Island and Yukon Territory, where the flooding hazards were not found to be a major concern. At the time the FDRP was ended by the federal government in 1995/96, most of the flood-prone areas and vulnerable major population centers across the country were mapped. Flood maps were created for 981 communities with a total cost of \$65.4 million. After the termination of the FDRP, provinces and territories took on the responsibility of updating and maintaining the existing flood maps and developing new maps for additional areas. Some of the provinces chose to define their own mapping standards and protection levels to satisfy their needs. Consequently, due to the lack of a federal level supervisory or a regulatory body, there is less consistency and coherency among flood mapping related technology and standards used across the country. Recently, some of the provinces have also started developing climate change informed flood maps for future planning purposes (e.g. British Columbia and Newfoundland and Labrador). Because of the above mentioned factors, the status of flood maps across the entire country is not clearly known.

To guide the development of flood and climate resilient national codes and standards, detailed information on the distribution of flooding depth and velocity of flood waters across the floodplain is required to identify various loads and related load combinations for design of buildings and CPI. To avoid duplication of the effort and to better understand new and existing flood maps, the first phase of this study was focused on acquiring information about existing and new flood maps and availability of supporting

datasets used in creating these maps. This work was completed through contacting various provincial/territorial and municipal government offices and reviewing available technical documents. The supporting information was gathered and analyzed separately for each province and territory and will be of significant value in identifying how best the existing maps and data sources can be utilized to develop new codes and standards.

This report presents a summary of the overall findings, by highlighting the existing practices and standards and identifying the gaps between bringing “flood and climate resilience into Canadian codes and standards” and “the information available from existing and new flood maps”. Therefore, this document along with the provincial and territorial reports will help develop a future framework concerning how flood and climate resilience can be effectively incorporated into Canadian codes and standards and development of related guidelines.

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1 Introduction

1.1 Background and purpose of the study

The National Research Council–Construction (NRC–Construction) Portfolio was awarded a five year project by the government of Canada to bring resilience into Canadian Core Public Infrastructure (CPI) against projected climate change by updating national codes and standards and developing related design guidelines. The project, Climate Resilient Core Public Infrastructure (CR–CPI), was initiated in September 2016. The impact of floods on buildings and CPI was identified as a primary area of study within the project. Climate change is expected to intensify the severity of flooding, which in turn will heighten the impact of floods on buildings and CPI. Therefore, the impact of climate change has also been identified as another major research area within the CR–CPI project. The Ocean, Coastal and River Engineering (OCRE) Portfolio of the NRC was engaged in this project by the NRC–Construction portfolio through an internal inter-departmental agreement.

Buildings and CPI located in a floodplain can be subject to various types of loads. These loads include the static load due to the depth of flood water and the dynamic load due to the speed/velocity of the flowing water as it inundates the floodplain. The same two variables have been identified by the Federal Emergency Management Agency (FEMA) in the US, Engineers Australia in Australia and Environment Agency in the UK to inform flood zoning by-laws and development activities in the floodplain, as well as to identify hazards to humans and built structures. Therefore, floodplain maps showing spatial patterns of both velocity and depth of flood water for flood-prone areas (both coastal and riverine) would be helpful in estimating target loads and updating national codes and standards.

The majority of flood-mapping work in Canada was carried out through a federally administered program, the Flood Damage Reduction Program (FDRP), on cost sharing basis between the provinces/territories and the federal government (IWD, 1976). The federal government ended this program in 1995/96 and the responsibility for updating and maintaining flood mapping was delegated to provinces and territories. Most of the flood maps produced within the FDRP were targeted to show flood extents following the two zone concept, i.e. floodway and flood fringe. The floodway is the portion of the floodplain where flood velocities are expected to equal or exceed 1 m/s and/or water depths equal or exceed 1 m. The flood fringe is the remainder of the flood zone where the flood velocities are under 1 m/s and the water depth is below 1 m.

Hydrological investigations and hydraulic modelling are often required for floodplain mapping studies in riverine situations. Hydrological investigations refer to the estimation of design flow values by means of flood frequency analysis or other suitable approaches. For the hydraulic component of the floodplain modelling studies, hydrologic response of the watershed in terms of design flow is the most relevant parameter. Statistical approaches are commonly used for the estimation of design flows given that high quality observed flows of sufficient length are available. This method entails fitting a statistical distribution to the sample of peak flows and then deriving the flow magnitude

corresponding to a range of selected design return periods. Large lake and coastal floodplains use a similar procedure; however flood levels are defined in terms of surge heights, which are superposed by wave-setups and run-ups.

Hydraulic modelling refers to the modelling of the movement of flood waters through the landscape using one-dimensional (1D) or two-dimensional (2D) hydraulic models. The most widely used approach to modelling this phenomenon has been the 1D finite-difference solution of the full Saint-Venant equations. These equations are based on the principle of conservation of mass and momentum and their 1D steady state solution is commonly implemented. In many practical situations the interaction of channel and floodplain flow fields can be quite complex. For such situations, 2D hydraulic models are generally preferred as they provide more detailed view of the flow fields and velocities. Now-a-days, 2D hydraulic models are becoming increasingly popular compared to 1D models due to continuous improvements in computing power. These models utilize depth-averaged Navier-Stokes equations, commonly called the Saint-Venant shallow water equations (SV-SWE), and produce more accurate and detailed analysis of floodplains. However, 2D models require greater competency and longer completion time compared to their simple counterparts, i.e. one-dimensional models. As mentioned above, the 2D modelling approach is more suitable for generating spatial patterns of flood depths and velocities. In riverine situations, where flooding is impacted or caused by ice buildups, estimation of design water levels for floodplain mapping becomes a non-trivial task and hence requires advanced analyses and engineering judgements. In coastal situations, floodplain modelling is relatively complex and requires even more sophisticated hydrodynamic models because the process of modelling not only involves the interaction of the river with the sea water but also the impact of storm tides and wave run-ups on buildings and CPI.

As the floodplain mapping programs within Canada are not controlled by a single federal government body (as in the US, Australia and the UK) it is difficult to ascertain the status of flood maps across the country. It was therefore necessary to determine the status of flood maps for each province and territory individually in order to identify gaps between what is currently available and the target of detailed maps displaying the spatial patterns of both velocity and depth of flood water. Additionally, to avoid duplication of the effort, it was necessary to collect information of existing flood maps and the associated datasets. It is important to note that flood mapping datasets, particularly the bathymetry and river cross-sectional data, come with a great expense and effort. In the light of these points, the study was visualized in terms of three phases: (i) The first phase (i.e. the current study) concentrates on collecting detailed information on the status of flood maps and associated datasets and on obtaining information on the availability of climate change informed flood maps to aid in identifying gaps and guiding the subsequent phases of the project; (ii) In the second phase, based on the degree of severity of flooding and the availability of associated datasets, some areas across the country will be identified for detailed pilot studies using the 2D modelling approaches to understand how various static and dynamic loads impact buildings and CPI in the selected flood-prone areas and to estimate flood loads and related load combinations to address design of buildings and CPI; (iii) The third phase will be extended to other jurisdictions of interest to the CR-CPI project.

This report presents a summary of the progress made during the first phase of the project and develops a broad vision and a road map for realizing the overall goal of the CR-CPI project.

1.2 Objectives

The first objective of Phase I was to identify gaps between the information available from existing flood maps across the country and the goal of bringing resilience into buildings and CPI against floods and climate change. A specific emphasis was to investigate “where and how the information on climate change has been incorporated in flood maps”. The second objective of the project was to acquire flood mapping related datasets (e.g. bathymetry, channel cross sections, information about calibration datasets, digital elevation model, etc.) from the provincial/territorial and municipal government entities responsible for developing, maintaining, and distributing flood maps. This was essential for the second phase of the study to achieve the targeted objectives in a timely fashion.

1.3 Project plan and execution strategy

This project was carried out in collaboration with the following Canadian consulting firms, with expertise in flood mapping related projects.

- Aquasphera, Gatineau, QC: This firm was assigned the Quebec part of the study
- CBCL Limited, Halifax, Nova Scotia: This firm was assigned all Atlantic Provinces, i.e. Nova Scotia (NS), Prince Edward Island (PEI), New Brunswick (NB), and Newfoundland and Labrador (NL)
- Kerr Wood Leidal Associates Ltd. (KWL), Burnaby, BC: This company was assigned British Columbia

Each of these firms was awarded a time and budget limited contract. The work related to Alberta, Ontario, Saskatchewan, Manitoba, and all three Territories was conducted by OCRE researchers. Throughout the report, the above three consultants are respectively referred to as Aquasphera, CBCL, and KWL for the sake of convenience.

1.4 Report organization

This report is divided into fifteen chapters including the introduction chapter and an Appendix. Chapter 2 presents a list of the focal points identified for flood mapping review at the outset of the study and describes the importance of all components for generating flood maps. Chapter 3 to 13 provide findings of the study and discuss the specific challenges, standards and approaches used in producing flood maps in individual provinces and territories. This format was followed for consistency reasons as the review of existing flood maps and supporting datasets was undertaken separately for each province and territory. Chapter 14 provides an overall summary of the gathered information and Chapter 15 presents a future outlook and the road map for generating targeted flood maps for developing flood and climate resilient codes and standards. This effort also entails selecting appropriate modelling packages, identifying flood-prone areas as pilot studies and possible way forward to realize the ultimate goal of the CR-CPI project. The Appendix at the end provides a list of acronyms used in the report.

1.5 Scope and limitations

The findings of the study presented in this report are summarized based on individual studies conducted separately for each province and territory. For the individual studies, the documents and information sources were obtained from provincial/territorial and municipal government offices and their respective websites and through emails and phone conversations with numerous government personnel at different levels. All individual reports contain appropriate references to technical documents consulted and government individuals contacted. In some cases, due to time and budget constraints, all municipalities and sources were not contacted. In those cases, efforts were made to review a variety of floodplains from rural, urban and coastal environments in order to obtain a general understanding of existing flood mapping. Therefore, the assessment of flood maps and associated datasets is not of an exhaustive nature. The focus of the individual studies was on acquiring information on floodplain mapping practices and standards in provinces and territories and how climate change aspects have been incorporated into flood maps. The information collected provides a strong basis for future steps to be taken for executing pilot studies for select flood-prone communities.

2 Assessment Process – Points of Consideration

When collecting information from provincial/territorial government offices, municipal entities, and technical documents, the following items were identified to be discussed with individuals, probed through questionnaires and finally for documentation purposes. As discussed below, some of these points are related solely to flood maps and mapping procedures, while others are related to issues of climate change and availability of flood mapping datasets.

2.1 Flood maps

2.1.1 Flood mapping regulatory body

For each province and territory, information about the provincial/territorial government office responsible for updating and maintaining flood maps was collected. This was important for: (i) acquiring copies of the flood maps (in soft or hard format) for detailed examination and assessment; and (ii) establishing future collaborations to initiate new flood mapping studies for select flood-prone areas in the subsequent phases of the study.

2.1.2 Information about updated maps

In order to determine the status of flood maps across the country, it was necessary to determine which region and municipalities have maps which have been updated since the FDRP ended in 1995/96. It is likely that new maps have been generated with improved hydraulic modelling and improved estimations of the designated flood flows. It is also possible that some provinces/territories or municipalities have adopted stricter standards than those originally proposed in the FDRP guidelines.

2.1.3 Hydrologic and hydraulic guidelines

With the initiation of the FDRP and to support the implementation of the flood mapping program, the Inland Waters Directorate of Environment Canada also developed hydrologic and hydraulic guidelines for floodplain mapping (IWD, 1976). Some provinces and territories still use those guidelines while others have developed their own (e.g. Ontario). It was necessary to find and examine this information in order to assess if any consistency exists with respect to flood mapping standards across the country and whether it is feasible to have a flood mapping standard throughout Canada.

2.1.4 Dissemination of maps

It was also useful to know how the maps were/are being disseminated to the public and property developers. It is very likely that many provinces and territories still use old paper format flood maps for certain areas where digital maps are not yet developed. In order to be conformant with the present day technology, it is useful to disseminate maps in digital format. Online availability generally enhances utility of the flood maps as the property owners or developers can easily access this information. Also, the database of digital maps can be linked to many online service providers and can be directly embedded into many online applications and documents. Due to limitations of internet service within some northern remote communities, paper copies of maps are perhaps still in use.

2.1.5 Hydraulic modelling packages

The quality and detail of the information displayed on the flood maps depend on the hydraulic modelling package used to establish flood lines. Therefore, it was important to determine which modelling packages (or software tools) were used to create flood maps in riverine, coastal, and large lake environments. The majority of the maps created under the FDRP umbrella were based on hydraulic calculations performed with one-dimensional hydraulic models. In most cases the HEC-2 model was used. Currently, this model is available in the HEC-RAS package under the steady state option (<http://www.hec.usace.army.mil/>). With HEC-2, the common strategy was to assume steady state conditions. However, modern day hydraulic modelling packages (e.g. MIKE FLOOD, SOBEK, TELEMAC, TUFLOW, etc.), including HEC-RAS 2D, offer unsteady state and even two-dimensional modelling options. One-dimensional packages are still used in many floodplains, but the two-dimensional packages are becoming popular because they can provide more detail of the flood water as it inundates the floodplain. For large lake and coastal settings, even more complex hydraulic models are used. For determining various loads and related load combinations for updating codes and standards, flood maps produced from the output of 2D modelling packages are more useful because one can easily produce detailed spatial information of flood depths and velocities.

2.1.6 Information about mapping parameters

Flood hazard maps can be prepared for many different purposes, ranging from flood inundation to flood risk, severity and damage maps. Flood inundation maps are the simplest form of the flood maps. These maps show the areal extent of flooding corresponding to some regulatory/designated design flood. Flood maps may be more complex, e.g. when the same map shows detailed information on flood depths and velocities, with superposed primary (e.g. hospitals) and secondary (e.g. buildings) structures, as well as emergency evacuation routes. Therefore, it was necessary to know what information the existing flood maps contain. It is useful to have flood maps display detailed information about flood depth, velocity and the product of both depth and velocity (in some form) across the floodplain as this information can be used for calculating various loads and related load combinations on buildings and CPI.

2.1.7 Derivation of flood magnitudes

Statistical approaches are commonly used to derive the magnitude of the flood corresponding to a selected return period. In some cases, historical observed severe storms are used for mapping instead of using a return period-based estimate. Therefore, it was useful to know how the magnitude of the regulatory flood, employed for mapping, was obtained.

2.1.8 Ice jam floods

Where there is a likelihood of ice being a significant contributing factor to flooding, it is important to know how the impact of ice has been factored into the regulatory design flood. Since there is no established methodology for considering the impact of ice on the estimation of flood magnitude, it was important to assess the feasibility of the approach for generalization purposes. For ice impacted floodplains, the high water levels are

typically considered for estimating design levels rather than the magnitude of flood in terms of volume or rate of flowing water. In cases where the ice impacted levels are lower than the levels of the regulatory flood, the regulatory flood levels are preferred for mapping purposes.

2.1.9 Changes in the level of the regulatory flood

The original FDRP guidelines (IWD, 1976) recommended using the 100-year return period flood (as the minimum protection level) for creating flood maps. This protection level was recommended at the time when the FDRP was launched as the same was commonly used in other countries for the same purpose. Based on the flooding history in Canada until 1976, it was determined that the 100-year protection level was sufficient for regulating development activities in floodplains in various parts of Canada. Apart from this explanation, no other justifications have been found in various technical documents to support this recommendation. Some provinces have adopted higher protection levels than the minimum ones prescribed in the FDRP guidelines. For example, 200-year return period flood in British Columbia and 500-year return period flood in Saskatchewan is considered for floodplain delineation and mapping purposes. It was important to know from the province/territories' perspective if there is a desire to raise the minimum protection level to 200-, 300- or even 500-year return period flood across the entire country.

2.2 Climate change informed flood maps

Conventionally for flood mapping purposes, flood magnitudes are estimated from historical records assuming that the future events will not be different from the past events. According to the findings of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2013), climate is changing around the world and the design of climate sensitive CPI can no longer rely solely on historical records of hydro-climatic variables (e.g. streamflow, precipitation, temperature, and wind extremes), as they may no longer be good predictors of future conditions. Consequently, structural sufficiency and functioning of existing CPI could be at risk due to climate change.

Research shows that climate change is expected to exacerbate the flooding problem in many parts of Canada, e.g. due to high intensity rainfall occurring over shorter periods and also due to the sea level rise in coastal areas (e.g. Lemmen et al., 2008). In this respect, it is important to demonstrate that the existing critical structures and CPI would be resilient in the future under a changing climate and new structures would be built to withstand the uncertain future climate. Many sectors of society have become increasingly involved over time in bringing climate change into decision-making, resource planning and the regulatory process. However, the difficult part is that there is no readymade recipe that can be used to incorporate climate change into engineering design due to uncertainties associated with future projections.

To investigate whether the impact of climate change has been incorporated in flood maps across the country, the following questions were investigated by contacting appropriate agencies and provincial and municipal government departments:

- Has the impact of climate change on floods been incorporated in creating flood maps?
- Are there any local, municipal or provincial level initiatives currently under way to address the impact of climate change and recreate flood maps?
- If any municipality or regional body has created climate change informed maps, then what were the main features of the adopted methodology?
- Which future time horizon was targeted for creating climate change informed maps?
- What were the main aspects of the methodology adopted for riverine, coastal and large lake flooding impacted by climate change?

At the outset of this study, it was thought that information on the above questions will be useful to devise appropriate line of action for developing climate resilient codes and standards and how best the information on climate change can be factored into the process. As stated by the American Society of Civil Engineers (ASCE) Committee on Adaptation to a Changing Climate (Olsen, 2015), “our engineered facilities and systems should adapt to changing climate, weather and extreme events”. Adaptation to the changing climate will increase climate resilience of the old and new buildings and CPI. As stated above, the difficulty is that climate science does not provide guidelines and a firm basis to alter our engineering practices and standards. It is hoped that through a concerted effort, mutual consensus, and well-informed engineering judgements that engineers will be able to adapt their codes and standards to the changing climate.

2.3 Supporting datasets for flood mapping

Floodplain mapping requires supporting datasets in the form of bathymetry, digital elevation model (DEM) data, boundary conditions, river cross-sectional information, information about the type and location of hydraulic structures, and roughness parameters. For detailed 2D modelling, high resolution DEM is very important. Some of these datasets are readily available while others are generally kept with consulting companies or the provincial or municipal government department involved in creating flood maps. These datasets are typically collected with great effort and expense. Therefore, it was important to know the availability of these datasets for possible reuse. It was also important to know if these datasets are available in the public domain, through setting up memorandum of understandings, cost-sharing agreements, or providing a fee-for-service. It can be expected that the supporting datasets for regions mapped during the FDRP initiative may be available free of charge while those collected for the most recent studies may not be freely available. It is also likely that some of the datasets collected for the FDRP may have become obsolete due to improvements in the underlying technology and the accuracy and resolution of instruments used. For the case of climate change informed flood maps, collection of climate model outputs was not necessary as those datasets are readily available online. However, it was important to collect processed datasets in the form of flood magnitudes for the future climate where available.

3 Alberta

3.1 Background

An evaluation of the status of floodplain mapping and supporting datasets in Alberta was carried out during January to March 2017 by NRC-OCRE (Murphy and Khaliq, 2017a). Details on the sources consulted and the methodology adopted for evaluating the status of floodplain maps and supporting datasets can be seen in Murphy and Khaliq (2017a). A selection of the main features of the evaluation and an overview of the findings are presented here.

The climate of the Prairie Provinces is one of the most variable in Canada and North America (Sauchyn et al., 2010), such that Alberta is vulnerable to both drought and flood hazards. The total estimated cost of floods in Alberta is higher than all other Canadian Provinces and Territories, based on all flood costs reported through the Canadian Disaster Database from 1970 to 2016 (Feltmate, 2016). At \$6 billion, the government of Alberta estimated that the devastating flood of June 2013 was the costliest natural disaster in Canadian history. Before the 2013 flood, severe flooding in 2005 resulted in over \$165 million of payments under the provincial disaster assistance compensation program, in addition to four recorded fatalities (Alberta Environment, 2011).

Flood mapping has been identified as an essential tool for flood risk management and building resilience in Alberta (Groeneveld, 2006). Understanding the current status of flood mapping in Alberta is an important first step in identifying potential needs for improvement or development, including incorporation of climate change effects.

Alberta municipalities are directly responsible for regulating development and land use (through zoning by-laws) under the Municipal Government Act 2000. The Provincial government may designate flood risk areas and specify acceptable land uses with respect to flood risk areas under the province's Water Act 2000, and provides support to local governments on the management of flood prone areas (Alberta Environment and Parks, 2016a). "Designation" of flood risk areas is the formal acknowledgement of the flood hazard areas by the Minister responsible for the Water Act 2000. Section 96(3) of the Act requires that the Minister must consult with the local authority responsible for a proposed flood risk area before making a designation. Once an area is designated as a flood risk area, the local government is expected to take flood risk into account when approving development, zoning or by-laws (Groeneveld, 2006).

Flood map maintenance, including updates and revisions are understood to be carried out on an "as-required" basis (Government of Alberta, 2013). On average, approximately two studies were completed or updated each year from 1990 through 2015. The median age of all flood hazard studies in Alberta is over 18 years. This exceeds the median age of 10 years reported by Public Safety Canada (MMM Group Limited, 2014). The discrepancy may be a result of studies having been undertaken in recent years but not listed on the Alberta Environment and Parks (AEP)' website, or flood maps from other sources (e.g. local municipalities) that may have been considered by MMM Group Limited (2014) in their analysis.

The Flood Hazard Identification Program Guidelines (Alberta Environment, 2011) suggest that a return period longer than 100 years may be appropriate for "...public facilities that perform a function of significant importance to the health, safety and welfare of a community." The guidelines recommend that "Lifeline Structures", such as administration buildings and essential roads should be protected against the 500-year return period flood. Furthermore, facilities considered to be "Vital Lifeline Structures", such as hospitals, should be protected against a 1000-year return period flood event. The guidelines suggest that following these standards will increase the likelihood that, in a severe flood event, vital infrastructure will still be able to operate and serve impacted communities.

Mapping and data acquisition to support future flood risk assessment work is included in the more recent terms of reference documents issued by Alberta Environment and Parks (2016b), which require combining flood inundation maps for a range of return periods (not just a single designated flood event) with spatial information on land use, population and infrastructure. The terms of reference (Alberta Environment and Parks, 2016b) specify the requirement that the consultant conducting the flood studies produce flood depth grids, based on guidance developed by the US Federal Emergency Management Agency (FEMA), to support future flood risk assessments.

3.2 Flood maps and their availability, modelling packages used, and flood mitigation initiatives

Flood hazard studies and mapping have been produced by the provincial government since the 1970s. The Canada-Alberta Flood Damage Reduction Program (FDRP) was initiated in 1989 between the government of Alberta and the federal government. The program was created to standardize and cost-share production of flood hazard studies and mapping, in order to increase public safety and awareness of flood hazards with an ultimate goal to mitigate flood damages. The program expired in 1999 before flood hazard studies and mapping was completed for all 66 of the original candidate communities identified under the FDRP.

Since 1999, Alberta Environment and Parks, previously known as Alberta Environment and Sustainable Resource Development (ESRD), continued to produce studies and mapping under the Flood Hazard Identification Program. The maps have been available online since 2004 (Government of Alberta, 2014) and show flood hazard areas (floodway and flood fringe) for the 100-year design flood, which is the current design or regulatory standard in Alberta. The floodway is defined as the area where the water is 1 m deep or greater, local velocities are 1 m/s or faster and if the river were encroached upon, the water level rise would be 0.3 m or more (Alberta Environment, 2011). The flood fringe is the land along the edges of the flood hazard area that has relatively shallow water (less than 1 m deep) with lower velocities (less than 1 m/s). Some local municipalities have incorporated flood hazard maps developed by ESRD in their by-laws (The Calgary Land Use Bylaw, 1P2007).

Following a devastating flood event in Southern Alberta in June 2013, the government of Alberta established the Southern Alberta Flood Recovery Task Force (SAFRTF), which commissioned a number of hydrologic and hydraulic studies, including review and updating of flood maps in some areas (AECOM, 2014; AMEC, 2014).

After the 2013 flood event, the City of Calgary, in partnership with ESRD, implemented new hydrologic and hydraulic modelling studies for the Bow and Elbow Rivers (Golder Associates, 2014; 2015). The output from the studies consisted of updated inundation maps, reflecting changes to waterways since the original mapping was carried out. The inundation maps show the area of surface flooding for 5-year, 10-year, 20-year, 50-year and 100-year return periods based on modelling completed in 2015, and are available in PDF format for download from the City's website (The City of Calgary, 2017). Several other municipalities have conducted studies that included flood mapping, some in collaboration with or supported by AEP. These include Woodland County (Northwest Hydraulic Consultants, 2015), the Town of High River (report reviewed by Deltares, 2015), and the Town of Canmore (BGC Engineering, 2014).

Since 2011, the flood hazard maps available on the AEP website have been developed based on the Flood Hazard Identification Program Guidelines (Alberta Environment, 2011). These guidelines include definitions (such as floodway, flood fringe and design flood), reference data collected to support the program, and provide recommendations for conducting flood hazard mapping studies (including hydrology, hydraulics and reporting). The output provided by each study commissioned under the program includes reporting and maps. More recent flood hazard mapping is being carried out under modified terms of reference, to address issues not explicitly covered by the original guidelines, such as climate change (Alberta Environment and Parks, 2016b). Study proponents are also required to prepare flood inundation maps for multiple return periods (2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1000-year floods) under the new terms of reference.

Flood hazard maps are publicly available to view on AEP's GIS-based Flood Hazard Map Application (Alberta Environment and Parks, 2016c). Users can click on flood hazard zones to obtain a PDF summary datasheet providing information on the study area, river flow rates, adjacent studies, dates of the study and any revisions. Detailed metadata for the flood hazard map products may be found on the GeoDiscover Alberta website (Government of Alberta, 2017).

The Hydrologic and Hydraulic Guidelines for Flood Hazard Area Delineation (Alberta Environment, 2008) recommend using the Hydrologic Engineering Center River Analysis System (HEC-RAS), a one-dimensional (1D) hydraulic modelling system developed by the US Army Corps of Engineers (Brunner, 2016), to convert design flood discharge to flood levels and flood extents. The guidelines recognize that there are other hydraulic modelling tools capable of fulfilling these objectives but HEC-RAS is preferred by ESRD on the basis that it is freely available, government staff is familiar with it, and it meets technical requirements (Alberta Environment, 2008). The majority of models developed under the Flood Hazard Identification Program are based on HEC-RAS (or HEC-2 for older studies). However, there are a few examples of flood related studies in Alberta that

have been carried out using other hydrologic and hydraulic modelling tools, including the RIVICE 1D hydraulic river ice model developed by Environment Canada (Lindenschmidt et al., 2015) and two-dimensional (2D) hydraulic models (Deltares, 2015).

Following the 2013 flood, a number of questions and public concerns surrounding the appropriateness of the 100-year return period designated flood standard for Calgary were documented in a report by an Expert Management Panel on river flood mitigation and resilience (Keller et al., 2014). The panel, which was formed by the City of Calgary, recommended several improvements to flood hazard mapping to support floodplain management (including regular reviews and updating of flood hazard and inundation maps).

Following the damaging flood of 2013, several other needs were also identified with respect to flood mapping in Alberta. The City of Calgary, in partnership with ESRD, commissioned new studies to revise flood maps based on updated hydrologic and hydraulic analyses taking into account the 2013 event, and post-flood observations of morphology changes (Golder Associates, 2014, 2015). A Provincial Flood Damage Assessment Study (IBI Group / Golder Associates, 2015a, 2015b) was conducted by ESRD, with multiple objectives. One of the objectives was to undertake flood damage estimates for select communities throughout Alberta. With respect to this objective, the City of Calgary was identified as a high priority and selected as the pilot municipality for updating of flood damage curves and development of a Rapid Flood Damage Assessment Model (IBI Group / Golder Associates, 2015b). This involved the development of flood inundation maps for nine return period events (in the range 1:2 years to 1:1000 years) based on output from two existing HEC-RAS hydraulic models. The computed flood elevations and a LiDAR-derived digital elevation model were used to derive water depths in the floodplain for each event. The flood depth information was then used in conjunction with depth-damage curve estimates to derive potential damages (direct and indirect) resulting from each flood event.

3.3 Climate change and floodplain mapping

In 2008, the provincial government published Alberta's Climate Change Strategy (Government of Alberta, 2008), which focused largely on greenhouse gas emissions reduction. This was followed in April 2010 by a Climate Change Adaptation Framework, a decision support tool for assessing climate change risks and identifying options to adapt and respond to climate change. The document (Alberta Sustainable Resource Development, 2010) identifies more frequent flooding as a projected consequence of climate change and provides a broad overview of risk-based approaches to adaptation. However, it does not provide specifics in terms of predicting climate change influences on flood frequency and intensity, and how to incorporate and reflect climate change effects in flood mapping. Also, the Alberta Flood Hazard Identification Program Guidelines (Alberta Environment, 2011) do not provide guidance on incorporating the effects of climate change in flood hazard maps. More recent terms of reference for flood hazard studies prepared by AEP have specified a requirement to provide commentary on the potential effects of climate change, to provide insight to how flood peaks and frequency estimates may be impacted (Alberta Environment and Parks, 2016b). This

includes a review of available research and standards applied to flood frequency analysis and flood mapping in other jurisdictions. However, these studies are ongoing, and there are no references to climate change effects in the draft flood hazard reports available for download from the AEP website (Northwest Hydraulic Consultants, 2015).

Some projections of future climate conditions for the Prairies include declining mean annual flows but higher winter and spring flood flows, and higher probability of severe flooding (Sauchyn and Kulshreshtha, 2008; Sauchyn et al., 2010). However, analyses of historical streamflow records for Rocky Mountain rivers (Rood et al., 2016) point to the likelihood of flood moderation, rather than flood intensification, possibly due to climate change effects including: (i) declining mean annual river flows (ii) reduced snow accumulation (and melt), and (iii) longer snowmelt periods resulting in less severe snowmelt-generated flood events. Yet another analysis of historical records by Whitfield and Pomeroy (2016) for the Upper Bow River showed that when snowmelt-generated floods were separated from rain-on-snow-generated floods, there was no significant trend (increasing or decreasing) in either type of flood event for that basin over the past 100 years. It is difficult to generalize this finding due to localized nature of the study.

Poitras et al. (2011) used simulated streamflows directly from the Canadian Regional Climate Model to examine the spatial patterns of projected changes to mean annual and extreme flows over 10 basins of western Canada, including several within Alberta. An ensemble of five current (1961–90) and five future (2041–70) simulations predicted an increase in the magnitude of winter streamflows and an earlier snowmelt peak for the northern basins. An analysis of selected return levels of extreme flows suggested significant changes to the timing, frequency, and magnitude of both low and high flows, with significant increases in 10-year return period 1-day high flows.

Several recent studies have developed ensemble-based regional climate model (RCM) projections of seasonal and extreme precipitation for Alberta, Saskatchewan and Manitoba, some including watershed-scale predictions (Khaliq et al., 2014; Masud et al., 2016). These studies predict increases in short- and long-duration extreme precipitation into the 21st century. However, Khaliq et al. (2014) point out that RCM representations of mountainous regions are limited and therefore projections for Rocky Mountain watersheds should therefore be viewed with caution.

A recent study by Teufel et al. (2016) investigated the climatological and anthropogenic aspects of the 2013 Alberta flood using the fifth generation Canadian Regional Climate Model. According to the study findings, the estimated return time of the 3-day precipitation event associated with the 2013 flood exceeds 50 years over a large region, and an increase in the occurrence of similar extreme precipitation events is projected by the end of the 21st century. Through the event attribution analysis the study suggests that greenhouse gas increases may have increased 1-day and 3-day return values of May–June precipitation with respect to pre-industrial climate conditions. However, no anthropogenic influence can be detected for 1-day and 3-day surface runoff. This could be due to a number of complex physical processes, and their respective uncertainties, involved in runoff generation compared to the precipitation.

The Bow River Project Consortium and South Saskatchewan River Basin (SSRB) Project Consortium have developed hydrologic (mass balance) models of the Bow River, Oldman and South Saskatchewan River Basins using OASIS software developed by Hydrologics, Inc. The SSRB Project was funded by Climate Change and Emissions Management Corporation (CCEMC) and executed by Alberta Innovates – Energy and Environment Solutions (AIEES, a branch of the Alberta Government) and WaterSMART Solutions (a Calgary-based fee-for-service company). The project was primarily aimed at exploring practical options for adapting to climate change and climate variability in managing water resources within the South Saskatchewan River Basin. As part of this work, the consortium used outputs from an ensemble of 50 Global Climate Model runs to simulate and project mean daily streamflows for the period 1905 to 2096 (AIEES and WaterSMART Solutions, 2013). However, the main emphasis of the study was on adaptation to prolonged drought, and it was recognized that the downscaling methodology to convert annual flows to daily flows did not capture peak high flows (i.e. floods) well. Consequently, the results were of little use for flood mapping purposes. The datasets for the Bow and Oldman-South Saskatchewan River basins are freely available to the public through the University of Lethbridge servers (University of Lethbridge, 2017).

The City of Red Deer developed a climate change adaptation plan in two parts. Part one of the plan (City of Red Deer, 2014) was accepted by City Council in March 2014 and identifies overall goals, the anticipated climate change impacts facing Red Deer and broad groupings/themes of response actions. The report identifies an increased risk of flooding due to increases in annual precipitation for the winter and spring seasons, based on a cited report by the International Council for Local Environmental Initiatives (ICLEI Canada) focused on climate data for Red Deer. Part Two of the climate change adaptation plan is currently being developed and will provide detailed actions under each major theme (City of Red Deer, 2017).

3.4 Supporting datasets

Many of the hydraulic models developed to support flood hazard mapping in Alberta incorporate local bathymetric and topographic survey datasets, channel cross section data (including surveys of bridges and hydraulic structures), LiDAR and other high resolution datasets acquired by third parties specifically for those studies (Golder Associates, 2015; Northwest Hydraulic Consultants, 2013). Recent terms of reference for flood hazard mapping under the Flood Hazard Identification Program (Alberta Environment and Parks, 2016b) require delivery of complete and detailed digital study files to AEP. The study file is the collection of all digital files related to the study, including all acquired and supporting datasets, and models. In theory, all data collected to support flood mapping under the Flood Hazard Identification Program would therefore have been provided as deliverables to AEP and should therefore be available upon request, subject to agreeing to the terms of the Data Distribution Unit's end-user license agreement.

However, given that current versions of some flood maps in Alberta are more than 25 years old and since only about 16% of maps have been updated or completed since the release of the 2011 guidelines, there is likely to be some inconsistencies in the quality and

availability of data. In particular, given the large quantities of data required to support each study, it is possible that not all data is contained (or at least readily accessible) within AEP archives.

3.4.1 Topography and bathymetry

Topographic data is freely available for download from the Canadian Digital Elevation Model (CDEM), developed by Natural Resources Canada (2016). The CDEM stems from the existing Canadian Digital Elevation Data, which were extracted from: the hypsographic and hydrographic elements of the National Topographic Data Base at the scale of 1:50,000; the Geospatial Database (GDB); various scaled positional data acquired by the provinces and territories; or remotely sensed imagery. Spatial resolution varies according to latitude but is 0.75 arc seconds throughout Alberta (approximately 20 m).

A historical hydrographic survey bathymetric map series covering select lakes and reservoirs in Alberta is freely available for download under the Open Government License – Alberta (Alberta Environment and Parks, 2016d).

The Town of Canmore has made LiDAR data acquired on 28 June 2013 available on the Calgary Region Open Data site (Calgary Regional Partnership, 2017). The data is available in a variety of formats, including 1 m resolution raster DEM, LiDAR point cloud files in 1 km x 1 km tiles, and shape files containing elevation contours at 0.25–1.00 m elevation intervals. The County of Grand Prairie has made several LiDAR datasets freely available for download from their website under Open Government license (County of Grand Prairie, 2014). The Alberta Energy Regulator / Alberta Geological Survey website hosts open access bathymetry datasets for 169 lakes, available for download as contours in ESRI shape file format or digital elevation models in ASCII raster grid format (Alberta Energy Regulator / Alberta Geological Survey, 2016).

3.4.2 High water marks survey

Alberta Environment and Parks has been collecting high water mark information since 1952. As of June 2013, 243 high water mark surveys had been conducted at 115 reaches and in 35 different years (Government of Alberta, 2013). At the beginning of 2017, AEP awarded a contract to develop a searchable database to make it easier to retrieve, analyze and share high water mark data. At present, high water mark survey reports and data are distributed to consultants engaged in flood hazard mapping (Alberta Environment and Parks, 2016b) or upon request by contacting the River Forecast Section (Government of Alberta, 2013).

3.4.3 Hydrometric data

Hydrometric data is collected and compiled by Water Survey of Canada. The information is housed in two centrally-managed databases: HYDEX and HYDAT (Environment Canada, 2016). HYDEX is the relational database that contains inventory information on the various streamflow, water level, and sediment stations (both active and discontinued) in Canada. HYDAT is a relational database that contains the actual computed data for the stations listed in HYDEX. This includes more than 450 active and 600 discontinued sites in Alberta, with some records extending from 1902 to the present day. Water Survey of

Canada offers hydrometric data and station information in a single downloadable file, either in Microsoft Access Database format or in SQLite format, updated on a quarterly basis (Environment Canada, 2016). The Environment Canada Data Explorer application is freely available for download and can be used to browse and extract hydrometric information from the HYDAT database.

3.4.4 Aerial photographs

Alberta Environment and Parks' Air Photo Distribution department manages and distributes a collection of over 1.5 million aerial photographs taken from 1949 to 2012 (Alberta Environment and Parks, 2016e). The AEP website includes links to view aerial imagery showing inundation and post-flood damage associated with the 2013 and 2014 flood events in Alberta, and links to third party providers of ortho imagery. The Town of Canmore has made high resolution (10 cm) orthophotos acquired on 28 June 2013 available in seamless image database and geotiff tile formats through the Calgary Region Open Data server (Calgary Regional Partnership, 2017).

3.4.5 GIS data

A variety of topographic data products are available for download from the CanVec database on the GeoGratis website (Natural Resources Canada, 2016). CanVec is a multi-source product coming mainly from the National Topographic Data Base (NTDB) and the GeoBase initiative. The GeoDiscover database (Government of Alberta, 2017) contains a variety of GIS and map products of potential use to support flood hazard mapping (including watersheds, vegetation maps, watercourses, etc.). Some of the products are freely available for download as ESRI shapefiles (including 2011 Watersheds of Alberta), KML files or ASCII CSV files. However, others (such as spot elevations from the provincial digital base mapping project) are only available to view online in the Map Viewer. The website indicates that provincial government employees have access to more data.

3.5 Concluding remarks

In Alberta, flood maps represent an important decision support tool for flood risk management, emergency response planning, and community resilience building. The official flood hazard maps prepared under the supervision of the provincial government are frequently adopted by municipalities in their zoning by-laws. Future climate change impacts on flood risks in Alberta are uncertain but most projections show an increasing likelihood of severe flooding, something that is not presently reflected in the flood hazard maps available in the province. Flood hazard studies and maps have been produced by the Provincial government since the 1970s. Since 1999, Alberta Environment and Parks (AEP), previously known as Alberta Environment and Sustainable Resource Development (ESRD), has continued to produce studies and mapping under the provincial Flood Hazard Identification Program.

The Flood Hazard Identification Program Guidelines provide guidance on the approach to flood hazard studies in Alberta. The resulting flood hazard maps are based on the 100-year return period "design flood" and are freely available to the public to view in a GIS-based application. A number of municipalities have incorporated the maps in their by-

laws. Hydraulic model outputs and other related datasets (such as LiDAR) are not yet available online, though Alberta Environment and Parks is already undertaking some work to populate a searchable database for high water mark survey data.

The Flood Hazard Identification Program Guidelines and more recent terms of reference documents prepared by AEP specify a requirement to use the one-dimensional (1D) HEC-RAS hydraulic model for flood hazard mapping. However, this requirement excludes the possibility of using hybrid (coupled or linked) 1D/2D models, fully 2D, or even 3D models, which may be more appropriate for enhanced floodplain modelling under certain circumstances.

The Flood Hazard Identification Program Guidelines provide limited information on how to properly determine flood hazards and water levels for large lakes. AEP has not undertaken flood studies for lakes historically and has no plans to do so (P. Stevenson, personal communication, 13 February 2017), likely because no urban areas have been identified as being potentially impacted by lake flooding.

The Flood Hazard Identification Program Guidelines do not provide recommendations for incorporating the effects of climate change in flood hazard maps. More recent terms of reference for flood hazard studies prepared by AEP specify a requirement to provide commentary on the potential effects of climate change (Alberta Environment and Parks, 2016b). However, there is no requirement or guidance for incorporating climate change effects in the flood hazard maps.

The devastating flood of 2013 exposed some shortcomings in flood mapping in Alberta, including the need to periodically review and update maps, and the incompatibility of a standard-based approach to mapping with managing flood risk in a changing climate. There is growing consensus in Alberta for a need to migrate towards risk-based approaches to flood management. The typically higher costs and data requirements for quantitative flood risk assessments would require increased investment in flood mapping and data acquisition in Alberta, and may prove prohibitively costly.

The review of flood hazard mapping in Alberta has shown that studies linking the hydrological and climate change aspects with state-of-the-art two- or higher-dimensional hydraulic models for detailed delineation of floodplains and development of flood hazard maps for risk assessment and decision-making are not yet available for the province. Such studies would be useful to support calculations of various types of loads acting on buildings and core public infrastructure due to flood waters. Therefore, focused pilot studies in high flood risk areas are needed to support the development of various codes and standards.

4 British Columbia

4.1 Background

An evaluation of the status of floodplain mapping and supporting datasets in British Columbia (BC) was carried out by KWL (KWL, 2017). Details on the sources consulted and the methodology adopted for evaluating the status of floodplain maps and supporting datasets are documented in the KWL report. Background information on floodplain mapping in BC along with the main features of the evaluation procedures and an overview of the findings are presented herein from the same report.

The provincial government delegated the management of flood hazards to local governments in 2003, and in 2004 the province published Flood Hazard Area Land Use Management Guidelines (revised in 2011) which tied floodplain mapping to flood construction levels by using a frequency analysis plus freeboard allowance. Many of the historical maps were developed for prioritized areas around the province through the Canada-BC Agreement Respecting Floodplain Mapping (1987–2003). After the termination of the agreement and delegated authority, little effort was directed towards developing new or updating the existing flood maps. Some local governments have, more recently, updated their maps; however, there is a significant gap still remaining.

Societal expectations and science have evolved since the conclusion of the Canada-BC Agreement Respecting Floodplain Mapping. Better understanding of flood hazards provides context for level of risk, tolerance and integration into other planning initiatives. This knowledge can then be interpreted in the development of work programs and products that meet multiple objectives and changing needs. For example, floodplain mapping developed under the Canada-BC agreement depicts the extent and likely depth of flooding typified by 1-dimensional modelling. Science and technology now allow for more accurate mapping and better interpretation of the flood hazard by including velocities and depths of flood waters, and consideration of other implications, such as climate change. Availability of LiDAR and more accurate topography and bathymetry surveys coupled with modern 2-dimensional or combined 1- and 2-dimensional computer hydraulic models provide considerable advancement in understanding and capability.

KWL (2017) obtained a list of 162 local governments from the Union of BC Municipalities. This list was refined to 26 municipalities and regional districts based on known flooding hazards and high risk developed areas. The names of the local governments and their contact information and the personnel contacted are available in KWL (2017). In addition, the Fraser Basin Council (FBC) and the BC Real Estate Association (BCREA) were contacted as their continued involvement in floodplain management, specifically floodplain mapping was seen to be beneficial to this assessment effort. The FBC assisted through the notification and distribution of nineteen of the twenty-six questionnaires to the selected local governments. The BCREA provided contacts for the remaining seven local governments. A form fillable secure Adobe PDF questionnaire was developed comprised of twenty-nine different questions. The questionnaire is available in Appendix A of KWL (2017) and was divided into three sections as described below:

- Status of floodplain mapping – this section was devised to obtain information about the status of mapping within the area, and to garner opinion about the flood mapping standards used.
- Climate change – the intent of this section was to determine whether factors, such as climate change were considered or planned to be considered in the floodplain mapping of the area. The organizations opinion was sought to identify what main features of the methodology adopted for riverine, coastal, and large lake flooding problems would be impacted by climate change.
- Supporting datasets – this section was setup to determine availability or lack of data from the organization, including what avenues would be considered for data sharing.

Each organization was e-mailed the questionnaire and later reminded by telephone to reiterate participation in the data gathering process. In some instances, KWL made several exchanges to clarify requirements or to identify alternates to complete the questionnaire. Copies of all filled questionnaires received are available in Appendix B of the report by KWL (KWL, 2017).

4.2 Flood maps and their availability, modelling packages used, and flood mitigation initiatives

Out of 26 municipalities contacted, only 12 responses were received by KWL by the due date. Out of those received, only 11 were found useful as one respondent resorted to simply providing a copy of the recent flood mapping study report. Thus, the information reported here does not represent the entire province and lacks high level of confidence. In spite of these shortcomings, the information provided by those who responded is still useful.

It was difficult to know the provincial authority or local government responsible for creating flood maps from the received responses. However, it was clear that the municipalities were located within designated floodplains as available here: [http://www.env.gov.bc.ca/wsd/data_searches/fpm/reports/index.html] from the BC government. Majority of the maps were updated less than 20 years ago and funding for the update came from various sources. The following list identifies the guideline documents used to generate floodplain mapping:

- Professional Practice Guidelines – Legislated Flood Assessments in a Changing Climate in BC (APEGBC, 2012).
- Coastal Floodplain Mapping – Guidelines and Specifications. Prepared for BC Ministry of Forests, Lands and Natural Resource Operations (Kerr Wood Leidal, 2011).
- Seismic Guidelines for Dikes. Prepared for BC Ministry of Forests, Lands and Natural Resource Operations (Golder Associates, 2011).
- Flood Hazard Area Land Use Management Guidelines (Ministry of Water, Land and Air Protection, 2011).

- Guidelines for Coastal Flood Hazard Mapping and Analysis for the Pacific Coast of the United States (FEMA, 2005).
- Climate Change Adaptation Guidelines for Seal Dikes and Coastal Flood Hazard Land Use: Guidelines for Management of Coastal Flood Hazard Land Use. Sea Dike Guidelines (Ausenco Sandwell, 2011).

Most of the respondents indicated that maps were available online in PDF, GIS, ESRI, and PDKB format. The list of hydraulic models used to create floodlines includes MIKE 11, MIKE 21, HEC-RAS, and HEC-2 for riverine environments. For coastal areas, RiCOM, SWAN, and TELEMAC2D were indicated. However, the majority of respondents did not know which hydraulic model was used to create their flood maps. Base maps were generally produced using LiDAR data. No information was found for lakeshore modelling in the province.

The flood maps generally showed inundation extent and depth of flooding corresponding to the designated flood. Velocity of flood waters is not commonly shown as only a few respondents mentioned availability of maps with this parameter. Ice buildup was not identified as a significant flood factor and therefore ice impacts were not considered in mapping. A few respondents suggested raising the regulatory flood level from 200- to 500-year level.

4.3 Climate change and floodplain mapping

The impact of climate change on floodplain mapping has been incorporated for certain flood prone communities across the province. This was evident from the responses received from a few organizations. The majority of the respondents recognize the importance of integrating climate change with floodplain mapping studies. In particular, recent studies commissioned by the FBC are important to mention (e.g. BC Ministry of Forests, Lands and Natural Resource Operations, 2014; Northwest Hydraulic Consultants, 2016; Fraser Basin Council, 2016). For developing climate change informed flood maps, future time horizons of 2020, 2050, 2080, 2100, and 2200 were targeted. The respondents indicated that the following items are expected to be impacted by climate change:

- Flood frequency;
- Water levels;
- Decreased snow pack;
- Severe rainfall events;
- River migration and avulsion;
- Increased peak flows due to increased precipitation;
- Sea level rise;
- Storm surges; and
- Changes in groundwater levels and ground subsidence.

4.4 Supporting datasets

About half of the respondents indicated that the LiDAR data, orthophotos, flow data, ESRI shape and data files, GIS data, consultants' files, cross section information, and floodplain mapping files can be made available while the rest were not sure if data sharing is possible. Majority of the respondents indicated affirmatively that some sort of arrangement may be made including: interdepartmental memorandum of understandings (MOUs), data share agreements, fee for service delivery, fees for data, and open data systems. Many of the organizations were even more interested in having access to more data including high resolution topographic data (i.e. LiDAR and DEMs) and hydraulic model calibration datasets including: bathymetry; bed material; field surveys of cross sections; bridge files; known flood scenarios; flood magnitude for riverine models; tide/wave heights for coastal and shoreline; and meteorological data. Majority of the respondents were also willing to share outputs of their 1D and 2D hydraulic models for further assessments.

4.5 Concluding remarks

KWL collected information about the status of floodplain mapping in BC through emailing a fillable questionnaire. The questionnaire was provided to individuals who had some working knowledge of flood hazards within the local government jurisdiction. The answers are therefore assumed to be provided to the best ability of the local government officials. The most significant shortcoming of this information gathering effort is the limited sample size and total reliance on individual responses. Twenty-six questionnaires were sent out and twelve responses were received, however, one response provided only a past mapping design brief. This represents a 42% response rate. The sample set thus was a fraction of all the potential local governments in BC and as such, the results do not bear high level of confidence. The following points provide the main findings of the responses:

- 44% had maps that were less than 10 years old which speaks to use of contemporary scientific methods, consideration of climate change, and modelling sophistication using high-end software tools.
- 27% have detailed information that includes depth and velocity of flood waters.
- 82% were willing to share the data they have.

Underlying themes suggest that funding (or access to funding) remains elusive. New national initiatives (e.g. the National Disaster Mitigation Program) could be better utilized to update their maps. Up-to-date data and the costs associated with data collection also appear to be an impediment. There is uncertainty around raising the standard of flood protection in BC. The current standard design flood is the 200-year return period flood which seems to be below design expectations. The uncertainty appears to stem from uncertain climate change and the increase in risk posed by an increase in developments within floodplains.

5 Manitoba

5.1 Background

An evaluation of the status of floodplain mapping and supporting datasets in Manitoba was carried out during January to March 2017 by NRC-OCRE (Babaei, 2017). Some of the main features of the findings are discussed in this section.

Manitoba has experienced some of the most severe floods in the Canadian history. The floods of 2009 and 2011 in southern Manitoba were among the worst riverine floods in Canada (MMM Group Limited, 2014). Red River of the North, in particular, has a well-known flood history including the flooding of 1950 and 1997 (Shrubsole et al., 2003). Flood damage mitigation and protection measures are of key relevance to the province when considering Manitoba's vulnerability to flooding, its considerable extent of farmlands (approximately 12% of total Canadian farmland extent (Statistics Canada, 2017)), and Manitoba's widespread rural and municipal population in most flood-prone regions.

The most extensive flood mapping initiative in the province was under the federally initiated Flood Damage Reduction Program (FDRP), which started in the 1970's, where 17 communities were mapped (Environment Canada, 2017). All communities were mapped for a regulatory 100-year flood, calculated by flow frequency analysis, except for Winnipeg which was mapped for a 160-year flood and two other communities which were mapped for the historical flood of 1976. Under the FDRP standards, new developments are not usually permitted in floodways, defined as portions of the flooded region where water depth is equal or more than a meter. The remaining portion of flooded regions is categorized as flood fringes. In this region developments are usually allowed if structures are flood-proofed (Government of Manitoba, 2017a). Several other communities in Manitoba are protected from large floods by ring dikes. A few of these communities are Emerson, Gretna, Letellier, Rosenfeld, and Dominion City (Government of Manitoba, 2017b). In addition to smaller communities protected by ring dikes, the City of Winnipeg has recently completed the expansion of a large floodway protecting the city against a 700-year flood (Government of Manitoba, 2017c).

Manitoba's provincial government, namely Manitoba Infrastructure, is the only entity that has been responsible for the creation of flood hazard maps in the province. All maps generated under the FDRP and its guidelines are still in use by the province except for the community of Brandon for which there is currently no applicable map. This is because the 2011 Assiniboine River flood levels in Brandon exceeded those of the regulatory 100-year flooding. The community of Carman was also mapped, but the community is now protected from major flooding by a diversion channel (Personal communications with Eugene Kozera, Director of Water Management, Planning and Standards of Manitoba Infrastructure and with Brad Allum, Development Review Officer at the Hydrologic Forecasting of Manitoba Infrastructure, 2017).

To find out whether any new flood hazard mapping initiatives have been or planned to be undertaken by governing bodies other than the province, all (18) Manitoban conservation

districts and many towns, cities, rural communities and villages (approximately 74) were contacted. A list of contacted entities, responders, and the responses are documented in Babaei (2017).

5.2 Flood maps and their availability and modelling packages used

The available flood maps cover a length of approximately 360 km. To cover a large majority of flood-prone communities, an additional 185 km of mapping has been identified by MMM Group Limited (2014).

FDRP flood maps were created using the US Army Corp of Engineers 1D HEC-RAS and its predecessor HEC-2 model. All maps show the extent of flooding and some of them additionally show the floodway, flooded region where the water depth is equal or more than 1 m. These maps are available from Manitoba Infrastructure upon request. However, it is unknown whether the data (if of any value at all because of data age) based on which the models have been developed are retrievable (personal communication with Brad Allum, 2017).

No FDRP map exists for communities in the vicinity of large lakes in Manitoba; all available maps are for regions prone to riverine flooding. In addition, none of the maps are for regions where ice-related flooding is greater than 100-year open-water flooding (personal communication with Eugene Kozera, 2017). It is believed that a considerable proportion of spring floods in Manitoba are impacted by the existence of ice and hence recorded flood levels are not purely open-water levels.

The province has not updated any of the maps after the FDRP, which terminated in 1996. The regulatory flood requirement has been since increased from 100-year to 200-year flood (Personal communication with Eugene Kozera, 2017). However, the province has not yet created any new flood maps based on the 200-year flood. However, Manitoba plans to produce flood hazard maps for three watersheds: Lower Assiniboine River, Souris River, and Whitemud River using the 200-year return period flood under the National Disaster Mitigation Program (NDMP) of the federal government. The list of communities for which FDRP maps are currently in use by the provincial government is available in Babaei (2017). The flood risk maps are not available online. This is mainly because of misinterpretation concerns; the province believes that not all the maps are entirely valid and maps need to be used with special care in order to avoid misinterpretation. It is a common belief that maps are required to be updated by utilizing new technologies such as LiDAR data, modern hydraulic models, and an expanded record of hydrometric and other supporting data (personal communication with Eugene Kozera, 2017).

In addition to the new maps developed for the Town of Virden, several other maps have recently been created for the Lower Pembina River floodplains and the southern part of the Red River. These maps have been developed by the National Research Council Canada for the International Joint Commission through a series of 2D hydrodynamic modelling studies using the 2D TELEMAC model (Faure, 2009; Faure and Jenkinson, 2012; Babaei and Cousineau, 2015). Several flood severities including 10-, 20-, 50-, and 100-year floods were modelled for the existing and natural conditions and for several

hypothetical scenarios to evaluate performance and feasibility of several flood damage mitigation measures. Direct model outputs of the 2D TELEMAC model (i.e. water depth and velocities throughout the modelled domain extending from Morris, Manitoba, located 40 km north of the Canada-USA border, to a region in the USA 20 km south of the border) are available for additional assessments.

5.3 Climate change and floodplain mapping

In the report (Babaei, 2017), a short literature review was conducted to report on the future projections of precipitation and streamflow in Manitoba. It is expected that the future holds more precipitation and streamflow for the region for the 2041–2070 period with respect to the historical observations (~1960–2000). For example, seasonal precipitation is expected to increase up to 30% in winter for northern parts of the province and up to 15% in spring and summer for most of the region (Khaliq et al., 2014). Various return values of short- and long-duration precipitation extremes are also expected to increase by a value ranging from 6 to 23% (Masud et al., 2016). Streamflow for most of Manitoba is also projected to increase by approximately 13% (Poitras et al., 2011). However, precipitation and streamflow projections are associated with large uncertainties as the projections vary considerably from one climate model to the other. This situation thus poses various challenges for decision-making.

The Climate Change and Air Quality branch of the Department of Sustainable Development of the Province of Manitoba was contacted to find whether predicted future intensifications in climatic events are being considered in future flood estimations. This branch along with other branches of Manitoba Infrastructure prepared a response and what follows is quoted from part of the response communicated by Eugene Kozera:

“Due to its location, many areas of Manitoba are vulnerable to flooding, extreme precipitation or periods of drought, and cold weather events. Current climate and precipitation prediction models do not adequately provide sufficient accuracy, confidence and details required to plan and prepare for long-term climate change. Through its engineering, planning and hydrology specialists, Manitoba will continue to address vulnerabilities and build resilience into the transportation and water control infrastructure network, thereby providing flexibility to respond to changing weather patterns, which in turn mitigates future damages and reduces emergency response costs. Evidence shows that our climate has warmed in recent decades and it is expected that future climate will be even more disruptive, bringing frequent extreme precipitation events, floods, droughts, and changing precipitation patterns and water regimes. Manitoba’s plans for enhancing the resilience to its bridges and crossings, water management and flood protection infrastructure include: expansion of the number of meteorological stations in Manitoba; continuing to develop and update IDF curves; exploring new methods for developing design discharge hydrographs; adoption of the 200-year return period flood as the design standard for flood protection levels.

In addition to the new regulatory flood magnitude of 200-year return period quoted above, an additional freeboard is recommended when designing new flood resistant structures and buildings. This recommendation ensures an additional measure to prevent

and mitigate probable future severe floods. The additional freeboard requirement is typically 0.6 m in the design of dikes and similar flood mitigation structures, and 1 m for buildings (personal communication with Eugene Kozera, 2017).

5.4 Supporting datasets

5.4.1 Topographic data

Natural Resources Canada (NRCan) provides a Canada-wide Digital Elevation Model (CDEM) with spatial resolutions of 0.75-arc seconds which depending on location is equivalent to spatial resolutions of tens of meters. CDEM is freely available through <http://geogratis.gc.ca>. In addition to the CDEM, the province and its partners have generated several other DEMs, for different regions at different times. These datasets are freely available through the Manitoba Land Initiative website <http://mli2.gov.mb.ca/dems/index.html>. The horizontal resolution of the provincial DEMs is generally 5 m or finer. In addition to these two sources of DEMs, there are two other DEM datasets prepared by Agriculture and Agri-food Canada (AAFC) for Manitoba; one for southern Manitoba in the Pembina River region and one for La Salle region, both with the horizontal resolution of 1 m. These datasets are available through open data portal.

5.4.2 Bathymetry

Water Management and Structures Division, Manitoba Infrastructure, is unaware of any bathymetry data. NRC is however aware of a few datasets: A 2009 bathymetric survey by AAFC for approximately 30 km of the Red River from Letellier to approximately 10 km upstream of the Pembina River junction. This dataset is available at NRC-OCRE. Another bathymetric dataset by AAFC for a short portion of the Red River, a few kilometers, is also available at NRC-OCRE (Faure, 2009). Additionally, the bathymetric surveys of watercourses in and around the town of Virden for the recent flood hazard mapping project is available through bilateral data use arrangements. Course depth contours of several Manitoban lakes are also freely available through http://www.gov.mb.ca/waterstewardship/fisheries/fish_stocking_gMap_MVC_V2/index.html.

5.4.3 Past flooding extents

Several remotely sensed past flood extents in Manitoba are freely accessible online through 130.179.67.140/dataset/nrcan-flood-maps. These maps will be useful for future flood mapping projects.

5.4.4 Aerial photographs

Approximately one million air photos of Manitoba taken since 1928 are available. It is believed that some of these photos show past flood events in the province. Manitoba air photos are available for purchase through MapSales@gov.mb.ca. More information about these photos is available online through gov.mb.ca/sd/geomanitoba/distribution/index.html#library.

5.4.5 Water levels and discharges

Water Survey of Canada is the primary source of these data which is freely accessible through wateroffice.ec.gc.ca. United States Geological Survey also has some gauges in Manitoba that are accessible through <https://nd.water.usgs.gov/floodinfo/red.html>.

5.4.6 Land use and land cover data

Extensive Canada-wide land cover information is available through NRCan website <http://geogratis.gc.ca>. This dataset is named circa 2000-Vector (LCC2000-V) and originated from remotely-sensed data with similar spatial resolutions to those of NRCan's CDEM data. In addition to this data source, several provincially generated datasets for different regions of the province are freely available through mli2.gov.mb.ca/landuse/index.html.

5.4.7 Culverts and bridges

A comprehensive list of culverts and bridges in Manitoba with their locations and other specifications is available from Manitoba Infrastructure and Transportation.

5.5 Concluding remarks

Although the government of Manitoba has taken major steps to reduce the impacts of flooding in the province including the construction and upgrade of several floodways and dikes, continuous update of IDF curves, and expansion of weather stations across the province, etc., there is still a need for the upgrade of existing flood risk maps (mainly dating back to the 1970's and 1980's) and the increase of spatial coverage of these maps. Additionally, more research is required to quantify how future climatic changes will impact Manitoba and whether present measures of adding specified freeboard will be adequate to prevent damages expected of future flooding. Presently, the impact of climate change has not been considered for generating flood maps. Several freely available data sources were identified that can be used for the development of future flood hazard maps.

6 New Brunswick

6.1 Background

An evaluation of the status of floodplain mapping and supporting datasets in New Brunswick (NB) was carried out by CBCL (CBCL Limited, 2017). Most of the information for NB presented herein is taken directly from the CBCL report. For additional information on the evaluation procedures and sample flood maps, CBCL Limited (2017) can be referred to.

The province of NB contains approximately 60,000 km of streams and rivers, about 2,500 lakes and ponds, and is bounded by thousands of kilometers of ocean coast. From 2008 to 2012, the estimated total cost of flood related damages in NB exceeded \$100 million (Province of NB, 2014). The areas in NB that are susceptible to inland flooding are along the Saint John River (from Fredericton to Lower Jemseg), the Kennebecasis River and tributaries (from the Sussex area to Hampton), and Marsh Creek (in the City of Saint John). Heavy rainfall, snowmelt and ice jams are the causes of NB riverine flooding and storm surges are the cause of coastal flooding. While some floods are attributable to a single cause, others are caused by a combination of many factors.

One significant challenge in addressing flood risks is the availability and maintenance of flood hazard maps. Many of NB's flood hazard maps are decades old and are based on outdated information. The maps do not reflect the impact of climatic and sea level rise predictions, nor the location of new infrastructure and the impact of expanding developments. Also, the flood maps lack the basis of high precision topographic data (e.g. LiDAR) and latest records of hydrometric, meteorological, and tidal and storm surge elevations. Due to increasing climatic variability and the effects of future changes in land cover and land use, flood hazard maps have to be updated regularly, which is not the case at the present time. Recent provincial initiatives are making progress on the inclusion of climate change and sea level rise in flood mapping.

For this review, information on flood mapping in NB was gathered through government websites, online catalogue of the NB Legislative Library, the Atlantic Climate Adaptation Solutions (ACASA) online repository, and through communications with several departments of the NB provincial government.

6.2 Flood maps and their availability and modelling packages used

The federal government initiated the Flood Damage Reduction Program (FDRP) in 1975 in an attempt to curtail escalating disaster assistance payments. In March 1976, NB was the first province to join this program. Over the next two decades since joining the FDRP, 13 flood risk areas were mapped and a total of approximately 237 flood hazard maps were produced. Most of the flood hazard areas mapped were adjacent to rivers, rather than in coastal areas. In addition, a sub-agreement was centered on building sea dikes in the Petitcodiac area, and another sub-agreement on ice research in the Restigouche River and the international section of the Saint John River.

Flood maps produced under the FDRP remains a valuable source of information on flood hazards in several communities. However, there is a need to update these maps to reflect advances in hydraulic/hydrodynamic modelling and digital elevation datasets (e.g. LiDAR); impacts of climate change; and new information on roads, bridges, and buildings. Furthermore, a significant number of existing floodplain maps were based on historic floods and therefore may not be representative of the frequency and extent of future floods. The FDRP flood maps are available electronically on GeoNB website (<http://elgegl.maps.arcgis.com/apps/PanelsLegend/index.html?appid=30b97c1830b84fbd8e581a6d05243bb9>). At the present time, coastal flood hazard maps are not available at the GeoNB website, but may become available soon. The province of NB also has a flood history database, which is a collection of brief information about historic floods.

The reports associated with the FDRP maps do not provide any information about the hydraulic/hydrologic guidelines used. Where required, flood magnitudes for the FDRP studies were almost exclusively obtained using either regional flood frequency analysis (RFFA), particularly for ungauged basins, or single station frequency analysis rather than using hydrological modelling. RFFAs were based on single station analysis conducted on annual maximum daily discharges from Environment Canada's HYDAT stations. Regional regression equations between flood characteristics and physiographic factors were developed for 5 separate regions. The primary hydraulic modelling packages used were the HEC-2 (for hydraulics) and HEC-ICE (for ice jamming). The commonly mapped parameter was flooding extent, while depths and velocities were not part of the FDRP mapping effort. Parameters for ice models (thickness and type of ice, size of ice flows, location and type of ice jams, length and thickness of ice jams, measurements of ice jam roughness) were typically obtained from previous reports, interviews, ice scars, and monthly measurements of ice thickness (in one study). It is noted that for several reports, ice jamming investigations were limited to a historical description/investigation and no modelling was conducted.

Flood hazard identification and mapping in NB did not end with the termination of the FDRP in 2000. In particular, the NB Flood Risk Reduction Strategy was created to initiate the renewal and expansion of NB's existing set of coastal and inland flood hazard maps in accordance with priority areas and new initiatives, including developing technical standards, preparing cost estimates, acquiring LiDAR data, and identifying a desired renewal cycle to help ensure that the mapping remains accurate into the future. The regulatory flood maps do not typically present events with specific return periods (e.g. 20-year flood or 100-year flood), but rather the extents of historic flood events. The maps are updated as new events occur. For example, in 2012, the NB government created electronic flood inundation mapping for the Tobique First Nation and the Village of Perth-Andover indicating the extent of the 2012 ice jam flood. Thus updating previous mapping of the 1976 and 1987 ice jam events that were completed by the province in 1989. In order to identify current community vulnerabilities to ice jams and associated flooding, the Department of the Environment and Local Government updated 1987 Ice Jam Location Map for the province in 2013.

6.3 *Climate change and floodplain mapping*

In 2003, Environment Canada initiated a 3-year, multi-partner study to quantify the impacts of climate change and sea level rise on coastal erosion and flooding in southeastern NB. Funding for the project was provided by the federal government agencies and the provincial government. Participants included researchers from five universities including Université de Moncton and the University of New Brunswick. The study produced an estimated “maximum potential” storm surge based on an analysis of historical events and the effects of predicted sea level rise and coastal subsidence.

In 2008, Natural Resources Canada (NRCan) announced a federal Regional Adaptation Collaborative funding program for adaptation to climate change. The program funded several Regional Adaptation Collaboratives across Canada. The four Atlantic Departments of Environment, led by NB, developed a partnership called the Atlantic Climate Adaptation Solutions Association (ACASA). The ACASA collaborated with non-profit and for-profit partners to design and implement various studies and projects across the Atlantic region. The projects began in 2010 and were completed by 2012. NB-based studies related to flood hazard identification included: climate change and sea level rise scenarios for NB municipalities; sea level rise estimates for coastal areas; and a number of reports related to impacts of climate change on dike erosion and flood risk. LiDAR data was acquired for use in some of these projects. Examples of ACASA studies for the province included: Rothesay-Quispamsis-Saint John; Maisonette to Le Goulet coastal area; Moncton, Dieppe, Riverview; Bay of Fundy; and extreme sea level predictions to 2100 along the coastline (CBCL Limited, 2017).

In addition to the ACASA initiative, several studies related to climate change adaptation were funded under NB’s Environment Trust Fund (ETF). From 2012 to 2015, the ETF supported a “Wet Areas” mapping project led by the University of New Brunswick. This screening tool used remote sensing to identify areas that were vulnerable to flooding, and used factors such as depth to water table, soil moisture, ground elevation, flow paths, flow obstructions, and upstream drainage. These studies used the standard IPCC tri-decades (2020s, 2050s, and 2080s) as their targeted time horizons since the standard IPCC tri-decades were the focus of ACASA sea level rise projections.

As of 2017, there were two other multi-year flood hazard mapping projects receiving support from the ETF. These projects are being completed by the Université de Moncton and other partners and will employ various methods to predict and map flood elevations for watersheds located in southeastern NB. The first project will develop a methodology for predicting flood elevations in ungauged watersheds with the anticipated impacts of climate change. The second project will compare results of geomorphological mapping and hydrotechnical mapping to see if the former could be used as a tool for floodplain delineation (for small and medium-sized river basins). Swansberg et al. (2004) and Anderson (2008) provide additional insights on the impacts of climate change on annual and peak flows and spring flooding.

6.4 Supporting datasets

Many of the datasets used for creating the FDRP flood maps are available in associated supplementary field data reports (e.g., field surveys of river cross sections and bridge piers), although some datasets related to hydraulic modelling (such as historical reference points of flooding depths) are detailed in the main reports. The hydrometric and tide data used are available publically from Environment Canada, and most aerial photos are available at the National Air Photo library. Availability of model outputs and supporting datasets (especially LiDAR and DEM) from NB government is unknown at this time.

6.5 Concluding remarks

Heavy rainfall, snowmelt and ice jams are the causes of riverine flooding in NB and storm surge is the common cause of coastal flooding. Though it was possible to attribute some floods to a single cause, others were caused by a combination of many factors. NB was the first province to join the federal government's FDRP program to map 13 flood-prone areas. Since the FDRP ended, no government led program has maintained flood hazard maps. Thus, many of NB's flood hazard maps are based on outdated data and technology. In addition, the maps do not reflect the impact of climatic and sea level rise predictions, nor the location of new infrastructure and the impact of expanding developments. Recent provincial initiatives are making progress on the inclusion of climate change and sea level rise in flood mapping. Most of the existing floodplain maps are based on historic floods and not on the basis of a designated flood corresponding to a specific return period and therefore do not reflect the influence of the entire flood records. Most recent efforts have been the work of ACASA, which has produced a range of maps that include impacts of sea level rise. However, the maps are based on drawing contours of the future sea level rather than the output of hydrodynamic modelling.

7 Newfoundland and Labrador

7.1 Background

An evaluation of the status of floodplain mapping and supporting datasets for Newfoundland and Labrador (NL) was carried out by CBCL (CBCL Limited, 2017). Most of the information for the province presented here is taken directly from the CBCL report. However, detailed information on the evaluation procedures, sample flood maps and scope of the review conducted by CBCL is available in CBCL Limited (2017).

The province of NL joined the Flood Damage Reduction Program (FDRP) of the federal government in 1981 in order to identify flood management measures that would reduce the social, environmental and economic impacts of flooding in sixteen flood-prone areas in the province. The program involved conducting hydrotechnical assessments, mapping flood risks, and identifying flood mitigation measures. This provincial-federal collaboration ended in 1993 and then until 1996 the province entered in the “General Agreement Respecting Water Resource Management” with the federal government. Since 2009, six of the previous studies conducted under the FDRP have been updated in order to incorporate new topographic information from LiDAR, the effects of the 2010 Hurricane Igor, and the effects of climate change.

The Water Resources Management Division of Newfoundland and Labrador Department of Municipal Affairs and Environment is responsible for protecting, enhancing, conserving, developing, and managing water resources in the province. This division has made available online a comprehensive database of flood studies and maps from around the province. For this assessment study, CBCL downloaded available reports and maps from the division’s website (<http://www.ecc.gov.nl.ca/waterres/flooding/frm.html>), devised an inventory matrix to develop an overall assessment, and requested access to the background data and model outputs (i.e. LiDAR information, air photos from significant historical floods, and computer models).

7.2 Flood maps and their availability and modelling packages used

Provincial flood maps show flood extents corresponding to the 20- and 100-year return period floods. The former extent is designated as floodway and it is the portion of the floodplain where the most frequent flooding occurs and where the flow of water is fastest. The latter extent beyond that of the 20-year return period flood is designated as flood fringe, which is the portion of the floodplain where less frequent flooding occurs and where the flow of water is considered to be tranquil (http://www.mae.gov.nl.ca/waterres/regulations/policies/flood_plain.html). Flood extents in older maps were generated through hydraulic assessments using the HEC-2 model. In the newer maps, the HEC-RAS package with steady state option was used. In some studies, XPSWMM was also used. This hydraulic model can facilitate both 1D and 2D hydraulic calculations under unsteady conditions. Since 2015, the province requires 2D hydraulic modelling for floodplain delineation (CBCL personal communication with Dr. A.A. Khan, Manager Water Rights, Investigations, and Modelling Section, 2017)

A wide range of references and guidelines were used in various studies related to floodplain delineations. In general, most of the studies followed the FDRP guidelines developed by Environment Canada (IWD, 1976). In addition, most of the studies primarily used streamflow records to estimate various flood return values through frequency analyses and delineated floodplains associated with the 20- and 100-year return period floods. Since 2009, deterministic hydrologic modelling and regional frequency analysis approaches have also been recommended to support estimation of flood return values (CBCL personal communication with Dr. A.A. Khan, Manager Water Rights, Investigations, and Modelling Section, 2017).

In areas where ice jams were identified as the main cause of flooding, ice modelling scenarios and hydraulic calculations were based on guidelines available in “Notes on Ice Hydraulics” by Beltaos (1982). These scenarios take into consideration Beltaos’ notes on ice formation processes, locations of ice accumulation, and ice breakup patterns and spatial extents. To address the impact of ice jamming, modelling capabilities of the one-dimensional hydraulic models were generally exploited. In certain cases targeted observational campaigns were initiated. For example, studies at Badger, Rushy Ponds and Bishop Falls implemented field ice monitoring programs to determine ice thickness at several locations, evaluate ice progression, measure ice scars elevation, and evaluate ice behavior during freeze-up, mid-winter and break-up seasons. The collected information was presented in river cross-section drawings at different locations of the Exploits River. To support ice jam modelling, historical ice jams including anecdotal recollection from residents, information on conditions before the events, location of blockage, and ice thickness were also explored.

Many of the studies and flood maps assessed by CBCL show only outline of the flooding extent. The maps produced since 2009 show also spatial distribution of depth of flood water. In two recently updated studies, spatial distribution of depth and velocity of flood waters corresponding to the 20- and 100-year return period events were also produced and shown on flood maps. One of these studies was for Portugal Cove by AMEC Foster Wheeler and the other was for St John’s by CBCL.

7.3 Climate change and floodplain mapping

Provincial flood risk studies have started considering climate change effects since 2009. Since that time all studies have included climate change effects, whether associated with changes in precipitation or sea level rise.

Changes in precipitation

Provincial projections of extreme precipitation (<http://www.turnbackthetide.ca/tools-and-resources/publications.shtml>) suggest that “extreme precipitation events will increase for all locations in the province; in most cases 1 in 100 year storms are projected to become 1 in 50 or 1 in 25 year storms; 1 in 50 year storms are projected to become 1 in 25 or 1 in 20 year storms; and 1 in 20 year storms are projected to become 1 in 5 or 1 in 2 year storms. Regionally, Newfoundland is expected to get more intense events than Labrador. In these projections, seven regional climate model simulations driven by four global models available through North American Regional Climate Change Assessment Program were used. Projected future precipitation values were input to a hydrologic

model to estimate future 20- and 100-year return period flows, and the calculated flows were input to a hydraulic model to produce associated maps. In a subsequent study, Conestoga-Rovers & Associates (http://www.exec.gov.nl.ca/exec/occ/publications/idf_curve_2015.pdf) developed updated projections.

Since 2009, the Water Resources Management Division of the Department of Municipal Affairs and Environment included considerations for climate change as a requirement for flood risk mapping in the province in their “New Template for Climate Change Flood Risk Mapping” (http://www.ecc.gov.nl.ca/waterres/flooding/FRMS_Brochure.pdf). Since then, flood risk maps with climate change considerations have been generated for at least twelve communities within the framework of eight different studies. These studies are listed on the division’s website (<http://www.ecc.gov.nl.ca/waterres/flooding/frm.html>) and generally indicate that the estimated changes in precipitation resulted in flow rates, water levels and flood extents larger than those calculated for precipitation estimates under historic climate conditions. In addition to these studies, many communities have updated their flood risk maps on their own with considerations of climate change (cf. Dr. A.A. Khan, Manager Water Rights, Investigations, and Modelling Section, 2017).

Sea level rise (SLR)

Since 2013, the flood risk studies for Goulds and Petty Harbour, Corner Brook Stream and Petrie’s Brook, Town of Portugal Cove-St. Philip, and Waterford River considered the effects of sea level rise as estimated by Batterson and Liverman (2010) in the “Past and Future Sea-Level Change in Newfoundland and Labrador: Guidelines for Policy and Planning”. Recently, the DFO has developed an online Canadian Extreme Water Level Adaptation tool based on the work of Zhai et al. (2014), with global projections from IPCC AR5 (IPCC, 2013). This tool provides sea level rise allowances for several sites in the Atlantic Region. Allowances are estimates of changes in the elevation of a site that would maintain the same frequency of inundation that the site has experienced historically.

7.4 Supporting datasets

The Department of Municipal Affairs and Environment of Newfoundland and Labrador (CBCL personal communication with Dr. A.A. Khan, Manager Water Rights, Investigations, and Modelling Section, 2017) agreed to make arrangements to share supporting datasets (i.e. LiDAR surveys, computer models, air photos of past flooding extents, etc.) with the NRC for future floodplain modelling studies. Additionally, CBCL on behalf of the NRC submitted a request to the City of St. John’s for sharing background data from the Rennies River Stormwater Management Study. This request was still in the process at the time of compiling this report.

7.5 Concluding remarks

In NL, the Department of Municipal Affairs and Environment is the responsible body for managing all flood studies in the province. The same department has also developed provincial standards for floodplain mapping and climate change assessments. CBCL

reviewed the studies conducted under the FDRP, including subsequent updates. In the studies reviewed by CBCL, where feasible, design flow values were derived from frequency analyses of available high flow records. In cases where high flow records were not available, Environment Canada's IDF curves were used to obtain extreme rainfall events and associated flows. In general the hydraulic assessments involving estimation of water levels and flood extents were carried out based on 1D steady-state modelling using HEC2 and HEC-RAS. Ice jams were a frequent source of flooding and were explicitly addressed in relevant studies. The Avalon Peninsula region reported significant ice-jam related flooding in the 1980s. Through the FDRP, a total of 24 communities were flood risk mapped in NL. In addition to the studies conducted under the FDRP and later updated since 2009, the province has also undertaken additional flood risk studies in areas not studied before. All studies conducted since 2009 include a detailed hydraulic capacity assessment of all existing hydraulic structures for current and future climate conditions (CBCL personal communication with Dr. A.A. Khan, Manager Water Rights, Investigations, and Modelling Section, 2017).

The website of the Department of Municipal Affairs and Environment, Water Resources Management Division, hosts most of the information related to flood risk mapping and study reports. Since 2009, flood risk mapping updates for at least twelve communities were conducted with consideration of climate change effects on precipitation based on studies commissioned by the province. The updated maps generally show water depth as the mapping parameter. The effect of sea level rise was addressed in four different studies since 2013. LiDAR data were used in most of the studies conducted over the last 10 years. The updates utilized surveys of river channel cross sections, water level monitoring, model calibrations, and produced outputs in digital format. The Department of Municipal Affairs and Environment offered sharing available data sources with the NRC.

8 Nova Scotia

8.1 Background

An evaluation of the status of floodplain mapping procedures and supporting datasets in Nova Scotia (NS) was carried out by CBCL (CBCL Limited, 2017). Most of the information for the province presented here is taken directly from the CBCL report. For more detailed information on the evaluation procedures and sample flood maps, CBCL Limited (2017) can be referred to.

There is no governing body responsible for the creation of flood maps in NS. A major part of the flood mapping work was accomplished during the last four years, supported through a provincial program, the Flood Assessment Fund. This program provided 50% of the funding for all flood studies. Apart from this program, administration, stewardship, creation, and dissemination of flood maps has been lacking in the province. The following flood mapping projects, conducted originally under the FDRP, have recently been updated:

- Sackville River (updated in 2017)
- Little Sackville River (updated in 2017)
- Rights River (updated in 2010)
- Truro (updated in 2016)

CBCL has developed updated maps for each of these communities. Almost all flood mapping studies conducted in the province of NS during the last 20 years were accounted for in preparing this review. Since those studies were carried out within the last 10 years and most within the last 4 years, the modelling tools used and the supporting datasets appear to be up to a modern standard.

The areas included in the assessment by CBCL (CBCL Limited, 2017) along with the year in which the studies were concluded are listed below:

- County of Colchester (2016)
- Town of Kentville (2015)
- Municipality of East Hants (2013)
- Eskasoni First Nation community (2016)
- Cape Breton Regional Municipality (2015)
- County of Kings (2013)
- Town of Antigonish (2008)
- Halifax Regional Municipality (2017)
- Town of Mahone Bay (2016)
- Municipality of West Hants (2016)

These communities exist throughout the province and represent the range of risks the communities are exposed to, including the Bay of Fundy tides (in Kentville or West Hants), the Cape Breton steeper watersheds, and the string of lakes in the Shubencadie

River System (in East Hants). Incorporating the impacts of climate change was sometimes requested by municipalities and towns, however not on a consistent basis. Typically, CBCL included an assessment of climate change impacts in proposals even if not requested by municipalities and towns.

In terms of guidelines, FDRP guidelines (IWD, 1976) were generally followed. Due to their generic nature, most of these guidelines are still applicable for present day studies. The guidelines encourage the modeler to make best use of the available technology to improve quality of the analyses and mapping products. Storm surge estimates for the Maritimes were supported by the research conducted at the Dalhousie University by Bernier and Thompson (2006). This source provided valuable information for many of the flood studies carried out in NS.

To identify values for astronomical tidal ranges, the DFO Canadian Tide and Current Tables were used in many studies. Information on the impacts of climate change on rainfall amounts were obtained from the publication by Lines et al. (2009) for several studies until the release of the Western University IDF tool. Interpolation of rainfall data where IDF curves were not available was conducted following the information from the Rainfall Frequency Atlas of Canada (Hogg and Carr, 1985).

8.2 Flood maps and their availability and modelling packages used

In areas where rivers meet the coast, or where large lakes are impacted by tidal influence, suitable models (e.g. dynamic models) were identified and used to understand these complex mechanisms. In locations where floodplain dynamics were found non-linear, 2-dimensional models were used. In locations where lake dynamics were driven by wind (e.g. wind-induced seiching in the Bras D'Or Lakes), 2-dimensional coastal modelling tools were used (e.g. MIKE 21). In locations where tidally driven sedimentation and the influence of climate change led to increased flood risks (in Truro for example), a 3-dimensional model with mud transport capabilities was used (e.g. MIKE 3 with the Mud Transport module).

In areas where ice jamming was a concern, ice jam modelling was undertaken following the methodology proposed in USACE (2006). This methodology involves calibration of the ice module on observed measurements of ice thickness. Though Environment Canada Ice Service provides this information, there were no ice jam measurements available for rivers where such problems were identified. Thus, the results of ice jam analysis were produced and discussed but were not included in flood mapping due to concerns related to legal issues.

For mapping purposes, estimates of design events (i.e. 20- and 100-year return period flows) were estimated directly from flow records using frequency analyses or were obtained from simulated flows corresponding to design storm events with some preprocessing steps. In all cases, simultaneous occurrence of extreme events from more than one mechanism was not considered when deriving the design events, such as an extreme storm surge combined with an extreme precipitation event. For determining water levels corresponding to the 20- and 100-year return period events, HEC-2, HEC-

RAS, SWMM, PCSWMM-2D, MIKE 21, and MIKE 3 were used depending upon the nature of the project. The impacts of tides, ice jams, and sedimentation were included where applicable. The outputs of the hydraulic analyses were mapped using the GIS technology for all new maps. However, the flood maps for the province are not generally available online through a single source, but they can be obtained from the respective municipality or town.

8.3 Climate change and floodplain mapping

In most of the studies completed by CBCL, the impact of potential climate change was considered for generating flood maps. Mostly changes to precipitation, estimated from climate model outputs, and sea level rise, obtained from various published reports, were considered. As the climate models have been evolving over the past several years, climate change projections have been changing as well. For daily precipitation return values, the changes have evolved from approximately +30% (Lines et al., 2009) to +70% (based on the Western University IDF Tool) for different regions of the province. Also, the sea level rise projections vary between 1 to 2.5 m depending upon the emission scenario considered and the region of study. Consequently, each flood mapping study attempted the best available knowledge and projections at the time of the study. The changes in precipitation were incorporated by scaling up the design rainfall events (i.e. 20- and 100-year return period events) for hydrologic analyses and raising the downstream water level boundary conditions by the estimated sea level rise when performing hydraulic analyses.

During the 2014 to 2015 period, the province's Climate Change Unit created a Flood Assessment Fund which provided 50% funding for flood studies in the province. The studies carried out in Truro (Colchester), Kentville and Mahone Bay benefitted from this funding. This initiative has now evolved into the Flood Risk Infrastructure Investment Program, which provides matching funds to communities to invest in identified flood mitigation infrastructure to reduce flood risks and damages. This program consisted of two parts. In the first part, provincial support was focused on building community capacity and incenting investments to reduce flood risk. The actions in part two were related to: improving provincially owned infrastructure; improving interdepartmental collaborations; and strengthening the tools used in the provincial-municipal relationship.

At the municipal level, each municipality was encouraged by the province to use the available funding programs. The province has been proactive in requiring that municipalities develop an Integrated Community Sustainability Plan and Municipal Climate Change Action Plan (MCCAP) for prioritizing their vulnerabilities and identifying infrastructure at risk. It was anticipated that this document will then support funding for more detailed flood studies. The three studies noted above for Truro, Kentville and Mahone Bay were carried out through this program. In addition, flood protection work (dike maintenance for example) in some parts of the province was carried out under this program.

As part of the MCCAP, municipalities were required to map flood extents by identifying the estimated sea level rise (including storm surge) from the report by Richards and Daigle (2011), and delineating corresponding contours on the topographical map of the

coastal areas. The storm surge values were estimated following Bernier and Thompson (2006), and sea level rise estimates were obtained from the IPCC Fourth Assessment Report (IPCC, 2007). The time horizon for both sea level rise and precipitation changes was roughly 100 years. For locations where it was not simple to estimate changes for the 100 year time horizon, tri-decadal values (i.e. 2070-2099) from sea level rise reports (e.g. Lines et al., 2009) were considered acceptable.

8.4 Supporting datasets

Since almost all flood maps for the province were developed by CBCL, all supporting datasets are available on CBCL servers. The towns and municipalities, who own flood mapping studies, have all agreed to share mapping datasets, except for those studies which were in progress. All project data, including bathymetry, bed material, field surveys of river cross sections and bridge piers, known flood scenarios, flood magnitudes for riverine and tide/wave heights for coastal and shoreline areas, etc., as well as model outputs for all studied scenarios can be made available to the NRC.

8.5 Conclusions

The province of NS has been active in raising awareness to the risks of climate change and flooding, and build flood protection infrastructure. In terms of flood mapping, provincial funding programs supported application of some modern hydraulic modelling techniques for creating flood mapping products, specifically for Truro, Kentville and Mahone Bay. Outside the provincial programs, some communities have taken actions to gather their own funding to support the development of new floodplain mapping products. In addition to the above mentioned efforts, the NS Department of Infrastructure Renewal funded a study for Antigonish and Indigenous and Northern Affairs Canada funded the Eskasoni study for floodplain mapping. In these studies, 1-dimensional, 2-dimensional, and 3-dimensional dynamic models (with including wind effects, sedimentation, etc.) were used. Though the flood maps that came out of these studies are relatively new, they only indicate flood extents and are lacking spatial distributions of flood depths and velocities. This information, however, can be generated from the archived model outputs kept on the CBCL servers. Apart from past studies conducted under the FDRP initiative, the impact of climate change in terms of changes to precipitation extremes and sea level rise has been taken into account. Since the information on predictions of future changes to precipitation and sea level rise are constantly changing, it is possible that the maps showing the impact of climate change will be subjected to frequent revisions. Most of the flood mapping products and supporting datasets are available on CBCL servers. In summary, there is no direct flood mapping related output (except the two-zone mapping extents) that can be used to inform development of codes and standards.

9 Ontario

9.1 Background

An evaluation of the status of floodplain mapping and supporting datasets in Ontario was carried out during January to March 2017 by NRC-OCRE. Some of the main findings are discussed here and detailed information can be found in Vouk and Khaliq (2017).

A large portion of resource management in Ontario, at least where the majority of the population resides (~90%) and thus covering the majority of urbanized areas of the province, is under the purview of the Conservation Authorities (CAs). These agencies, a present total of 37, operate on a large watershed basis and have been created by the provincial government in 1946. Their primary responsibility lies in floodplain management, flood forecasting and warning, amongst some others. In areas where CAs have not been established, floodplain management is the onus of the provincial government. It is the Ministry of Natural Resources and Forestry (MNRF) that leads the natural hazard policies and programs which take into account flooding. In the early 2000s, MNRF created the Provincial Policy Statements under which Natural Hazard Policies were specified. From these policy statements, regulations were developed with respect to development, interference with wetlands and alterations to shorelines and watercourses by which all of the CAs must abide by. Though the riverine floodplain mapping—delineating a watercourse and the associated floodplain—is the responsibility of the CAs or the province (i.e. MNRF) where CAs do not exist, delineation of drainage flooding (i.e. the flooding caused by municipal water infrastructure) is the responsibility of the municipality. Provincial guides, policies and regulations do not prevent the CAs to go beyond these policies, thus allowing CAs to create local policies with local procedures to address the specific needs within their watersheds.

Ontario is divided into three zones, known as the Flood Hazard Criteria Zones of Ontario and Conservation Authorities. Each of these zones applies flood hazard standards depending on the location of the intended project or development. In these zones, historic storms (like Hurricane Hazel and Timmins), design floods (e.g. 100-year return period flood) and other more local significant events are taken into account for guidance to developing flood maps. For lakes whose surface area is greater than 100 km² and the Great Lake–St. Lawrence River System a different flood standard is applied. Where one hundred years of wind and water level records exist, the greatest wind setup and the maximum known water level is used, and is referred to as the 100-year level. If the wave rush-up causes the water level to be greater than the 100-year level, it too must be added to the map standards.

For this assessment study, only the CAs and MNRF have been contacted as they seem to hold all of the information required; however further research might indicate that other entities such as municipalities or even industrial operations might hold some information. For example, one entity of interest that has not been contacted is the Canadian Nuclear Safety Commission (CNSC). The CNSC has developed an Integrated Action Plan for federal nuclear plants to respond to the accident at TEPCO's Fukushima Daiichi nuclear power plant. Within the plan, it has been set out to create a flood standard using such

methods as the Probable Maximum Flood standard for the federally run plants (personal communication, Mark Peacock from Ganaraska Region CA, 2017).

In 2015 a number of CAs (under the auspices of Conservation Ontario (CO)) have conducted a comprehensive review with all 37 CAs and the province to develop a Floodplain Mapping Inventory of Ontario. The inventory contains 94 attributes and (as of 2016) holds the information for 739 floodplain mapping projects across Ontario. The attributes in the inventory consist of the following information:

- General information related to the project such as the location of the area and size of the project (i.e. watercourse, watershed, drainage area, length of watercourse, width of widest cross-section, maximum floodplain extent, etc.), the entity responsible for delivering or completing the project, year or planned year of completion, the planned frequency of updates to the work, identification of structures and at risk buildings within the floodplain, hazard identification of the mapped area such as high/medium/low, etc.;
- Imagery information available from the project such as the type of imagery, season of acquisition, geospatial references, accuracies, resolution and the level of verification/peer review;
- Elevation information available from the project such as type (i.e. digital or not), format of data, source of data (primary and secondary), ownership, geospatial references, accuracies, resolution, and the level of verification/peer review;
- Hydrology information such as the identification of the hydrologic method used to derive the flow, number of years in the dataset, the number of and identification of events modelled, identification of quality of calibration and validation (where applicable), quality of input parameters, incorporation of snowmelt for peak flows, consideration of climate change in flood mapping, and the level of verification/peer review;
- Hydraulics information such as the identification of hydraulic model used to derive regulatory flood elevations, identification of flow regimes, identification and quality of calibration and validation, quality of input parameters, and the level of verification/peer review.

For all sub-sections of attributes above, the inventory also provides whether the data of each sub-section has appropriate amount of documentation and reporting to allow qualified personnel to “fully understand and reproduce the results”. Through conversations with CO, it seems that some CAs have gone as far as developing maps with water levels and velocities for areas that are high risk. According to the review, the average year of completion for all floodplain projects within the inventory is 1992, meaning that the average age of floodplain mapping in the province of Ontario is 24 years; 2015 is the most recent year of mapping and 1971 the oldest. Also, at the time of the survey 33,932 km of mapping has been completed within CAs watersheds where most of the mapping (89%) has been completed along watercourses such as rivers and streams, whereas the remainder has been completed inland, shoreline mapping and Great Lakes shoreline and channel mapping.

For better communications the CAs and the province meet on an annual basis for a workshop known as the “Floodplain Mapping Knowledge Transfer Workshop”, where latest projects, technology and innovation are presented to a wider audience comprised of stakeholders that stand to benefit from the information available. In general, the latest information with respect to floodplain mapping in Ontario is presented at the workshop.

9.2 Flood maps and their availability and modelling packages used

A number of the CAs have made flood hazard maps available free of charge, online, in digital form that follow the regulatory zones and flood hazard standards as they pertain to each CA. Many of the CAs have provided regulatory maps online though most do not indicate which flood hazard standard was used for the information provided. Many of the CAs are actively updating their floodplain maps through the National Disaster Mitigation Program funding. For the Toronto and Region Conservation Authority, maps are available upon request as a PDF document, but are associated with a small fee. Other formats are available at a higher cost.

Maps generally show flood fringe and floodway following the two zone concept. The floodway is prohibited to development. However, developments are allowed in the flood fringe, but a number of considerations must be taken into account during development. Special Policy Area designation is reserved for historic developments which were established before the creation of recent policies. For these areas, the one and two zone concepts are not applied and special approvals are required from the MNRF or/and Ministry of Municipal Affairs and Housing (MMAH).

In most cases, 1D hydraulic modelling tools were used (e.g. HEC-2 in older projects and HEC-RAS in new projects). For some recent projects, the TRCA (Toronto and Region Conservation Authority) used MIKE FLOOD for coupled 1D-2D hydraulic modelling. Similarly, the GanRCA (Ganaraska Region Conservation Authority) has recently completed 2D modelling using two different packages, i.e. HEC-RAS 5 and MIKE FLOOD. The Ottawa Region Conservation Authority (ORCA) also used MIKE FLOOD to better characterize spills in the floodplain where a 1D model could not. Though the need for the use of 2D models has been identified for certain portions of the watersheds in various CAs jurisdictions, these models have not yet been widely adopted.

9.3 Climate change and floodplain mapping

Ontario’s existing reference documents (Ontario Ministry of Natural Resources, 2001a, 2001b, 2002; Ministry of Municipal Affairs and Housing, 2014) do not provide any guidance on undertaking floodplain mapping with respect to incorporation of climate change projections. The Provincial Policy Statement (Ministry of Municipal Affairs and Housing, 2014) indicates the need for considering climate change impacts when undertaking natural hazards assessment, but clear guidelines are not provided. In 2009 Ontario’s Expert Panel on Climate Change Adaptation (2009) produced a report titled “Adapting to Climate Change in Ontario” providing recommendations “to help the Ontario government, municipalities and Ontarians prepare and plan for the impact of climate change”. Recommendation 15 of the document advocates reviewing, filling existing gaps and updating floodplain maps, and subsequently incorporating climate

change projections with a planning horizon of 2050; with successive reviews taking place every five years. Recommendation 15 also advocates updating of local and development of regional Intensity Duration Frequency (IDF) curves. The purpose of Recommendation 15 was to provide best available data for municipal land use planning and development, amongst other essential activities. The Ministry of the Environment produced a document, titled “Climate Ready: Ontario’s Adaptation Strategy and Action Plan”. The plan does not take into account any review or updates to floodplain mapping, but it designates the Ministry of Transportation for updating IDF curves and improving quality of rain gauge data.

It seems that climate change is a topic of high interest to the CAs, where they have been recommending the province to modify relevant policies and take climate change into account. However, a number of the CAs are still in the midst of understanding the impacts of climate change and are developing plans with respect to risk and mitigation, however none have yet integrated this information with their floodplain mapping.

A number of academic studies (e.g. Wang et al., 2014, 2015a, 2015b, 2016) on the impact of climate change have been completed with respect to projections of future precipitation and temperature in Ontario. Similarly, some watershed-based regional studies are also available, e.g. Simonovic and Peck (2009), King et al. (2012), Goyal et al. (2012), Coulibaly et al. (2015), and Ahmed and Tsanis (2016).

9.4 Supporting datasets

Currently, the provincial portion of the metadata and supporting data are available to the public and thus to CR-CPI project also. The data however are mapped datasets stemming from the FDRP. The inventory discussed above contains information for 65 project areas where only 14 projects date in the 1990s, the majority of the projects date in the 1980s and several stem back as far as the 1970s. It should also be noted that this area represents only an approximate 10% of Ontario’s population.

Topographic data is available from Natural Resources Canada (2016) for most of the country as discussed in Murphy and Khaliq (2017a). Much of the information feeding into the federal data is derived from provincially prepared information. Recent DEMs are derived from LiDAR, whereas older DEMs were derived from photogrammetry. TRCA, GanRCA, RVCA, and Kawartha Lakes Conservation Authority are notable CAs which use LiDAR derived DEMs. Although the province owns a provincially run data dissemination website known as Land Information Ontario (LIO), the review of Ontario’s Floodplain Mapping Inventory (Ganaraska Region Conservation Authority, 2015) is not available on this website due to some technical and administration related issues. It should be noted though that LIO does contain information on the following spatial datasets, albeit incomplete (does not cover the whole province): flood flow statistics, tactical flood maps, and baseline hydrology. Most of the mapping information is available in the inventory. CO is the custodian of the inventory but does not have blanket permission for its dissemination. It is the CO’s belief that most of the information will easily be made available to the NRC if the future modelling work can be done in

collaboration with the CAs, especially those that already have an interest in the development of flood maps with a focus on climate change resilience.

Hydrometric data is collected and compiled by Water Survey of Canada (WSC). In Ontario, there are 524 real-time hydrometric stations. These stations and the data can be found online. HYDAT database currently contains 1082 historic hydrometric stations for the province of Ontario, some date as far back as 1850. Some regions have access to local (or independently operated) gauging stations which are used alongside the WSC gauges. For example, the TRCA has a network of 18 real-time and 24 standalone gauges. Data from both WSC and TRCA gauges are used in modelling studies.

9.5 Concluding remarks

Floodplain mapping standards in Ontario have been set through province led policies and guidelines. The province is divided into three different flood hazard criteria zones, where floodplain mapping is based on criteria prescribed for each of the three zones (i.e. Zone 1, Zone 2, and Zone 3). Zone 1 covers the Southwestern Ontario and the Golden Horseshoe region; Zone 2 covers Eastern Ontario; and Zone 3 covers a portion of Central Ontario and Northern Ontario. Zone 1 and Zone 3 are based on synthetic storms each guided by a large, historic event in the province known as the Hurricane Hazel and the Timmins storms, respectively. Zone 2 is based on a statistically derived flood magnitude corresponding to the 100-year return period. Each zone's standard can be superseded by an observed and documented storm in cases where the prescribed flood event is exceeded, or even where land uses are dramatically changing. A large portion of Ontario's resource management, or at least where approximately 90% of Ontario's population resides, is subdivided into watershed based regions (a total of 36) known as the Conservation Authorities (CAs). Floodplain management and mapping is the responsibility of the CAs; whereas in areas where CAs have not been established it is the responsibility of the provincial government (i.e. the Ministry of Natural Resources and Forestry (MNRF)).

In 2015 a comprehensive review of floodplain mapping across all of Ontario was led by the CAs and the province (Ganaraska Region Conservation Authority, 2015). The results of the review showed that floodplain mapping across the province vary widely, where some of the oldest mapping stems from 1971 while the latest mapping dates to 2015. The review also showed that provincial floodplain mapping lags behind quite extensively compared to that of the CAs. The latest floodplain mapping by the MNRF was completed in the 1990's around the same time when the federal-provincial program, the Flood Damage Reduction Program, was discontinued. Some of the existing maps are being updated under the National Disaster Mitigation Program.

Most up-to-date maps in ON are available from CAs. However, between the 36 CAs the information varies widely. CAs that encompass larger cities with a higher tax base seem to have most up-to-date information readily available. For the current assessment, four different CAs (i.e. GanRCA, TRCA, RVCA, and GRCA – Grand River Conservation Authority) were contacted and all of them have floodplain maps available in various forms. For example, the GanRCA and the GRCA maps can be accessed directly from the

CA; the TRCA maps can be accessed through a third-party service for a fee; and the RVCA maps can be accessed in PDF form through technical reports available online. Other CAs may have similar or different ways of dissemination.

Most of the available floodplain maps were developed using 1D-hydraulic modelling tools including, HEC-2, HEC-RAS and MIKE 11. Recently, some 2D-hydraulic modelling has been initiated to delineate floodplains for areas where 1D-hydraulic modelling was not deemed suitable (e.g. GanRCA, TRCA, ORCA and GRCA).

Understanding climate change impacts are of importance to the province. However, a number of CAs believe that better guidance is required by the provincial government in order to incorporate climate change impacts into floodplain mapping. In some cases, Intensity Duration Frequency curves that take impacts of climate change into account have been used (e.g. Peck et al., 2012), but there is no consensus across the province on this issue. The Ontario Climate Change Data Portal was developed for the Ontario Ministry of Environment and Climate Change in order to provide practitioners with access to climate change projections, but that information has been used for floodplain mapping.

The review of Ontario floodplain mapping has mainly been made possible through collaboration with the CAs and CO. The GanRCA, TRCA, and GRCA all seem to be open to further collaborations with the NRC, where maps, models and underlying data may be made available. CO is also willing to work further with the NRC to bring any other CAs and information needed (if necessary) into the fold.

10 Prince Edward Island

10.1 Background

An evaluation of the status of floodplain mapping and supporting datasets in Prince Edward Island (PEI) was carried out by CBCL (CBCL Limited, 2017). Most of the information for PEI presented here is taken directly from the CBCL report. Additional information on the study and sample flood maps can be found in CBCL Limited (2017).

The province of PEI did not participate in the Federal Damage Reduction Program (FDRP) and therefore did not undertake any joint federal-provincial flood mapping studies since flood hazards were not found of significant concern during the time of the FDRP, which ended in 1995/1996. Soon after, the province was hit with a major storm surge in January 2000 and again in December 2010, with all references citing the December 2010 event was a significant flood event that caused widespread damages and stranded residents. These events triggered several actions from the provincial government. Also due to growing concerns of the impacts of sea level rise on low-lying communities, several coastal flood mapping studies have recently been carried out in the province between 2012 and 2016. The studies however have generally focused on climate change adaptation and protecting the coast from erosion and flooding during future storm surge events.

On the CBCL request, supported by the NRC, the government of PEI Department of Communities, Land and Environment was able to provide a list of all known coastal flood studies that were carried out within the province, and information on supporting documentation and datasets for those studies where the province was involved. Most of the studies and flood maps were available through Atlantic Climate Adaptation Solutions Association (ACASA) website (<https://atlanticadaptation.ca/>). ACASA is a non-profit organization which coordinates projects related to climate change adaptation initiatives in Atlantic Canada. In addition, the Charlottetown Area Development Corporation was also contacted to gather information on coastal studies related to sea level rise, hydraulic and wave modelling.

10.2 Flood maps and their availability and modelling packages used

For the review of flood maps, the following coastal studies and associated maps were evaluated by CBCL (CBCL Limited, 2017):

- Climate Change Vulnerability Assessment: Mount Stewart, Prince Edward Island (Jardine, 2012a)
- Climate Change Vulnerability Assessment: North Rustico, Prince Edward Island (Jardine, 2012b)
- Climate Change Vulnerability Assessment: Souris and Souris West, Prince Edward Island (Jardine, 2012c)
- Climate Change Vulnerability Assessment: Victoria, Prince Edward Island (Jardine, 2012d)

- Coastal Flood Risk Mapping: Borden-Carleton, Prince Edward Island
- Coastal Flood Risk Mapping: Covehead Bay and Brackley Bay, Prince Edward Island
- Cost–Benefit Analysis of the Risks of Coastal Flooding and Erosion on Infrastructure and Properties in Prince Edward Island (Parnham, 2015)
- Charlottetown Waterfront Assessment (Davies and MacDonald, 2016).

All flood maps produced in these studies show only flood extents based on predictions of future sea level rise and estimations of storm surge residuals. Though the floodlines were produced in GIS format, downloadable layers are not available online. All studies, with the exception of Davies and MacDonald (2016), used global sea level rise projections that originated from the IPCC Fourth Assessment Report (IPCC, 2007). These projections have now been superseded by the IPCC Fifth Assessment Report (IPCC, 2013). A recent report by the National Ocean and Atmospheric Administration (NOAA) of the United States Department of Commerce predicted significantly higher upper bound estimates of sea level rise (Sweet et al., 2017). However, none of the studies have used these updated predictions. Furthermore, none of the studies, with the exception of Davies and MacDonald (2016), included a modelling component.

In the flood maps associated with the above mentioned studies, 100-year return period for the storm surge component of total sea level was used. Discussions with the provincial government officials suggest little interest in changing the flood return period, which is currently set at 100 years.

10.3 Climate change and floodplain mapping

As most of the flood mapping studies mentioned in the above section are basically related to coastal flooding and reflect the influence of future sea level rise, the impact of climate change on flood mapping have explicitly been taken into account.

The studies by Jardine (2012a) for Mount Stewart, Jardine (2012b) for North Rustico, Jardine (2012c) for Souris/Souris West, and Jardine (2012d) for Victoria provided coastal flood maps for 10-, 25-, 50-, and 100-year storm surges, and for sea level rise conditions for the year 2050 and 2100. These studies also analyzed flood damages caused by all major historical storm surges. The studies by the PEI Department of Agriculture and Fisheries for Covehead Bay and Brackley Bay in 2013 and for Borden-Carleton in 2015 were related to the studies conducted by Jardine.

ACASA carried out a cost-benefit analysis study in 2015 on coastal flooding and erosion for two locations in the province: North Cape Coastal Drive and Tracadie Harbour (Parnham, 2015). This study considered 100-year return period storm surge flood mapping and sea level rise conditions for the years 2010, 2040, 2060, and 2070. Sea level rise predictions used for the study were from Zhai et al. (2014) for the Representative Concentration Pathway (RCP) 8.5 scenario.

In the City of Charlottetown, the Charlottetown Area Development Corporation carried out a study for developing planning strategies for the Charlottetown waterfront, including coastal flood mapping (Davies and MacDonald, 2016). Floodlines were delineated for the

2-, 10-, and 100-year return period storm surge for sea level rise conditions for the years 2015 and 2090, obtained from the Fifth Assessment Report of the IPCC (IPCC AR5). The flood levels were estimated using a three-dimensional hydrodynamic model (ADCIRC), a two-dimensional wave generation model (SWAN) and a wave agitation model (Hyper).

10.4 Supporting datasets

The government of PEI has collected LiDAR data and high resolution orthographic photography for the entire province, which is available for purchase at: <http://www.gov.pe.ca/gis/index.php3?number=77867>. The province also provides free GIS data which is available at: <http://www.gov.pe.ca/gis/index.php3?number=77868>.

Coastal bathymetry charts published for the province are available from the Canadian Hydrographic Service, Department of Fisheries and Oceans (DFO). Historical tide data for various DFO tide gauging stations within the province is available online at: <http://www.isdm-gdsi.gc.ca/isdm-gdsi/twl-mne/inventory-inventaire/list-listeeng.asp?user=isdm-gdsi®ion=ATL&tst=1>.

Modelling outputs from hydraulic and wave models were only available for the study conducted by Davies and MacDonald (2016). These outputs are owned by Coldwater Consulting Limited and it is not clear if those outputs will be released soon in the future.

10.5 Concluding remarks

The province of PEI did not participate in the FDRP and hence no mapping studies were carried under that initiative. Recently during the 2012 to 2016 period, multiple coastal flood studies were initiated by the government of PEI, ACASA, and the Charlottetown Area Development Corporation. In these studies, the impact of future sea level rise and extreme storm surge events were analyzed within the province. However, the sea level rise information used within most of these studies was based on predictions which have become outdated now. New predictions as of year 2017 (i.e. Sweet et al., 2017) suggest that most updated global sea level rise estimates by the IPCC (2013) could be on the lower end. The flood lines produced in the above studies need to be updated to reflect more recent predictions. Furthermore, most of the studies did not conduct hydrodynamic modelling, nor had they considered the impact of waves and currents. Future studies should therefore consider the impacts of seiching, waves, and currents to improve flood maps and assessment of coastal erosion.

11 Quebec

11.1 Background

An evaluation of the status of floodplain mapping and supporting datasets in Quebec (QC) was carried out by Aquasphera (Aquasphera, 2017). Most of the information for QC presented here is taken directly from the Aquasphera's report. However, some additional information on the study, methodology adopted for data collection and sample flood maps is available in the report by Aquasphera.

In Quebec, floodplain mapping falls under the responsibility of 14 major cities, 87 MRCs (Municipalités régionales de comtés), two northern region entities, and two metropolitans (Aquasphera, 2017), all referred to here as organizations for convenience. These organizations conduct floodplain mapping studies and update existing maps and are responsible for integrating floodplain maps into urban planning regulations and master plans. All new studies are reviewed by the Centre d'expertise hydrique du Québec (CEHQ) and are expected to be endorsed by regional administrators of the "Ministère du développement durables, de l'environnement et de la lutte contre les changements climatiques (MDDELCC)" before their integration into master plans. Two flood zones are regulated in the province: a high risk zone associated with flows of less than and equal to 20-year return period and a moderate risk zone associated with flows of greater than 20-year and less than and equal to 100-year return period. In the high risk zone new developments are generally not permitted. In the moderate risk zone filling is generally prohibited and construction of buildings is not allowed without proper flood proofing.

Most of the floodplain maps of larger river systems that are currently in use were produced by the CEHQ and a few municipal entities. Most floodplain mapping studies were produced during two government assisted programs. The first mapping program started in 1976 and ended in 2001. It was created following an agreement between the federal and provincial governments (i.e. the Flood Damage Reduction Program) and it covered approximately 245 municipalities. During this program, more than 500 flood risk maps were produced using the 20- and 100-year return period flows. The second program was also coordinated by the CEHQ, started in 1998 and lasted for 5 years. This program covered less urbanized areas and led to mapping of about 155 new lakes and river sections. Several other floodplain maps were generated based on photo interpretations (i.e. using the "large brush" method) to cover regions that were in remote/rural areas and characterized by smaller populations. These maps seem to be less accurate as flood lines often fall on high grounds.

Aquasphera (Aquasphera, 2017) made an inventory of all floodplain mapping studies produced by the CEHQ. This inventory included the review of over 200 studies and over 1200 mapping files, available online as PDF documents. A summary of the review was compiled based on the following set of points: name of the responsible entity (i.e. the municipality or government department); region of study; year of the study when the maps were produced; type of water body and the name associated with it; hydrometric data sources and their availability; nature of regulation (whether controlled or uncontrolled watercourse); influence of tide—whether present or not; watershed area;

length of studied reach; hydrological methodology used; flow data—number of years of record; peaking factors; hydraulic methodology used; calibration procedures used; downstream boundary conditions used for hydraulic models; availability of bathymetry data; water level/flow data used for calibration purposes; climate change information; consideration of ice jam flooding; availability of maps; the type of flood lines available on maps (whether those are return period based or correspond to historical event); availability of topographic data; availability of aerial photography; and information about observed flooding problems (approximate number of houses, roads, etc. impacted).

For information gathering purposes, Aquasphera prepared a questionnaire which was sent to 105 organizations (i.e. MRCs and larger cities) responsible for creating and disseminating flood risk maps across the province. The questionnaire is available in Aquasphera (2017). All organizations were requested to provide published reports and information on maps not available from the CEHQ website, specifically information on the studies produced after 2004. A total of 73 organizations responded to the survey by the due date and that number corresponds to roughly 70% of the organizations surveyed. The population served by the responding organizations represents 74% of the estimated population of the province (according to the 2016 census). Also, 79% of the larger organizations (i.e. the larger cities that are also MRCs) responded to the survey.

11.2 Flood maps and their availability and modelling approaches and packages

In Québec, most of the floodplain mapping studies and associated maps of larger river systems are available from the CEHQ website: <https://www.cehq.gouv.qc.ca/zones-inond/carte-esri/index.html>. More than 91% of these studies were produced more than 10 years ago. Over the last 15 years, several floodplain maps were updated. These studies were funded by MRCs and municipalities who now have the responsibility of providing these maps to various users. Following responses of about 47% of the surveyed organizations, a total of 72 studies were conducted outside the government-funded programs and still 12 of these studies were in progress at the time of the survey. In some of these studies, flood maps were updated while in others, new areas were mapped. Flood mapping products are available from these organizations in both PDF and GIS format.

Provincial government studies were generally based on a consistent set of hydrologic and hydraulic methods. However, no official standards are available for the study of floodplains in the province. Some hydrological and hydraulic modelling methods are described on the CEHQ's website. In the provincial government studies, hydrological analyses generally refer to the following approaches:

- A single-site statistical analysis of flow records (from a local station or from a station located on a similar watershed) combined with a watershed area or flow based transfer function. This method involves determination of 2-, 20- and 100-year flood flows from the annual maxima series recorded at a gauging station. These estimates are then prorated using a watershed area or flow based transfer function to the studied watershed. To be applicable, watersheds have to be physically similar. The transfer function is usually a ratio of watershed areas.

- A regional statistical analysis of flows, where data from several stations are combined, is applied to a local site using a watershed area or flow based transfer function. The regional frequency analysis approach developed by Anctil (1998) is one of the methods described and used in the CEHQ studies carried out after 1998. This method is based on flow data collected from near-natural or almost unregulated rivers.
- Some studies followed a flood indices approach. This approach involves photo interpretations to identify frequently flooded area (which generally corresponds to the 2-year flood), site visits and/or survey of local populations to identify flood level marks (it is not always possible to identify the recurrence interval of the flood lines). This approach was mostly applied for floodplain delineation around lakes.
- Fewer studies followed a hydrological modelling approach, where the physical response of a watershed (i.e. the runoff produced) due to rainfall and/or snowmelt was simulated.

Most hydraulic models developed by the CEHQ were created using the HEC-RAS (1D) package. In some studies, Hydrosim and Modeleur software were used. Most of the hydraulic studies included calibration of models using measured flows and water levels. In some parts of the St-Lawrence and Ottawa rivers, flood maps were developed following a statistical analysis of measured water levels.

The second popular flood level estimation approach found in provincial government studies pertains to establishing a relationship between water levels measured at different sites and the water level measured at a reference station (a stage-stage relationship), for a given flow condition. A relationship between stage and flow at the reference station (a stage-flow relationship) allows for determining flood levels for different return periods at the reference station. Then, flood levels at other locations along the watercourse can be estimated based on the previously determined stage-stage relationships.

For regulatory purposes, flood extents on flood maps are commonly delineated for three severity levels: the 100-year, 20-year and 2-year return period floods. Some organizations used historical data for floodplain delineation. The maps that show flood extents for the 2- and 20-year return period floods are used to delineate the high risk zone. For the larger river systems, the maps always show flood extents for the 100-year return period flood. The 100-year flood extents are used in combination with the 20-year extent to delineate the moderate risk zone.

Some organizations have reported that flooding is often induced by ice jams. However, no floodplain maps were found based solely on ice jam mechanisms. A few organizations have mapped ice jam areas, but it is unknown if those were determined by field observations or following an ice jam modelling approach.

11.3 Climate change and floodplain mapping

A few years ago Centre d'expertise hydrique du Québec (2013) completed a floodplain mapping study by considering the impact of climate change. In their study rainfall intensities were modified to incorporate the impact of climate change when performing

hydrologic analysis. This study makes reference to another study on climate change by Villeneuve et al. (2007). Among the studies received by Aquasphera, one considered the impact of climate change by increasing rainfall intensities by 10% for the 20- and 100-year return period cases following recommendations from the provincial stormwater management guide (*Guide de gestion des eaux pluviales du Québec*, Gouvernement du Québec, 2011). Another study recommended 0.5 m freeboard to be added to the calculated flood levels to address the impact of climate change and other uncertainties. In addition to the above, still another study considered the impact of climate change by increasing spring flood flows according to the values provided by the Hydroclimatic Atlas of Southern Québec (Gouvernement du Québec, 2015).

According to the Gouvernement du Québec (2015) study climate change may have a negligible impact (or a positive impact) from the viewpoint of flooding (i.e. decreases in spring flood flows are expected) on most watercourses in the southern part of the province, where most of the population lives. This provincial study was prepared by several experts representing Ouranos Consortium, École des technologies supérieures, Institut national de la recherche scientifique, and CEHQ. The study was based on climate change simulations that represent various scenarios of the potential evolution of greenhouse gas concentrations. Large scale modeling results were produced using the Hydrotel hydrological model. In the study, model calibration was achieved using gauged data from 50 different watersheds. This study concludes that the 20-year return values of peak flows are expected to increase by 10 to 15% at a few sites in the northern portions of the Outaouais, Saguenay and Côte-Nord regions. Other studies (e.g. Calvet-Gaumont et al., 2012; Jeong et al., 2013) suggest somewhat different projections based on the direct use of Regional Climate Model simulated flows and caution about the higher level of uncertainties associated with longer return period flows. It seems that no organization has taken initiatives to address the impact of climate change on floodplain mapping, although climate change seems to be a concern for some organizations.

11.4 Supporting datasets

Some organizations (i.e. cities and MRCs) are willing to share supporting datasets for future floodplain mapping projects based on data use and/or data sharing agreements. Some of these supporting datasets are available for purchase only.

LiDAR and other topographic data are available for purchase from various organizations and the private sector. LiDAR data can also be purchased from the Géoboutique, which is a provincial government service of the Ministère de l'Énergie et des ressources naturelles du Québec (MÉRNQ). Most of the LiDAR data used by the CEHQ were gathered between 2000 and 2003. Since then, LiDAR coverage has increased in the province. A 2016 LiDAR program, ended recently, covers important portions of the urbanized territory, located on the northern side of the St-Laurence and Ottawa rivers. These parts were not covered before. Digital elevation models derived from LiDAR data are available for free from the Ministère de la sécurité publique du Québec (MSPQ) and are provided by the Ministère des Forêts, de la Faune et des Parcs du Québec (MFFPQ). This data covers 55,000 km² of the Saguenay-Lac-Saint-Jean, Mauricie and Outaouais regions. The

MFFPQ intends to cover a total of 500,000 km² before 2021. Some LiDAR data is also available for free from The City of Montréal.

The CEHQ sells data from their hydraulic models (e.g. bathymetry, river cross sections, geometry of bridge piers, etc.). The organizations (i.e. MRCs and cities) generally do not have access to hydraulic models, especially the ones which were developed by consulting engineering firms after 2004. These models are generally owned by consultants and have not been shared with the organizations.

11.5 Concluding remarks

In Québec, the majority of floodplain maps are outdated and mapping coverage is also insufficient for most communities. To aid decision-making, significant efforts will be required to improve flood risk assessment and floodplain mapping and mitigation activities. Most of the floodplain maps in the province, currently in use for larger river systems, were produced between 1976 and 2004 by the provincial government and those maps have not been updated since that time. Most of the organizations reported that they have to rely on maps that were derived based on simplistic and inaccurate floodplain delineations following the “wide brush” method. Some maps lack precision as the properties at risk are often not identified in floodplain areas and properties at low risk are often located within delineated floodplains. Consequently, flood events often result in damage to properties, cultivated lands, and infrastructure. Flooding is often caused by ice jams but floodplain maps are generally not based on ice jam considerations.

Only a few floodplain mapping studies have considered the impact of climate change by increasing the rainfall amounts arbitrarily. A recent study (Gouvernement du Québec, 2015) has suggested that climate change may have a negligible impact on spring floods (i.e. 20-year return period values). Other studies (e.g. Calvet-Gaumont et al., 2012; Jeong et al., 2013) suggest somewhat different projections. Therefore, more studies might be required to better assess potential impacts of climate change on flood magnitudes.

The main barrier to updating floodplain maps identified by respondents of the survey is the lack of funding. A recent study submitted to Public Safety Canada reported that about \$153 million would have to be invested in floodplain mapping projects in Québec (MMM Group Limited, 2014). Aquasphera’s survey results have revealed that 86% of the organizations have a significant interest in improving their floodplain maps. All of the organizations have supporting datasets that can be made available for future floodplain mapping projects. Data acquisition methods have improved and availability of data has significantly been increased over the last decade. For example, there is a good opportunity to access recently surveyed LiDAR data to improve hydraulic models and floodplain delineations. LiDAR coverage has significantly been improved in the province.

12 Saskatchewan

12.1 Background

An evaluation of the status of floodplain mapping and supporting datasets in Saskatchewan was carried out during January to March 2017 by NRC-OCRE (Murphy and Khaliq, 2017b). Details on the sources consulted and the methodology adopted for evaluating the status of flood maps and datasets can be seen in Murphy and Khaliq (2017b). Main findings of the evaluation are discussed herein.

The climate of prairies is one of the most variable in Canada and North America (Sauchyn et al., 2009). After drought, flooding has historically been the second most common cause of disasters in Saskatchewan, with 19 flood disasters recorded in the Canadian Disaster Database between 1900 and 2005 (Insurance Bureau of Canada, 2012).

Flood mapping has been identified as an important tool for flood risk management and building resilience in Saskatchewan (Saskatchewan Water Security Agency, 2012a; 2012b). Understanding the current status of flood mapping in Saskatchewan is an important first step in identifying potential needs for improvement or development, including incorporation of climate change effects.

The Statements of Provincial Interests Regulations 2012 (SPI) includes the requirement that development be prohibited in the floodway of the 500-year flood elevation of any watercourse or water body and that new development in the flood fringe to be flood-proofed to an elevation 0.5 meters above the 500-year flood elevation. In this context, the floodway is defined as the portion of the floodplain adjoining a watercourse where the water depth meets or exceeds 1 m or a velocity of 1 m/s during the 500-year flood. The flood fringe is the portion of the floodplain where water depths and velocities are less than a depth of 1 m or 1 m/s, respectively (the SPI).

Saskatchewan was an active participant in the national Flood Damage Reduction Program (FDRP) since joining in 1977 and signed general and combined Mapping and Studies Agreements with the federal government (Environment Canada, 2013). Moose Jaw was one of six communities selected for pilot mapping to support the early implementation of the FDRP (Handmer, 1980). Maps produced under the FDRP are held by the Saskatchewan Water Security Agency (WSA), formerly known as the Saskatchewan Watershed Authority. WSA works with provincial agencies, municipalities, conservation and development authorities, and watershed associations to develop plans to address flood risks in the province. There are approximately 90 conservation and development authorities and 15 watershed associations in Saskatchewan (Provincial Auditor of Saskatchewan, 2014).

Under the FDRP, flood risk areas were officially designated for 17 communities during the period 1980 to 1996 (with “interim designation” status for an additional 3 communities), based on a variety of flood events or standards including the 100-year return period, 500-year return period and historical floods of record. The hydraulic modelling for these studies was typically carried out using the HEC-2 1D hydraulic

modelling software developed by the US Army Corps of Engineers (A. Kashem, personal correspondence, 2017). Although the FDRP was discontinued in 1997, there is evidence to suggest (Water Security Agency, 2012b) that the use of the maps in preparation of zoning by-laws and development plans has helped to mitigate flood damage during significant flood events in Saskatchewan (e.g. Regina and Lumsden in 2011).

In Saskatchewan development in flood prone areas are regulated by municipalities through official community plans (OCPs) and zoning by-laws. The SPI, authorized and adopted under the provincial Planning and Development Act 2007, link provincial and municipal objectives for land use planning. The SPI states that all new OCPs and zoning by-laws must contain policies to address the management of lands subject to natural hazards, including flooding (Government of Saskatchewan, 2017a, 2017b).

Although most flood maps are now more than 25 years old, there have been demonstrated benefits associated with the mapping work, in terms of restricting development in the floodplain and reducing the cost of damages. Historically, there has been a lack of consistency in flood standards applied by municipalities in Saskatchewan, i.e. some maps correspond to 100- or 500-year return period floods, while others to the historical flood of record. However, provincial legislation enacted in 2012 has now set a consistent basis for managing floodplain development based on the 500-year return period flood. This legislation has caused a few municipalities that had adopted lower standards to begin the process of updating/revising their maps, generally by or with the support of WSA.

Limited new studies for updating flood maps are being undertaken in Saskatchewan and in some areas there is a heavy reliance on informal knowledge (e.g. based on historical flooding) as a basis for assessing areas at risk of flooding. This is a cause for some concern, as there is evidence to suggest a significant shift in the causes of extreme flooding in the province (from snowmelt to rainfall), which would invalidate historical records as a basis for determining flood risk and cause different areas to be more prone to flooding.

12.2 Flood maps and their availability and modelling packages used

Under the FDRP program, flood maps were developed for a total of 17 communities. Existing maps and available data held by WSA for these communities can be acquired from WSA. As most are older studies with limited underlying data available and also not in digital formats, these datasets may not be very useful for future studies. Pilot studies in a few areas where LiDAR data is available would likely be more feasible. However, the major challenges will involve (i) determining how to deal with the lack of usefulness of historical streamflow data, given the shift from snowmelt to rainfall as the main driver for extreme flooding; and (ii) how to account for future climate change given the significant uncertainty in projections (i.e. some climate models predict increases in streamflows, while others predict decreases).

Several older maps for northern Saskatchewan communities are available to download in PDF format from the “Planning for Growth North” website (Ministry of Government Relations, 2017). Maps produced under the FDRP can be requested through the WSA

(free of charge) for several communities. The maps are available to view only in PDF or TIFF format. GIS vector files (file geodatabase feature class) are available for floodway and flood fringe polygons. The intention is that the data will be made available for download from WSA's website in the future (A. Kashem, personal communication, 2017). WSA does not have a map management program in place and maps have generally not been updated. A need for additional funding to support maintenance or improvement of flood mapping capabilities has been identified.

Interestingly, Agriculture and Agri-Food Canada (AAFC) has completed three flood mapping-related studies in rural Saskatchewan during 2006-2009 and 2012-2013 period under the Land and Resiliency Assessment (LIRA) project, using the Wetland DEM Ponding model developed at the University of Saskatchewan. High resolution LiDAR data collected for these studies is freely available to download from the open data portal.

12.3 Climate change and floodplain mapping

Potential climate change effects are not presently incorporated in the flood hazard maps produced by the WSA. A lack of funding has been identified as a potential barrier to facilitating incorporation of climate change effects in provincial flood maps. However, there are also technical challenges associated with the distinctive topography and hydrology of the prairies and difficulties in understanding how the system will respond to climate change. Some evidence of a potential shift from snow melt to rainfall as the main driver for extreme flood events in Saskatchewan means that historical streamflow records (and conventional approaches to flood frequency analysis) may not be useful for directly determining the statistics of extreme floods. Predictive numerical models of future climate, weather, hydrology and streamflows, though not without uncertainty, could be promising options for assessing flood risk in Saskatchewan.

Valeo et al. (2007) highlighted the lack of consensus within the scientific community on the implications of climate change for flood frequency and intensity in prairie watersheds. A report published by Natural Resources Canada suggested that most projections of future climate conditions for the prairies include declining mean annual flows but higher winter and spring flood flows, and higher probability of severe flooding (Sauchyn and Kulshreshtha, 2008). Some recent studies utilizing ensemble-based regional climate model predictions suggest increasing mean annual stream flows and extremes into the second half of the 21st century (Poitras et al., 2011).

Martz et al. (2007) used downscaled climate scenarios from general circulation models (GCMs) to project surface water supplies in the South Saskatchewan River Basin (SSRB) under different climate change scenarios. Hydrologic models, calibrated to records within the SSRB and forced by the downscaled GCM scenarios, were used to predict future water availability in terms of "naturalized" streamflows (i.e. without the impacts of flow regulation and withdrawals). There were broad variations in the impacts of climate change on annual precipitation in the SSRB predicted by different down-scaled GCM scenarios, ranging from a 3.8% decrease to an 11.5% increase by 2050. Significant variability in predicted peak monthly flows within and across sub-basins is reported,

suggesting increases or decreases relative to the 1961–1990 baseline period depending on the sub-basin, the time of year and the GCM or climate scenario used.

Alam and Elshorbagy (2015) used a large ensemble of GCM predictions, a stochastic rainfall generator calibrated against historical records, and a frequency analysis in an attempt to determine climate change impacts on extreme rainfall for the City of Saskatoon. Based on the analysis, it was concluded that the direction and magnitude of changes in future extreme daily rainfall intensities derived from GCMs is highly uncertain at local scales and the resulting intensity-duration-frequency curves are dependent on many factors including the choice of GCM and the emission scenario. This finding is in agreement with the findings of Mladjic et al. (2011) who demonstrated such local scale uncertainties based on the Canadian Regional Climate Model (CRCM) simulations. Several other studies have developed ensemble-based regional climate model projections of seasonal and extreme precipitation in the Canadian Prairie provinces, some including watershed-scale predictions (Khaliq et al., 2014; Masud et al., 2016). These studies predict increases in short- and long-duration extreme precipitation into the 21st century.

Poitras et al. (2011) used simulated streamflows directly from the CRCM to examine the spatial distribution of projected changes to mean annual and extreme streamflows over 10 basins of western Canada, including several within Saskatchewan. An ensemble of five current (1961–1990) and five future (2041–2070) simulations predicted an increase in the magnitude of winter streamflows and an earlier snowmelt peak for the northern basins. An analysis of selected return levels of extreme flows by Poitras et al. (2011) suggested significant changes to the timing, frequency, and magnitude of both low and high flows with significant increases in 10-year return period 1-day high flows.

In summary, the impact of climate change on future floods and development of future flood hazard maps and how the increased flooding will impact buildings and core public infrastructure have not been studied adequately throughout the province at both regional and local scales.

12.4 Supporting datasets

According to Saskatchewan WSA, limited supporting data is available from the studies undertaken by the province to produce flood maps. Available data includes some LiDAR, DEM and cross-sectional survey data for some of the more recent studies. For older studies carried out under the FDRP, some photogrammetrically derived topographic contours are available to view (as a raster image only) based on scanned large scale maps. The data is freely available upon request to WSA.

12.4.1 Topography and bathymetry

Topographic data is freely available for download from the Canadian Digital Elevation Model (CDEM), developed by Natural Resources Canada (2016). The CDEM (Natural Resources Canada, 2016) stems from the existing Canadian Digital Elevation Data (CDED), which were extracted from: the hypsographic and hydrographic elements of the National Topographic Data Base (NTDB) at the scale of 1:50,000; the Geospatial Database (GDB); various scaled positional data acquired by the provinces and territories;

or remotely sensed imagery. Spatial resolution varies according to latitude but is 0.75 arc seconds throughout Saskatchewan (approximately 20 m). LiDAR data collected in 2011 and 2012 by Agriculture and Agri-Food Canada (AAFC) for several sites in southern Saskatchewan (Admiral, Lafleche, Russell Creek and Cadillac-Gouveneur) is freely available for download under Open Government Licence (Government of Canada, 2013). The data consists of 1 m resolution bare earth and full feature grids in ASCII, ESRI geodatabase and hillshade (geotiff) formats. The City of Prince Albert LiDAR data, acquired in 2015 to support ongoing efforts to update and upgrade flood maps within the municipality, can likely be made available on either a free or cost-sharing basis, subject to a formal request and discussions with interested parties.

More than 900 historical lake bathymetric surveys carried out from the 1950s to 1970s for fisheries assessments are available for download in PDF file format from the provincial government's web-based GIS application (Government of Saskatchewan, 2017d).

12.4.2 Hydrometric data

Hydrometric data is collected and compiled by Water Survey of Canada (WSC). WSC now offers hydrometric data and station information (HYDAT) in a single downloadable file, either in Microsoft Access Database format or in SQLite format, updated on a quarterly basis (Environment Canada, 2016). The Environment Canada Data Explorer application is freely available for download and can be used to browse and extract hydrometric information from the HYDAT database.

12.4.3 Flood extent polygons

Several flood extent polygons are available for download under Open Government Licence for the 2011 flood event that occurred in southern Saskatchewan (Government of Canada, 2017). The flood extent products are derived from satellite imagery with a system developed and operated by the Earth Sciences Sector (ESS) of NRCan. This emergency mapping service is activated for large flood events in Canada. Products are generated and distributed in near real time as processed imagery becomes available.

12.4.4 GIS data

A variety of topographic data products are available for download from the CanVec database on the GeoGratis website (Natural Resources Canada, 2016). CanVec is a multi-source product coming mainly from the National Topographic Data Base (NTDB) and the GeoBase initiative. The provincial government's interactive GIS web application (Government of Saskatchewan, 2017c) hosts a variety of map-based products of potential use to support flood hazard mapping (including locations of watercourses, infrastructure maps, earth imagery). The information can be viewed online or exported to various image-based file formats.

12.5 Concluding remarks

Given history of damaging floods in Saskatchewan, flood maps represent an important decision support tool for flood risk management, emergency response planning, and community resilience building in the province. The mapping conducted under the federal-

provincial Flood Damage Reduction Program, and subsequent zoning and development restrictions by municipalities, have significantly reduced the cost of recent floods (Saskatchewan Water Security Agency, 2012b). The Statements of Provincial Interests Regulations 2012 has addressed historical inconsistencies in standards adopted by municipalities by setting a consistent basis for determining flood requirements (i.e. the 500-year return period flood).

The impacts of climate change on flood hazards in Saskatchewan are highly uncertain. However, most projections of future climate conditions for the Prairies include higher winter flood flows, and higher probability of severe flooding. Studies linking hydrological and climate change aspects with state-of-the-art two-dimensional hydraulic models for detailed delineation of floodplains and development of related flood maps for risk assessment and decision-making are not available for the province. Also, there are no government sponsored initiatives currently underway or planned for the future in the province along these lines.

Many of the flood maps produced under the FDRP are now more than 25 years old and are inconsistent in terms of return periods, parameters mapped, modelling aspects, data quality, and technological advancements. Maps are not periodically updated and available funding is presently not sufficient to sustain a comprehensive map maintenance program. As a consequence, there is a heavy reliance on informal knowledge (e.g. based on historical flooding) as a basis for assessing flood risk. The risks associated with this ad hoc approach have likely been mitigated by the relatively high standard adopted for flood mapping in Saskatchewan (i.e. 500-year return period). However, in light of the uncertainty surrounding climate change impacts on flood frequency and intensity in Saskatchewan, there is a need for a more methodical approach to flood risk management and mapping.

Ensemble-based regional climate model predictions offer prospects to support assessments of future flood hazards and for predicting climate change effects on floods in Saskatchewan. However, there remain several challenges to be addressed including the uncertainty in downscaling global climate model predictions and making best use of the high-resolution regional climate model outputs to obtain small regional and local scale estimates of extreme floods.

In Saskatchewan, most flood mapping has been carried out under the FDRP guidelines. However, the validity of some of the conventional approaches to hydrologic and hydraulic analyses outlined in the guidelines have become questionable, due to Saskatchewan's distinctive hydrology (e.g. snowmelt and rainfall events, extreme inter-seasonal and inter-annual variability, and the presence of large number of non-contributing sloughs or potholes) and the uncertainty surrounding climate change impacts on flooding in the province. There is a clear need to develop updated codes and associated guidelines to address flood hazard, in particular to support objectives related to the design and rehabilitation of buildings and infrastructure for improved resilience.

13 Territories

13.1 Background

An evaluation of the status of floodplain mapping and supporting datasets in Northwest Territories, Nunavut and Yukon Territory was carried out by NRC-OCRE (Piché, 2017) during January to March 2017. Some main features of the findings are discussed here.

Due to the isolation and small size of many northern communities even a relatively minor flood may result in undue strain on the communities' resources. While the territories have not had a large amount of flood disasters within the past century, with only five events in the Northwest Territories (including Nunavut) and three within the Yukon between 1900 and 1997 (Brooks et al., 2001), despite representing nearly 40% of the landmass within Canada, these events have still resulted in significant costs.

Flooding within the territories is heavily impacted by the spring freshet and ice breakup, which can often lead to ice jam floods within the rivers. Changes to the ice breakup, winter length and amount of precipitation due to climate change have already been noticed by locals, and will have an impact on the arrival of the spring freshet and ice breakup and may have a potential impact on the flood hazard within the communities (IPCC, 2007; Nunavut Climate Change Centre).

Within the Northwest Territories 11 communities and two government departments were contacted, for the Yukon three departments were contacted but no communities, while for Nunavut one city and two departments were contacted. A majority of the communities/departments responded indicating whether they have access to flood maps or are in the process of making them.

To date the most extensive flood mapping initiative within the territories was conducted under the federal Flood Damage Reduction Program (FDRP) which was signed between the Federal Department of Environment and Indian and Northern Affairs in 1979. Under this initiative nine at-risk communities within the Northwest Territories were mapped, at the time of this program Nunavut was considered to be part of the Northwest Territories, however no communities within Nunavut were deemed to be at risk (Environment Canada, 2016). All designated communities were mapped for a regulatory 100-year flood, as calculated by flood-frequency analysis; the flood hazard within these communities was divided into both a floodway and a flood fringe zone. Under the FDRP new developments were discouraged within the floodway, while suitably flood-proofed developments were allowed within the flood fringe zone (Environment Canada, 2016). At the time of the FDRP the Yukon did not sign an agreement with the federal government in order to conduct flood mapping; however, they are currently working on the development of these maps through a territorial initiative.

At the present time, the status of floodplain mapping within the territories is not known and access to a sample map from the FDRP era is available only for Northwest Territories. As no new initiative for flood mapping was undertaken by the Territories, the impact of climate change on flood mapping has not been addressed. However, the

communities and government personnel are interested in the topic and knowing how the climate change is going to impact their operations and design of infrastructure.

13.2 Flood maps and their availability and modelling packages

Northwest Territories

The flood maps generated under the FDRP are still available and are in use by the territory. As part of the FDRP nine communities, located predominantly along the Mackenzie River, were designated as high risk and were mapped. All of the FDRP flood maps show the extent of flooding for the 100-year flood and delineate the floodway, which is the region where the water depth is equal or greater than 1 m. These maps are available online through the territories ATLAS mapping system (atlas.lands.gov.nt.ca/Website/index.asp) which is maintained by the Department of Lands (www.lands.gov.nt.ca). Physical copies of the flood maps may be obtained by request. The territory has not officially updated any of the maps since the termination of the FDRP. At this point in time the territorial government has no initiatives in place to update the designated flood areas or to map new regions due to lack of funding, and the flood hazard is only considered a priority at the time of flood events. There is no documentation on the tools used for creating floodlines. It is expected that as these flood maps were generated during the FDRP, most probably the HEC-2 model was used to determine the flood elevation as was the case for flood mapping done within the provinces. Most of the communities contacted are still reliant on the flood hazard maps developed through the FDRP and do not have any initiatives at this time to create updated maps.

Yukon

While no department has a mandated responsibility for the development of flood hazard maps within the Yukon, Environment Yukon alongside the Yukon Emergency Measures Organization (EMO) is currently in the process of developing maps for communities which are deemed to be at high risk (EDI, 2015). This initiative is currently in progress and will determine the flood inundation extent using ArcGIS, with consideration for ice-related flooding. Though no information is yet available on the intended flood return periods to be considered for mapping, inclusion of climate change is deferred to a later stage.

Aside from the territorial initiative to conduct flood mapping a few communities within the Yukon were found to have flood maps obtained through their own initiatives. The town of Carmacks had flood hazard mapping completed in 2001 by Northwest Hydraulic Consultants to delineate the 200-year return period floodplain, which was included in their official community plan. The community of Tagish also had flood mapping completed for the 200-year return period flood along Tagish Lake and Six Mile River.

Nunavut

There are currently no flood hazard maps available within Nunavut and there are currently no territorial initiatives to create maps for this region. The territory felt that as none of the communities were constructed within known flood plains there was no need

to develop any flood maps. At the current time permafrost thaw appears to be the biggest concern within Nunavut and hence permafrost hazard mapping is being completed.

13.3 Climate change and floodplain mapping

The potential impact of climate change within the territories is significant, with changes within the land and environment already being felt by the local communities and populace. These changes manifest in the form of melting permafrost, changes in the river ice breakup, shorter winters, and melting sea ice (IPCC, 2007). All of these factors have an influence on coastal, lake, and river flooding which may have an impact on the northern communities. However, no floodplain mapping taking into account the impact of climate change have been completed within the territories and therefore it is difficult to comment on the exact changes that climate change may have on the regulatory flood and inundation extents.

Northwest Territories

Climate change is expected to result in an increase in temperature across the territory (with increases of 3-4° Celsius already having been noted within the past 50 years (Vanguard EMC Inc., 2014). Projections also indicate that the amount of Arctic rain and snowfall will increase with the greatest increase in snowfall occurring in winter and autumn (AMAP, 2012).

Within the Northwest Territories, the Hazard Identification Risk Assessment (HIRA) identified the hazards within the territory and assessed their risks with respect to the people, property, environment, and the economy (Vanguard EMC Inc., 2014). These were examined with consideration to climate change in anticipation of the impact that climate change may have on the Northwest Territories. Floods were found to be one of the highest risk hazards throughout the territory, and they projected that the flood frequency would increase as a result of climate change, causing more extensive damage to communities in the future. Changing precipitation due to climate change has already been linked to flooding in Aklavik and Fort Good Hope (NWT CC, 2008, p. 10).

Yukon

Changes within the climate of Yukon have already occurred (Werner et al., 2009). For Dawson City, temperatures are expected to increase as is the annual precipitation, with the majority of the precipitation expected to occur during the winter months (Werner et al., 2009). Whitehorse is expected to see similar changes with the annual winter temperature increasing due to climate change, the winter being projected to warm the fastest, and mean annual precipitation increasing (Hennessey et al., 2011b).

Four communities within the Yukon were part of a collaborative initiative to increase their adaptive capacity through the development of adaptation plans to respond to challenges and opportunities arising from climate change. Dawson City recommended adaptations to ensure that building codes are consistent with the expectations of climate change and to integrate the climate change assessment into the rural planning processes (Hennessey et al., 2011a). Similar to Dawson City, Mayo proposed climate change adaptations to ensure that building codes, zoning, and by-laws are sufficient for the

changing climate and to ensure that climate-change projections are integrated into new infrastructure planning (Hennessey et al., 2012). Whitehorse also considered hazards such as flooding to be high risk within its communities, with “increased risk of catastrophic flood and infrastructure failure (e.g. bridge)” listed as a high priority risk (Hennessey et al., 2011b).

Nunavut

Most of the communities within Nunavut are along the coast; however the impact of climate change on the relative sea level rise will vary across the territory due to the isostatic rebound the landmass is currently undergoing. As such, some of the land is rising so quickly that the sea level appears to drop even accounting for the rising sea level (Government of Nunavut, 2011). Within Nunavut reports by scientists, hunters, and elders have suggested significant warming trends; this change in temperature may also have caused variations in the weather patterns, causing an increase in storms and unpredictable wind. Precipitation patterns within Nunavut are also expected to change, though the predictions are uncertain due to its highly spatial variability (Nunavut Climate Change Centre). While Nunavut is looking into incorporating climate change into land development and infrastructure, their focus is on permafrost melting as opposed to flooding or sea level rise.

The City of Iqaluit developed a climate change adaptations plan (Lewis and Miller, 2010) which included recommendations to help the community adapt to the impact of climate change. This plan recommended adopting policies which recognize the long term impact of climate change such as considering the changes caused by permafrost melt, sea level rise (or relative land rise), increased temperature, precipitation and extreme weather for the design and operation of infrastructure.

13.4 Supporting datasets

Natural Resources Canada (NRCan) has Canadian Digital Elevation Models (CDEM) and Canadian Digital Elevation Data (CDED) is freely available for all three territories. This data is available at a scale of 1:50,000 and 1:250,000 for CDED and 1:250,000 for CDEM. Though DEMs were derived from LiDAR data, the source data however is not available for public use due to licensing and sharing issues. Yukon’s LiDAR data is relatively recent that was collected during 2014–2015 to obtain elevation data to support their flood mapping initiative for thirteen communities.

In the case of the Northwest Territories and the Yukon, the majority of the designated at risk communities are located alongside lakes and rivers, though some communities are located within the Beaufort-Delta region in the Northwest Territories. In the case of Nunavut, the majority of the communities are located along the coastline. There is a lack of accurate hydrographic surveys that have been conducted in the northern waters for coastal bathymetry. The Canadian Hydrographic Service (CHS) has estimated that 10% of the coastal waters in northern Canada have been mapped (CIDCO, 2014); however, the CHS does have electronic and paper charts for some of the coastal regions, and for the Mackenzie River, Great Bear River, and Great Slave Lake in the Northwest Territories, and for Chesterfield Inlet and Baker Lake in Nunavut (CHS, 2013). These maps are

available for purchase through the CHS, though the quality of bathymetric data represented within these charts is unknown. The bathymetry data for select locations is available, e.g. data for Hay River in the Northwest Territories is available from the University of Alberta, the thirteen communities targeted for mapping from Yukon Environment (www.env.gov.yk.ca/maps/media/uploads/pdf-maps/), and for Lake Geraldine from NRCan (Budkewitch et al., 2011).

The National Air Photo Library and Aerial Survey Data Base, which are maintained by NRCan, have archives of over 6 million aerial photographs from across Canada, dating back to 1920. These aerial photographs can be obtained from the National Earth Observation Data Framework (NEODF) online application which allows the user to access over 3 million of the archived photographs (neodf.nrcan.gc.ca/neodf_cat3/). It is possible that some of these archived photographs may be of past flooding events. Aerial photographs within the Yukon can be obtained through the Energy, Mines and Resources (EMR) Library, which has over 100,000 photographs from the 1940s until the current day. Many of these photographs have been scanned and are available on the Skyline air photo located service (mapservices.gov.yk.ca/Skyline/Load.htm), or can be obtained by request from the EMR library directly (emrlibrary@gov.yk.ca).

Water Survey of Canada is the primary source of water levels and discharges within Canada. This information is housed in two separate databases: HYDEX and HYDAT. The HYDEX database contains inventory information on the streamflows, water levels, and sediment stations within Canada, while the HYDAT database contains the actual computed data for each of the HYDEX stations. This information can be accessed at wateroffice.ec.gc.ca/. There are a number of active and discontinued stations within the territories. The Northwest Territories has a total of 224 hydrometric stations, with 94 of them being active as of 2017. The Yukon has a total of 124 hydrometric stations, with 75 of them being currently active, and Nunavut has a total of 118 stations, with 25 of them being active as of 2017.

13.5 Concluding remarks

The territories have been impacted by a few large flooding events and it is expected that the number of events will increase due to projected climate change. The government of Northwest Territories is still reliant on the flood maps generated through the FDRP and has planned few potential new flood mapping projects in the future. The government of Yukon is currently undertaking flood mapping in a number of at risk communities with the intent of generating prototypes soon. The government of Nunavut does not see flooding as a significant hazard within the territory and so has no plans to initiate any flood mapping initiatives now or in the near future.

All of the maps developed during the FDRP and those being developed by the government of Yukon are flood inundation maps, showing only the extent of the regulatory flood and not the variable water depths and velocities across the floodplain. As such, flood extents will not be as valuable for the development of codes and standards, as it will not be possible to estimate various loads and combination of load factors acting on the buildings and CPI. However, as the Yukon flood maps are still under development it

may be possible to obtain flood depths and velocities from them in order to inform the codes and standards at a later date. Within the Northwest Territories, the Hay River region is a potential project site for future studies due to data availability, history of flooding, etc.

Available data for flood hazard mapping is limited in the North which may impact any attempts to update or develop new flood maps. The changing climate is already being felt within the northern communities, with increases in precipitation and higher temperatures which increases the potential for flooding within the communities. Many communities have indicated a need to account for climate change into infrastructure planning in order to ensure the safety of their communities.

14 Synthesis of the Assessment

The reviews and assessment of flood hazard mapping presented in Chapters 3 to 13 for provinces and territories suggest that studies linking the hydrological and climate change aspects with state-of-the-art two-dimensional hydraulic models for detailed delineation of floodplains and development of flood hazard maps for risk assessment and decision-making are not yet available. Some studies have emerged recently in the east and west coasts of Canada wherein the flood maps were prepared by taking into account the impact of climate change and sea level rise, and using higher precision LiDAR datasets. In certain cases, detailed spatial information on flood water depths and velocities was also mapped. However, for a large majority of the riverine and coastal floodplains across the country, flood hazard maps are available only in the form of flood inundation maps. Such maps have limited utility for developing flood and climate resilient codes and standards as they show only flooding extents or extents in the form of floodway and flood fringe. The floodway is defined as “the portion of the floodplain within which the design flood can be conveyed while meeting certain water elevation rise, water velocity, and water depth criteria”. More specifically, the floodway includes portions of the floodplain where, during the design flood, the estimated water depth is 1 m or greater or the flow velocity is 1 m/s or greater. The flood fringe is essentially any other inundated area during the design flood that is not part of the floodway.

Most of the flood maps were developed under the framework of a federal government funded initiative, Flood Damage Reduction Program, which ended in 1995/96. In some parts of the country no additional flood maps were created after this federally funded initiative ended. Thus, most of the flood maps are pretty old from the technological perspective, lack precision and do not reflect recent changes in the landscape. In addition, most of the flood maps do not reflect the influence of climate change which is an issue that cannot be overlooked. Lack of funding and up-to-date data, and the costs associated with data collection have been identified as few of the impediments in updating existing flood maps. Understanding climate change impacts are of importance to the provinces and territories, however, lack of guidance on incorporating climate change information into the flood mapping process has been identified as another significant challenge. In a nutshell climate change information has not been integrated with flood maps for most of Canada. How flooding depth, dynamics, and debris including ice, rocks and boulders impact buildings and public infrastructure need to be evaluated for Canadian floodplains to devise a basis for updating national codes and standards.

For quick reference purposes, the assessment presented in Chapters 3 to 13 is synthesized further based on a common criteria consisting of a number of questions related to various aspects of floodplain maps, climate change information, and availability of supporting datasets, as described below:

Floodplain maps:

- Who is responsible for creating flood maps?
- How are the flood maps being disseminated?
- What is the level of severity (i.e. return period) of the designated/design flood?

- What is shown on the flood maps (i.e. inundation, depth or velocity)?
- Which numerical models and statistical approaches were used for hydrologic analyses?
- Which numerical models were used for hydraulic calculations?
- Was the impact of ice jamming considered in flood mapping?

Climate change information:

- Were climate change impacts on floods incorporated in creating flood maps?
- What were the main features of the methodology adopted for creating climate change informed flood maps?
- What future time horizons were targeted to address the impact of climate change?

Supporting datasets:

- Is LiDAR data available?
- Is the DEM data available?
- Are the bathymetry surveys available?
- Are the surveys of river cross sections available?
- Are the aerial photographs of past flood extents available?
- Are the existing model outputs available?
- What other supporting datasets are available?

The information presented in Chapters 3 to 13 is assessed against each question separately for each province and territory in the form of a table. The tables are shown below and they provide a quick view of the assessment across the country.

Table 14-1: Who is responsible for creating flood maps?

Province / Territory	Supporting information (Category: Floodplain maps)
Alberta	Alberta Environment and Parks
British Columbia	Local governments
Manitoba	Manitoba Infrastructure and Transportation; Local municipalities and towns
New Brunswick	Various entities including local governments and ACASA
Newfoundland & Labrador	Water Resources Management Division, Department of Municipal Affairs and Environment
Nova Scotia	No provincial body is officially responsible for creating maps
Ontario	36 Conservation Authorities; Ministry of Natural Resources and Forests
Prince Edward Island	No provincial department is designated to take on this responsibility
Quebec	Fourteen major cities, 87 Municipalités régionales de comtés (MRCs), two northern region entities, and two metropolitan communities
Saskatchewan	Saskatchewan Water Security Agency
Northwest Territories	Department of Lands
Nunavut	Maps do not exist. Not on the radar for the near future
Yukon	Environment Yukon; Yukon Emergency Measures Organization

Table 14-2 How are the flood maps being disseminated?

Province / Territory	Supporting information (Category: Floodplain maps)
Alberta	Online – Flood Hazard Map Application of Alberta Environment and Parks
British Columbia	Online – various websites
Manitoba	On request from Manitoba Infrastructure and Transportation; Some are available with local municipalities
New Brunswick	Online – GeoNB website; Coastal maps are not yet available online; NB Legislative Library’s online catalogue
Newfoundland & Labrador	Online – Water Resources Management Division’s website
Nova Scotia	Available with municipalities. No provincial body is responsible for dissemination of maps
Ontario	Online – through conservation authorities
Prince Edward Island	Available in reports as the mapping effort is relatively new
Quebec	Online – CEHQ website
Saskatchewan	Online – through Water Security Agency
Northwest Territories	Online – Territories ATLAS mapping system
Nunavut	Maps do not exist
Yukon	Maps do not exist. New initiative to develop maps is underway

Table 14-3 What is the level of severity (i.e. the return period) of the designated/design flood?

Province / Territory	Supporting information (Category: Floodplain maps)
Alberta	100-year flood
British Columbia	200-year flood
Manitoba	100-year flood for old maps; 200-year flood has been approved but no maps have been created with this level; historic floods
New Brunswick	Historic flood events
Newfoundland & Labrador	20- and 100-year floods for floodway and flood fringe delineations, respectively
Nova Scotia	20- and 100-year floods for floodway and flood fringe delineations, respectively
Ontario	100-year flood and historical storms (Hurricane Hazel and Timmins)
Prince Edward Island	10-, 25-, 50-, and 100-year storm surge
Quebec	20- and 100-year floods for floodway and flood fringe delineations, respectively
Saskatchewan	500-year flood
Northwest Territories	100-year flood
Nunavut	Maps do not exist
Yukon	Unknown for the new initiative; some communities were mapped with 200-year flood

Table 14-4 What is shown on the flood maps (i.e. inundation, depth or velocity)?

Province / Territory	Supporting information (Category: Floodplain maps)
Alberta	Inundation only corresponding to the designated (100-year) flood on old maps and corresponding to the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 100-year return values on new maps
British Columbia	Inundation and depth corresponding to the designated flood. New maps show spatial distributions of velocity of flood waters
Manitoba	Inundation only
New Brunswick	Inundation only. Updated maps where 2D hydraulic model was used show spatial distributions of flood depths and velocities
Newfoundland & Labrador	Inundation only. Updated maps where 2D hydraulic model was used show spatial distributions of flood depths and velocities
Nova Scotia	Inundation only. Updated maps where 2D hydraulic model was used show spatial distributions of flood depth and velocities
Ontario	Inundation only. Spatial information of flood depths and velocities is available only in new maps for urban areas
Prince Edward Island	Inundation only corresponding to sea level rise
Quebec	Inundation only
Saskatchewan	Inundation only
Northwest Territories	Inundation only (based on FDRP guidelines)
Nunavut	Maps do not exist
Yukon	Inundation only

Table 14-5 Which numerical models and statistical approaches were used for hydrologic analysis?

Province / Territory	Supporting information (Category: Floodplain maps)
Alberta	Frequency analysis to estimate design floods; Information on deterministic modelling is unknown
British Columbia	Frequency analysis to estimate design floods; VIC model outputs
Manitoba	Frequency analysis; MANAPI model
New Brunswick	Frequency analysis; HYMO
Newfoundland & Labrador	Frequency analysis; HEC-HMS
Nova Scotia	Frequency analysis; SWMM, PCSWMM
Ontario	Frequency analysis; HSPF, NWSRFS, SWMM, HYMO, SSARR, USDAHL-74, VUH-HYMO, QUALHYMO
Prince Edward Island	Not applicable
Quebec	Frequency analysis; Rational method
Saskatchewan	Frequency analysis; Information on deterministic modelling is unknown
Northwest Territories	Frequency analysis; Information on deterministic modelling is unknown
Nunavut	Maps do not exist
Yukon	Unknown

Table 14-6 Which numerical models were used for hydraulic calculations?

Province / Territory	Supporting information (Category: Floodplain maps)
Alberta	HEC-2, HEC-RAS, RIVICE, 2D models from Deltares
British Columbia	MIKE 11, MIKE 21, HEC-RAS, HEC-2, RiCOM, SWAN, TELEMAC 2D
Manitoba	HEC2-2; HEC-RAS (in one new study)
New Brunswick	HEC-2, HEC-ICE, DWOPER; hydrodynamic modelling was not used for coastal areas
Newfoundland & Labrador	HEC-2, HEC-RAS, XPSWMM
Nova Scotia	HEC-2, HEC-RAS, SWMM, PCSWM-2D, MIKE 3, MIKE 21, Mud Transport Model
Ontario	HEC-2, HEC-RAS, MIKE 11, HEC-RAS 5, MIKE FLOOD
Prince Edward Island	Unknown
Quebec	HEC-2, HEC-RAS, Modeleur, HYDROSIM
Saskatchewan	Only 1D models; No initiatives to resort to 2D models in the future
Northwest Territories	1D model (HEC-2)
Nunavut	Maps do not exist
Yukon	No information is available yet

Table 14-7 Was the impact of ice jamming considered in flood mapping?

Province / Territory	Supporting information (Category: Floodplain maps)
Alberta	Yes, 100-year water level in ice jam situations
British Columbia	No, ice impacts were not considered as ice jamming is not considered a significant flood factor
Manitoba	Unknown
New Brunswick	Yes, explicitly addressed
Newfoundland & Labrador	Yes, explicitly addressed
Nova Scotia	Yes, addressed where applicable
Ontario	No, not a dominant flooding mechanism in populated areas
Prince Edward Island	Unknown
Quebec	No; the ice jam mechanism is recognized but has not been incorporated in flood maps
Saskatchewan	Unknown
Northwest Territories	This mechanism has been identified but never used in flood mapping
Nunavut	Maps do not exist
Yukon	No information is available yet

Table 14-8 Were climate change impacts on floods incorporated in creating flood maps?

Province / Territory	Supporting information (Category: Climate change)
Alberta	No, impact of climate change is not reflected in maps
British Columbia	Yes, some recent maps have considered the impact of climate change specifically for floodplains in the Fraser River basin and coastal areas
Manitoba	No, impact of climate change is not reflected in maps
New Brunswick	Yes, most new maps reflect the impact of climate change, i.e. the studies conducted by ACASA and those funded through the NB Environment Trust Fund
Newfoundland & Labrador	Yes, most new maps reflect the impact of climate change and the new maps are adopted by respective communities for regulation purposes
Nova Scotia	Yes, for certain communities, new flood maps were generated with the impact of climate change incorporated
Ontario	No, impact of climate change is not reflected in maps
Prince Edward Island	Yes, impact of sea level rise is reflected only
Quebec	No, the majority of the maps do not reflect the impact of climate change. Only a few new maps show the impact of increases in rainfall amounts
Saskatchewan	No, impact of climate change is not reflected in maps
Northwest Territories	No, impact of climate change is not reflected in maps
Nunavut	No, maps do not exist
Yukon	No, impact of climate change is not reflected in maps

Table 14-9 What were the main features of the methodology adopted for creating climate change informed flood maps?

Province / Territory	Supporting information (Category: Climate change)
Alberta	No such information exist
British Columbia	GCM-based scenarios and sea level rise
Manitoba	No such information exist
New Brunswick	GCM-based scenarios and seal level rise projections
Newfoundland & Labrador	RCM-based scenarios and information from the IDF Tool developed by the Western University
Nova Scotia	GCM-based scenarios
Ontario	No such information exist
Prince Edward Island	Sea level rise scenarios
Quebec	No such information exist
Saskatchewan	No such information exist
Northwest Territories	No such information exist
Nunavut	No such information exist (maps do not exist)
Yukon	No such information exist

Table 14-10 What future time horizons were targeted to address the impact of climate change?

Province / Territory	Supporting information (Category: Climate change)
Alberta	Not applicable as the impact of climate change has not been addressed in flood maps
British Columbia	2020, 2050, 2080, 2100, and 2200
Manitoba	Not applicable as climate change has not been addressed in flood maps
New Brunswick	IPCC standard tri-decades (2020s, 2050s, and 2080s)
Newfoundland & Labrador	Sea level rise by 2049 and 2099; 2038–2070 for 19 climate indices
Nova Scotia	2070–2099
Ontario	Not applicable as climate change has not been addressed in flood maps
Prince Edward Island	2010, 2040, 2060, and 2070 for sea level rise
Quebec	Not applicable as assumed percentage changes and freeboard were experimented in a few studies to address climate change
Saskatchewan	Not applicable as climate change has not been addressed in flood maps
Northwest Territories	Not applicable as climate change has not been addressed in flood maps
Nunavut	Maps do not exist
Yukon	No information is available yet

Table 14-11 Is LiDAR data available?

Province / Territory	Supporting information (Category: Supporting datasets)
Alberta	Available from Alberta Environment and Parks on request
British Columbia	Available through data sharing arrangements
Manitoba	Availability is unknown at the provincial level; Available for some river sections
New Brunswick	Unknown
Newfoundland & Labrador	Yes, available from Water Resources Management Division
Nova Scotia	Available from CBCL
Ontario	Unknown (held with a consultant - First Base Solutions)
Prince Edward Island	Available for purchase
Quebec	Available from Geoboutique for purchase
Saskatchewan	Available from AAFC for several sites
Northwest Territories	Available but not for public use
Nunavut	Available but not for public use
Yukon	Available but not for public use

Table 14-12 Is DEM data available?

Province / Territory	Supporting information (Category: Supporting datasets)
Alberta	Available from Alberta Environment and Parks on request
British Columbia	Available from NRCan's GeoGratis ; Most local governments are willing to share their DEMs
Manitoba	Available from NRCan's GeoGratis
New Brunswick	Information from provincial sources is not available; DEM data can be obtained from NRCan's GeoGratis
Newfoundland & Labrador	Yes, available from Water Resources Management Division
Nova Scotia	Available from CBCL
Ontario	Available from NRCan's GeoGratis and also from MNRF
Prince Edward Island	Available from NRCan's GeoGratis
Quebec	Available from NRCan's GeoGratis
Saskatchewan	Available from NRCan's GeoGratis and from SWA for more recent studies
Northwest Territories	Available from NRCan's GeoGratis
Nunavut	Available from NRCan's GeoGratis
Yukon	Available from NRCan's GeoGratis

Table 14-13 Are bathymetry surveys available?

Province / Territory	Supporting information (Category: Supporting datasets)
Alberta	Available from Alberta Environment and Parks on request
British Columbia	Available from local governments (willing to share)
Manitoba	Unknown
New Brunswick	Available in supplementary field data reports
Newfoundland & Labrador	Available from Water Resources Management Division
Nova Scotia	Available from CBCL
Ontario	Available from CAs
Prince Edward Island	Available from Canadian Hydrographic Service
Quebec	Available from CEHQ for purchase
Saskatchewan	Available from provincial government website (lake bathymetry)
Northwest Territories	Partial coverage available (some for free and some for purchase)
Nunavut	Partial coverage available (some for free and some for purchase)
Yukon	Available for 13 targeted communities (free)

Table 14-14 Are the surveys of river cross sections available?

Province / Territory	Supporting information (Category: Supporting datasets)
Alberta	Available from Alberta Environment and Parks on request
British Columbia	Available from local governments (willing to share)
Manitoba	Available from Manitoba Transportation and Infrastructure
New Brunswick	Available in supplementary field data reports associated with individual studies
Newfoundland & Labrador	Yes, available from Water Resources Management Division
Nova Scotia	Available from CBCL
Ontario	Available from CAs
Prince Edward Island	Not applicable as the province does not have riverine flooding issues
Quebec	Available from CEHQ for purchase
Saskatchewan	Available for more recent studies from SWA
Northwest Territories	Unknown
Nunavut	Maps do not exist
Yukon	Available from Yukon Department of Environment

Table 14-15 Are the aerial photographs of past flood extents available?

Province / Territory	Supporting information (Category: Supporting datasets)
Alberta	Available from Alberta Environment and Parks on request
British Columbia	Available from local governments (willing to share through data share agreements)
Manitoba	Available online from GeoManitoba website
New Brunswick	Available from National Air Photo Library
Newfoundland & Labrador	Available from Water Resources Management Division
Nova Scotia	Available from CBCL
Ontario	Unknown (may be available from CAs)
Prince Edward Island	Unknown
Quebec	Available from CEHQ for purchase
Saskatchewan	Available from Earth Sciences Sector of NRCan
Northwest Territories	Available from National Earth Observation Data Framework
Nunavut	Available from National Earth Observation Data Framework
Yukon	Available from National Earth Observation Data Framework

Table 14-16 Are the existing model outputs available?

Province / Territory	Supporting information (Category: Supporting datasets)
Alberta	Unknown
British Columbia	Yes, most local governments are willing to share
Manitoba	Unknown
New Brunswick	Unknown
Newfoundland & Labrador	Yes, available from Water Resources Management Division
Nova Scotia	Available from CBCL
Ontario	Partially available
Prince Edward Island	Unknown
Quebec	No; owned by consultants
Saskatchewan	Unknown
Northwest Territories	Unknown
Nunavut	Maps do not exist
Yukon	Mapping initiative is underway

Table 14-17 What other datasets are available?

Province / Territory	Supporting information (Category: Supporting datasets)
Alberta	Hydrometric data available from EC
British Columbia	Hydrometric data available from EC; Tide/wave heights are available from Canadian Hydrographic Service
Manitoba	Hydrometric and tide data available from EC; Culverts and bridges data available from Manitoba Infrastructure and Transportation
New Brunswick	Hydrometric and tide data available from EC
Newfoundland & Labrador	Hydrometric and tide data available from EC
Nova Scotia	Hydrometric data is available from EC; Tide/wave heights and known flood scenarios available from CBCL
Ontario	Hydrometric data is available from EC, MNR and Hydropower companies
Prince Edward Island	Historical tide data available online from the DFO
Quebec	Hydrometric data is available from EC and provincial sources
Saskatchewan	Hydrometric data is available from EC and provincial sources
Northwest Territories	Hydrometric data is available from EC
Nunavut	Maps do not exist
Yukon	Mapping initiative is underway

15 Future Outlook

After documenting the status of flood maps from across the country and learning whether the impact of climate change has been considered in creating new flood maps, this chapter provides a broad outlook and a road map for the next phase of the study and highlights the necessary steps to be undertaken. In doing so, a number of guiding principles and research directions have been identified to help inform the development of flood and climate resilient codes and standards. Adherence to these principles will aid significantly in developing the fundamental tools necessary to effectively manage and mitigate flood risk across Canada. Though important, development of key standards and guidelines for undertaking flood mapping is not the intent of this section. These initiatives have been addressed elsewhere as discussed later in this section. Also, it is not the intent of the work proposed here to overhaul the large number of outdated flood maps available in many parts of the country as it will involve massive efforts involving millions of dollars and dedicated resources.

Availability of flood mapping guidelines are discussed first followed by economics of flood mapping, selection of pilot studies and hydraulic analyses, climate change considerations, and flood protection levels. How to effectively use the available information from existing flood maps is discussed in a separate subsection.

15.1 *Flood mapping guidelines*

Nationally accepted guidelines are generally used in order to prepare flood maps. In Canada, flood mapping guidelines were developed in 1976 (IWD, 1976) to support the Flood Damage Reduction Program of the federal government. These guidelines are still in use in some parts of the country for updating and generating new flood maps. In 2015, the federal government through Public Safety Canada (PSC) launched a multi-million dollar five year project, National Disaster Mitigation Program (NDMP), to update flood maps across the country. For the implementation of the NDMP, PSC is being assisted by Natural Resources Canada (NRCan). The Canada Centre for Mapping and Earth Observation of NRCan is engaged in developing a comprehensive set of flood mapping guidelines by updating previous guidelines and to make them compatible with the evolving digital technology and new scientific and technical advancements. In this effort, experts from across the country are participating in the form of a working group. These experts include individuals from Canadian consulting firms, provincial government departments, Environment Canada, National Research Council, hydropower companies, and professional engineering organizations. The series of proposed guidelines consist of the following guideline documents:

- Federal Floodplain Mapping Framework
- Federal Hydrologic and Hydraulic Procedures for Floodplain Delineation
- Federal Geomatics Guidelines for Floodplain Mapping
- Canadian Floodplain Mapping Guidelines and Specifications
- Canadian Airborne LiDAR Data Acquisition Guideline
- Case Studies on Climate Change in Floodplain Mapping
- Flood Risk Assessment

- Risk-Based Land-Use Guide: Safe Use of Land Based on Hazard Risk Assessment
- Bibliography of Best Practices and References for Flood Mitigation

Some of these guidelines have already been completed by NRCan while others are still in progress. It will be advisable to benefit from these guidelines and make adjustments where necessary to realize the objectives of the CR-CPI project. The NRC-OCRE contributed towards these guidelines by developing four different reports on various aspects of the flood mapping process for NRCan/PSC (i.e. Khaliq and Fergusson, 2016; Khaliq, 2017; Murphy and Khaliq, 2017c; Khaliq and Piché, 2017).

15.2 Selection of pilot studies

Ideally new flood maps should be developed for the entire country in order to reveal and understand unique features of various floodplains and how the flood waters can impact buildings and CPI present within those floodplains. From a feasibility and financial viewpoint (discussed below in Section 15.3), it is difficult to achieve this goal. Therefore, in the next phase of this study, a number of flood-prone areas from across the country will be selected and remapped using state-of-the-art 2D modelling packages. These areas will be selected where high quality supporting data in the form of DEM, bathymetry, river cross-sectional information, and information about hydraulic structures is readily available. Provincial, territorial and municipal government departments will be consulted to finalize selection of these areas and ensuring availability of supporting datasets. Another factor will be that at least one pilot study should be carried out in every province and territory and these studies should reflect both riverine and coastal environments. It will be useful to undertake riverine studies first to gain knowledge on establishing guidelines and then apply the gained knowledge to coastal studies in a subsequent phase of the project. The accuracy of flood maps depends on a number of factors, primarily the quality of input data used for hydraulic and hydrologic analyses. Therefore, when selecting pilot studies for detailed flood mapping, it is important to pay considerable attention to the quality of available input data.

15.3 Economics of flood mapping

Before undertaking the development of the targeted flood maps to inform codes and standards, it is important to understand the anticipated cost of preparing new flood hazard maps. The actual cost of mapping would likely depend upon the complexity of the floodplain; proximity to the sea or large lakes; length and width of the floodplain; number of buildings and core infrastructure; population density; and the approach to be used for estimating flood magnitudes and performing hydraulic calculations. On average, the cost would range from \$7,500/km in a rural setting to \$10,500/km in an urban setting if 1D hydraulic modelling is used for the delineation of the floodplain (MMM Group Limited, 2014). It is important to note that, unless a multi-zone concept is used, the outputs from 1D model would require considerable post-processing to extract any useful information for codes and standards. Compared to the 1D modelling tools, the outputs from 2D hydraulic models can be used directly to inform development of national codes and

standards as these tools can produce detailed information about the distribution of flood velocity and depth across the entire floodplain. However, in this case, the cost would jump to roughly \$50,000/km (MMM Group Limited, 2014). The cost of developing new flood maps depends largely on the costs associated with the following data processing and related tasks:

- Processing and collection of DEM data;
- Undertaking targeted bathymetric surveys and subsequent data processing;
- Collection of cross-sectional information;
- Collection of information about various permanent and temporary structures that can impact flow of water through the main channel and floodplain, e.g. culverts, bridges, levees, etc.;
- Performing hydrologic analyses;
- The choice of the hydraulic model – whether to use a commercial or public domain tool;
- Training of the technical personnel – expert vs. normal user – an expert would require less processing time than a normal user; and
- Preparing flood hazard maps following the agreed upon mapping framework, etc.

15.4 Selection of hydraulic modelling packages

For many floodplain modelling studies, selection of a hydraulic modelling package is not an easy task. Many natural and anthropogenic characteristics of the floodplain play a significant role in the selection of a model. The former category includes features like climate, topography, land cover type, soil type, relief of the landscape, etc. As discussed in Khaliq and Piché (2017), the propagation of flood water onto the floodplain is governed by combinations of features such as (i) the amount of water passing through the system, (ii) the topography and relief of the area that impact the flow rate and direction of flow, (iii) the resistance caused by the land cover, and (iv) infiltration capacity of the soil (an already saturated soil will aggravate the flooding further). The anthropogenic features could be storage reservoirs, dams, levees, urbanization, changes in land use, industrial activities, encroachments, etc. Both natural and anthropogenic features of the floodplain interact with the flood waters in a very complex manner and occasionally simplifications are required. One-dimensional (1D) steady state models have been commonly used in practice. It is simpler to setup and run 1D models as they generally require less computational time. Examples include HEC-RAS 1D and MIKE 11. The HEC-2 model was one of the most commonly used hydraulic program in the world, which is available now in the HEC-RAS package under the steady state option. However, it is difficult to obtain detailed descriptions of flow depth and velocity within the floodplain when using a 1D model, a feature required to inform national codes and standards.

Two-dimensional (2D) hydraulic models are particularly suitable when detailed information about flow velocities and depths are required, flow-depth hazard to humans is important, and lateral variation in water surface elevations need to be accounted for. Other situations where 2D models are preferred are when the interaction of channel and floodplain flow fields is quite complex, e.g. situations where the flow is poorly confined,

flow attenuation and floodplain storages are important, and complex nature of overflow along streets and between developments is present (Horritt and Bates, 2002; Hunter et al., 2008). An obvious drawback is that these models require a longer computational time compared to 1D models. However, due to rapid improvements in computing resources, the use of 2D models is becoming popular. These models utilize depth-averaged Navier-Stokes equations, commonly called the Saint-Venant shallow water equations (SV-SWE), and produce more accurate and detailed analysis of floodplains. Some examples of the 2D modelling packages are MIKE FLOOD, SOBEK, TELEMAC, TUFLOW, HEC-RAS 2D, etc.

15.5 Inclusion of climate change impacts into flood mapping process

Literature on climate change overwhelmingly supports that the climatic extremes will intensify in the future and therefore the buildings and CPI within flood zones will be subjected to withstand additional loads and stresses. The primary means used to assess future climate change are the transient climate change simulations produced with the coupled Global Climate Models (GCMs) when these models are integrated from the recent past to some time-point in the future under prescribed emission scenarios, e.g. the Representative Concentration Pathways (Flato et al., 2013). There is a greater uncertainty about potential future changes to climatic variables from both climate modelling and scenario perspectives because of the disagreements between the outputs of different GCMs produced with the same RCP and also due to their inability to resolve many local scale topographic features due to their coarse spatial resolution that could range from 100 to 300 kilometers. Currently, a large number of simulations from multiple GCMs with multiple scenarios are available through CMIP5 (Climate Model Inter-comparison Project Phase 5). These simulations can help address some uncertainties, but their use is considerably limited because of the scale mismatch between the resolution of a typical GCM and the local scale of the built infrastructure. Regional Climate Models (RCMs) are able to overcome the resolution issue, but these models still require the outputs from GCMs at boundaries of their respective domains. Consequently, RCMs can inherit the weaknesses of their driving GCMs. Despite many advances in climate science and understanding the impact of climate change on the environment and infrastructure, there is a lack of consensus on the guidelines to incorporate the information on climate change into the engineering design and estimates (American Society of Civil Engineers – Olsen, 2015). During the flood mapping review and data collection process, many provinces have shown interest in incorporating climate change in the flood mapping process, but they require guidance on how to do so. Additionally, there is the issue of consistency for the climate change projections used among different communities and the requirement to update flood maps when the climate change projections change.

The flood mapping process faces additional challenges in converting climatic information available from global and regional climate models into flood magnitudes to be mapped. Some studies have used additional modelling in order to transfer the information available from climate models about the future state of the climate to obtain estimates of future floods through simulating flows, while others have used direct regression relationships between flood magnitudes and flood sensitive climatic variables. As there is

no perfect solution, often compromises have to be made to derive some useful information about climate change to be integrated in the flood mapping process.

When changes to flood magnitudes are desired for any flood mapping problem, it is advisable to adopt a robust approach, i.e. consider an ensemble of simulations from an ensemble of climate models rather than using outputs from a single model. This approach would help derive robust estimates of changes to flood magnitudes. After obtaining projected changes to flood magnitudes and having obtained future estimates, hydraulic models can be run to obtain climate change informed floodlines, extents, and other variables of interest to evaluate safety of existing structures and to revise codes and standards.

15.6 Common protection levels

There should be a national vision and standards that would apply across Canada. Flood mapping should be extended to more riverine and coastal communities where the population is being threatened. Events more severe than the 100-year return period event could be given serious considerations for flood hazard mapping and risk assessment. This may not be suitable for regulatory purposes in certain jurisdictions, but higher standards have been adopted in some Canadian provinces. Considering higher levels are particularly important when one considers both the degree of uncertainty associated with the estimates and knowing that statistically a 100-year event has a 65% (and not 100%) chance of occurring in a 100 year period. For example, this could be the life span of a specific structure (e.g. a bridge) being protected. Serious discussions are needed with different levels of government institutions, public and private sector representatives, policy makers, and individuals from the consulting and professional engineering organizations.

Currently there are views that floodplain management should move beyond hazard mapping to considering actual risks to communities, industry and agriculture. Though the idea of providing required protection based on the localized risk is appealing, how to handle this from the modelling and policy perspectives is debatable and open to questions.

15.7 Floodplain zoning concepts

Zoning of the floodplain is a useful concept for calculating different loads and load combinations on buildings and CPI and regulating developments in the floodplain. In the US, FEMA has adopted multi-zone strategy in regulating the floodplain. Canada has adopted mostly a two-zone framework, i.e. floodway and flood fringe. The floodway is defined as the portion of the floodplain where the water depth equals or exceeds 1 m or the velocity of water equals or exceeds 1 m/s during the regulatory flood. In some jurisdictions this demarcation is based on the extent of a low return period (e.g. 20-year) flood. The flood fringe is the portion of the floodplain where water depth and velocity are less than a depth of 1 m or 1 m/s, respectively. Generally developments are prohibited in the floodway and are regulated in the flood fringe by imposing necessary flood proofing. As the developments are prohibited in floodway, no specific consideration is required for

providing flood resilience in national codes and standards. For flood fringe part of the floodplain, new requirements need to be developed to provide appropriate flood resilience in national codes and standards. One possibility is to adopt a uniform strategy for the entire flood fringe as is currently followed across the country. Another possibility is to divide the flood fringe into multiple zones and provide flood resilience separately for each of these new zones. Both possibilities will allow best use of the existing information and available flood maps. A brand new strategy would require input from multiple stakeholders. This can be achieved through targeted workshops and focused discussions.

Any floodplain zone will shift with the inclusion of climate change information. In most cases, the impact of climate change will show up in terms of increased severity of flooding, putting additional loads on buildings and CPI. Therefore, irrespective of utilizing two zones or multiple zones, appropriate provisions are required in the codes and standards to address the impact of climate change. The most severe impacts will be due to lateral expansion of the floodway zone.

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Appendix – List of Acronyms

AAFC	Agriculture and Agri-food Canada
AB	Alberta
ACASA	Atlantic Climate Adaptation Solutions
ADCIRC	Three-dimensional hydrodynamic model for storm surge predictions
AEP	Alberta Environment and Parks
AIEES	Alberta Innovates – Energy and Environment Solutions
AR5	IPCC’s Fifth Assessment Report
ASCE	American Society of Civil Engineers
BC	British Columbia
BCREA	British Columbia Real Estate Association
CA	Conservation Authority
CAs	Conservation Authorities
CBCL	CBCL Limited (Consulting Company)
CCEMC	Climate Change and Emissions Management Corporation
CDEM	Canadian Digital Elevation Model
CEHQ	Centre d’expertise hydrique du Québec
CHS	Canadian Hydrographic Service
CMIP5	Climate Model Inter-comparison Project Phase 5
CNSC	Canadian Nuclear Safety Commission
CO	Conservation Ontario
CPI	Core Public Infrastructure
CR	Climate Resilient
CRCM	Canadian Regional Climate Model
DEM	Digital Area Model
DFO	Department of Fisheries and Oceans
DHI	Danish Hydraulic Institute
DWOPER	Dynamic wave flood routing model
EMO	Emergency Measures Organization (Yukon)
ESRD	Environment and Sustainable Resource Development
ETS	Environment Trust Fund
FBC	Fraser Basin Council
FDRP	Federal Damage Reduction Program
FEMA	Federal Emergency Management Agency
GanRCA	Ganaraska Region Conservation Authority
GCM	Global Climate Model
GDB	Geospatial Database
GIS	Geographical Information System
GRCA	Grand River Conservation Authority
HEC	Hydrologic Engineering Center
HEC-2	HEC’s hydraulic model
HEC-ICE	HEC’s ice jamming model
HEC-HMS	HEC’s Hydrological Modelling System
HEC-RAS	HEC’s River Analysis System for one-dimensional hydraulic modelling

HEC-RAS 2D	HEC's River Analysis System for two-dimensional hydraulic modelling
HIRA	Northwest Territories Hazard Identification Risk Assessment
HSPF	Hydrologic Simulation Program Fortran
HYDAT	Environment Canada's streamflow database
HYDEX	Environment Canada's relational database
HYDROSIM	Hydrologic Simulation Model
HYMO	Hydrologic model for simulation and management of stormwater runoff
Hyper	Wave agitation model
ICLEI	International Council for Local Environmental Initiatives
IDF	Intensity Duration Frequency Curve
IPCC	Intergovernmental Panel on Climate Change
KML	Spatial data file format
KWL	Kerr Wood Leidal Associates Ltd. (Consulting Company)
LIO	Land Information Ontario
LiDAR	Light Detection and Ranging
LIRA	Land and Resiliency Assessment
MÉRNQ	Ministère de l'Énergie et des ressources naturelles du Québec
MIKE 3	DHI's model for 3D free surface flows
MIKE 11	One-dimensional model of Danish Hydraulic Institute
MIKE 21	Two-dimensional model of Danish Hydraulic Institute
MIKE FLOOD	Combined one- and two-dimensional model of Danish Hydraulic Institute
MN	Manitoba
MOU	Memorandum of Understanding
MCCAP	Municipal Climate Change Action Plan
MDDELCC	Ministère du développement durables, de l'environnement et de la lutte contre les changements climatiques
MFFPQ	Ministère des Forêts, de la Faune et des Parcs du Québec
MMAH	Ministry of Municipal Affairs and Housing
MNRF	Ministry of Natural Resources and Forestry
MRCs	Municipalités régionales de comtés
MSPQ	Ministère de la sécurité publique du Québec
NB	New Brunswick
NDMP	National Disaster Mitigation Program
NL	Newfoundland & Labrador
NRC	National Research Council of Canada
NRCan	Natural Resources Canada
NS	Nova Scotia
NTDB	National Topographic Data Base
NWSRFS	National Weather Service River Forecast System
OASIS	A software developed by Hydrologics, Inc. for modelling water resource systems
OCPs	Official Community Plans
OCRE	Ocean, Coastal and River Engineering
ON	Ontario

ORCA	Ottawa Region Conservation Authority
PCSWM2D	Urban and rural watershed modelling software (2D)
PDF	Portable Document Format
PDKB	Map file format
PEI	Prince Edward Island
PSC	Public Safety Canada
QC	Quebec
QUALHYMO	Modelling engine for water balance modelling applications developed by Ontario Ministry of Environment
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
RFFA	Regional Flood Frequency Analysis
RiCOM	Unstructured-grid finite-element coastal ocean model
RIVICE 1D	Hydraulic River Ice Model of Environment Canada
RVCA	Rideau Valley Conservation Authority
SAFRTF	Southern Alberta Flood Recovery Task Force
SK	Saskatchewan
SLR	Sea Level Rise
SOBEK	It is a modelling suite developed by Deltares
SSARR	Streamflow Synthesis and Reservoir Regulation Model
SSRB	South Saskatchewan River Basin
SWAN	Simulating Waves Nearshore wave model
SWMM	Storm Water Management Model
TELEMAC	It is a hydrodynamic modelling system
TRCA	Toronto Region Conservation Authority
TUFLOW	Combined 1D and 2D hydrodynamic modelling system
USDAHL	United States Department of Agriculture Hydrology Laboratory model for watershed hydrology
VUH-HYMO	Peak flow model for urban watersheds
WSA	Water Security Agency
WSC	Water Survey of Canada
XPSWMM	Fully dynamic hydraulic and hydrologic modelling software

