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ASSESSMENT OF CANADIAN FLOODPLAIN MAPPING AND SUPPORTING DATASETS FOR BUILDINGS AND INFRASTRUCTURE DESIGN CODES AND STANDARDS

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Abstract: The Canadian Government, through Infrastructure Canada, has recently initiated the Climate Resilient Buildings and Core Public Infrastructure (CRB-CPI) project, led by the National Research Council of Canada. A key objective of the project is to update codes and standards and develop new guidelines to reflect the impact of climate change on the design (rehabilitation) of new (existing) buildings and CPI in order to enhance their resilience against extreme weather and climate change. To support this initiative, an assessment of Canadian floodplain mapping and supporting datasets was undertaken. This included a review of hydrologic and hydraulic techniques, and federal/provincial/territorial/local government initiatives to modernize floodplain maps from the technological, climate change and accessibility viewpoints. Some of the key points explored during the review included: the best ways of utilizing existing floodplain maps, which were originally developed to inform land use planning and development bylaws, to support the development of new codes and standards; the degree to which climate change has been incorporated in floodplain maps; and the status, availability and quality of available datasets to support quantification of flood loads for the design of buildings and CPI. This paper focuses on the findings of the assessment and the suggested path forward to develop structural design provisions for flood loads that can be implemented in the National Building Code as well as guidelines for addressing flood- and climate-resilience of existing buildings and infrastructure. This includes consideration for buildings of varying importance and with different functional requirements in response to flooding, e.g. residential, industrial, lifeline and post-disaster buildings and places of refuge/shelters.

1 Introduction

The National Research Council of Canada (NRC) is leading the Climate Resilient Buildings and Core Public Infrastructure (CRB-CPI) project to build resilience into the Canadian CPI (i.e. roads, bridges, water and wastewater systems, and rail transit gateways) and buildings against projected climate change and extreme weather events by updating model codes, standards, guides and decision-support tools (Infrastructure Canada 2016; Global News 2017). Public Safety of Canada's records (https://www.publicsafety.gc.ca/) reveal that over the last two decades, Canada has seen a notable increase in flooding, resulting in billions of dollars of damages and flood payouts. Therefore, within the CRB-CPI project, enhancing flood-resilience of buildings and CPI has been identified as a primary research need. All reports of the Intergovernmental Panel on Climate Change (IPCC), including the most recent Fifth Assessment Report (IPCC 2014), suggest 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 be even more severe (IPCC 2014). As climate change is expected to intensify the severity of flooding, which in turn will heighten the impact of floods on buildings and CPI, the impact of climate change has also been identified as another major research area within the CRB-CPI project. Currently, the National Building

Code (NBC) of Canada (NBC 2015) does not address flood related loads for structural design of buildings and CPI.

In Canadian floodplains, flood loading for buildings and CPI design must be determined, at a minimum, for (i) flood depth, (ii) flood velocity, (iii) waves generated by moving water in coastal locations, and (iv) debris impact including that from ice, similarly to the approach suggested in the American Society of Civil Engineers Standards ASCE/SEI 7-16 (ASCE/SEI 7-16 2017). Flood provisions in ASCE/SEI 7-16 include those related to: hydrostatic loads caused by depth of water; hydrodynamic loads caused by the effects of moving water; erosion and scour; wave conditions and wave loads; and flood-borne debris and debris impact loads. Therefore, floodplain maps showing spatial patterns of both velocity and depth of flood water for flood-prone areas (both coastal and riverine) can be useful in estimating flood loading for building and infrastructure design purposes and developing related codes and guidelines.

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 (IWD 1976; Environment and Climate Change Canada 2016). 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 of concern at that time. In 1995/96 when the FDRP ended, most of the flood-prone areas and vulnerable major population centers across the country were flood risk mapped. Majority 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.

After the termination of the FDRP, provinces and territories assumed responsibility of updating and maintaining existing flood maps and developing new maps for additional areas. Furthermore, some provinces chose to define and advance their mapping standards and flood protection levels to satisfy concurrent needs. Consequently, lack of nationally agreed-upon oversight has resulted in less consistency and coherency among flood mapping related technology and standards used across the country. As well, some provinces have recently started developing climate change informed flood maps for future planning purposes (e.g. British Columbia and Newfoundland and Labrador). In light of the aforementioned factors, the status of flood maps across the country is unclear to informing a national level initiative on flood-resilient design of buildings and infrastructure.

A nation-wide assessment of new and existing flood maps and availability of supporting datasets was undertaken by NRC in collaboration with Canadian consulting companies to guide the development of national codes and standards for the design of flood- and climate-resilient buildings and infrastructure. It is worthwhile noting that datasets supporting the development of flood maps, particularly the bathymetry and river cross-sectional data, come with a great expense and effort and therefore collecting information about and availability of these datasets was necessary. This paper presents a summary of the overall findings of this study by highlighting existing practices and standards across the country and identifying the gaps impeding flood- and climate-resilience in the Canadian codes and standards and the information available from existing and new flood maps. This assessment also helped in devising a framework to incorporate flood- and climate-resilience, including the impact of climate change, into the Canadian codes and standards and development of related guidelines.

This paper is organized as follows: Section 2 focuses on the methodology adopted for collecting information on floodplain maps and supporting datasets. Section 3 presents and discusses some of the important findings of the study. Future research and important challenges with respect to the engineering practice in a changing climate are discussed in Section 4, along with a path forward to support development of flood-and climate-resilient design of buildings and CPI. Final remarks and limitations of the study are provided in Section 5.

2 Methodology–Assessment Process and Points of Relevance

As noted above, this study was led by NRC and carried out in collaboration with Canadian consulting firms, with expertise in flood mapping related projects. Aquasphera conducted the assessment for the province of Quebec, CBCL Limited for all Atlantic Provinces (Nova Scotia, Prince Edward Island, New Brunswick, and Newfoundland and Labrador), KWL for British Columbia, and NRC for Alberta, Saskatchewan, Manitoba, Ontario and the territories. The aim of these studies was to acquire information on various aspects of: (i) flood maps and mapping procedures, (ii) climate change and (iii) availability and quality of flood mapping datasets. For these three focus areas, the following aspects were identified for data collection and evaluation purposes.

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 necessary for acquiring sample copies of flood maps for detailed examination, access to published government reports and initiating future collaborations.

2.1.2 Information on Updated Maps

New maps may have been generated with improved technology, modelling approaches and stricter standards than those originally proposed in the FDRP guidelines (IWD 1976). A better understanding was required of which regions and/or municipalities may already have or are in the process of developing updated maps.

2.1.3 Hydrologic and Hydraulic Guidelines

The Inland Waters Directorate of Environment Canada assumed the leading role of the FDRP and developed hydrologic and hydraulic guidelines for floodplain mapping (IWD 1976) to support the implementation of the flood mapping program. Some provinces and territories still use these guidelines while others have developed their own (e.g. Ontario). Further examination of this information was performed in order to assess if any consistency exists with respect to flood mapping standards across the country and if the idea of having uniform flood mapping standards throughout Canada is feasible or not.

2.1.4 Dissemination of Maps

Of interest to this study was to understand whether digital maps were available. Many provinces and territories may still be served by old paper format flood maps for areas where digital maps have not been developed. To conform to present day technology, dissemination of maps in digital format is of importance. Online availability generally enhances utility of the flood maps as the property owners or developers can easily access this information.

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. One-dimensional packages are still used in many riverine floodplains, but the two-dimensional packages are becoming popular because they can provide more detail of the flood water as it inundates the floodplain. In large lake and coastal settings, even more complex hydraulic models are used. For determining flood loading and load combinations for updating codes and standards, flood maps produced from the output of two-dimensional modelling packages are more useful because one can easily produce detailed spatial information of flood depths and velocities.

2.1.6 Information on Mapping Parameters

Flood hazard maps can be prepared for many different purposes, ranging from flood inundation to flood risk, severity and damage maps. 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, contents of existing flood maps were of necessity. As well, detailed information about flood depth, velocity and the product of both depth and velocity (in some form) across the floodplain is of value as it can be used for calculating flood loadings for 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 (Khaliq and Ferguson 2016). In some cases, historically observed severe storms are used for mapping instead of using a return period-based estimate (MNRF 2002). Understanding how the magnitude of the regulatory flood, employed for mapping, was obtained was of interest for this study.

2.1.8 Ice-jam Floods

In areas of ice impacted floodplains, 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 (Alberta Environment 2011). In cases where the ice impacted levels are lower than the levels of the regulatory flood, 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 across Canada. This recommended protection level was concurrent with international recommendations at the time. Since then, 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 understand the province/territories' perspective if a desire exists to raise the minimum protection level to 200-, 300- or even 500-year return period flood across the entire country for regulatory purposes.

2.2 Climate Change Informed Flood Maps

Conventionally for flood mapping purposes, design flood magnitudes are estimated from historical records assuming that the future flood events will not be different from past events (i.e. assuming stationarity of the underlying time series of flood events). According to the findings of the Fifth Assessment Report of the IPCC (IPCC 2014), 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, demonstrating the resilience of the existing critical structures and CPI in the future under a changing climate and the design of new structures to withstand the uncertain future climate is of importance. To investigate whether the impact of climate change has been incorporated in flood maps across the country, following questions were investigated:

- 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?

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 two-dimensional modelling, a high resolution DEM is very important. Some of these datasets are readily available while others generally reside with consulting companies or the provincial or municipal government department involved in creating flood maps. Thus, it is assumed that the supporting datasets for regions mapped during the FDRP initiative may be available free of charge while those collected for the more recent studies may not be freely available.

3 Results and Discussion

Information on floodplain maps and supporting datasets were collected from different sources and reported for Alberta in Murphy and Khaliq (2017a), for British Columbia in KWL (2017), for Manitoba in Babaei (2017), for Ontario in Vouk and Khaliq (2017), for Quebec in Aquasphera (2017), for Saskatchewan in Murphy and Khaliq (2017b), for three territories in Piche (2017) and for all Atlantic Provinces in CBCL (2017). This information for individual provinces and territories was synthesized further in Khaliq and Attar (2017) for the entire country following common evaluation criteria. Information gathering sources and responsible organization/firms, along with the reporting, filtering and synthesis steps are schematically shown in Figure 1 to portray an overall view of various processes involved.

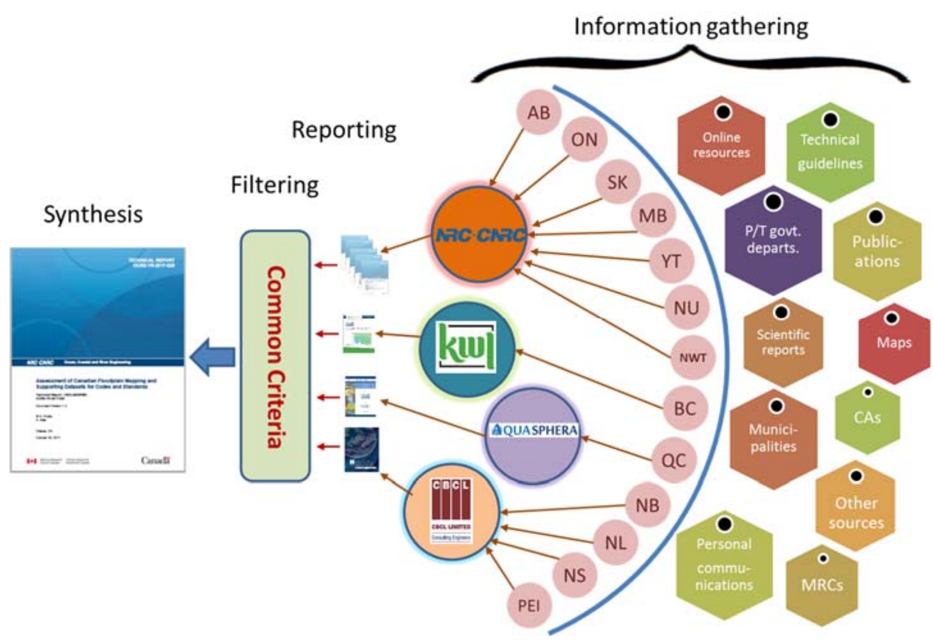

Figure 1: A schematic diagram showing the sources considered for information gathering (e.g. provinces/territories and municipal government departments, agencies involved in floodplain mapping, online resources, and published literature), entities involved in data collection, and filtering mechanism to synthesize all information collected for national assessment of floodplain mapping and supporting datasets.

Information on selected features of floodplain maps, climate change aspects–whether considered or not in floodplain mapping and supporting datasets for all provinces and territories are displayed in Figure 2 (cf. Khaliq and Attar 2017).

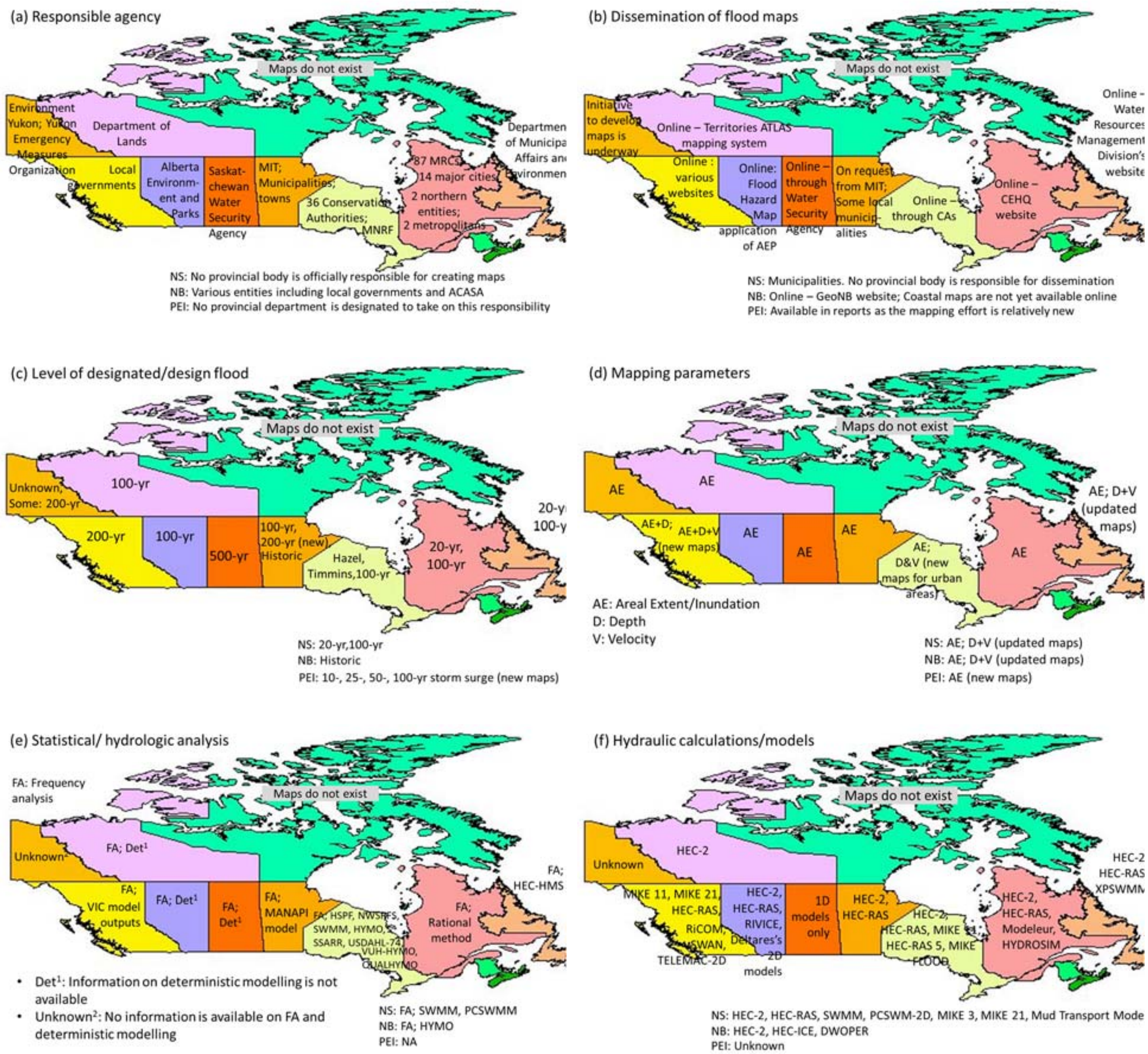

Figure 2: Country-wide information on (a) regulatory agency responsible for creating and maintaining flood maps; (b) dissemination of flood maps; (c) level of designated/design flood; (d) mapping parameters; (e) statistical/hydrologic analysis; (f) hydraulic calculations/models; (g) impact of ice jamming; (h) climate change impacts on flood maps; (i) features of the climate change methodology; (j) future time horizons for climate change; (k) availability of LiDAR data; and (i) availability of DEM data. Map source: http://www.nws.noaa.gov/geodata/catalog/national/html/province.htm.

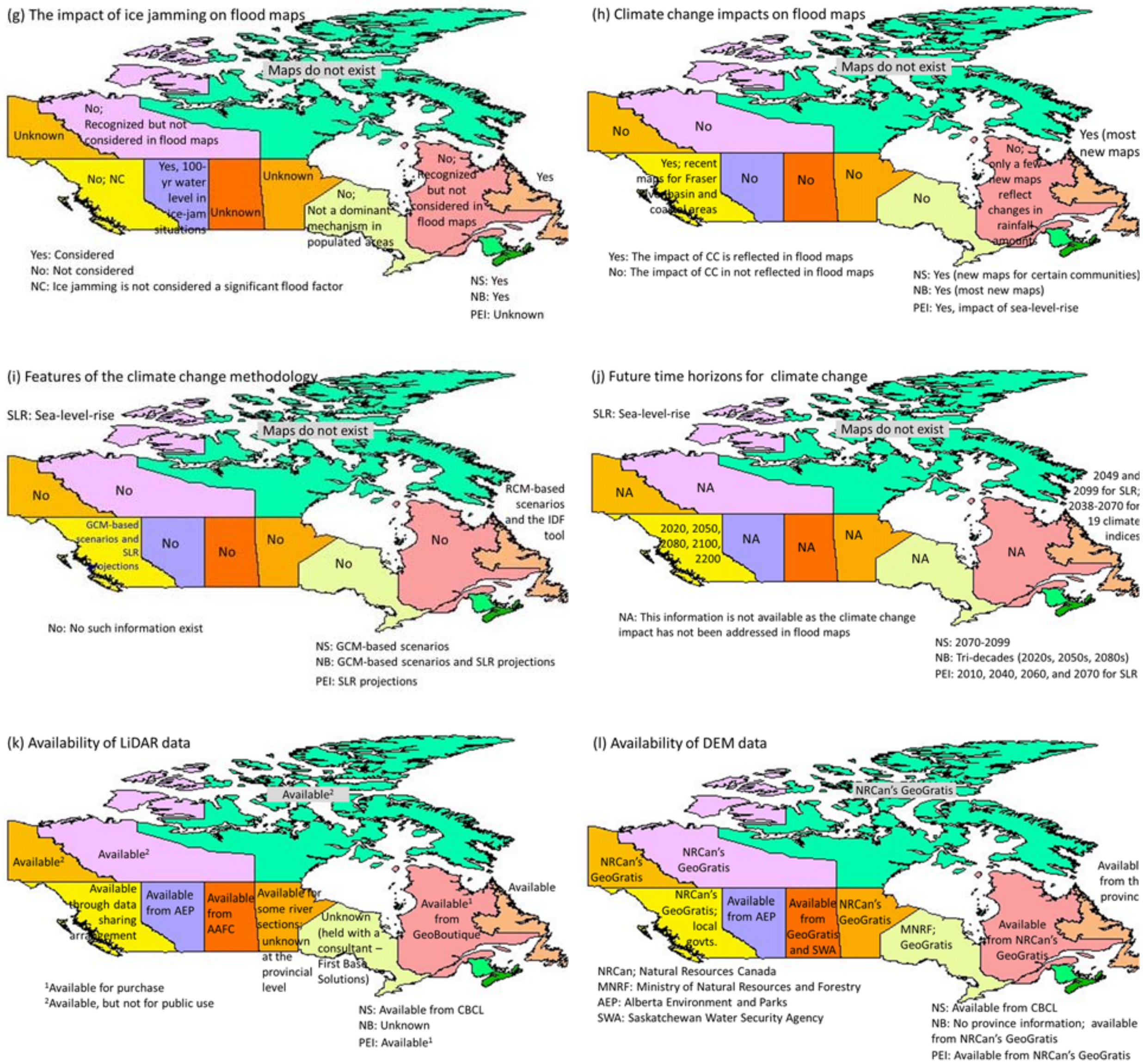

Figure 2: Continued.

Main findings of the study are discussed below:

- Across Canada, floodplain mapping started in 1976 through the FDRP initiative of the federal government. After the termination of the FDRP in 1995/96, the responsibility of floodplain mapping was transferred to provinces and territories. Some provinces continued this effort and employed divergent methodologies to update older flood maps and develop new flood maps for additional areas, while others were less proactive. As a result, flood hazard maps developed since 1995 generally do not follow a nationally acceptable unified methodology. Recently in 2014, federal government, through Public Safety Canada, started a new 5-year initiative under the National Disaster Mitigation Program (NDMP) to update and modernize Canadian floodplain maps and to map additional areas. Natural Resources Canada (NRCan) is supporting the NDMP by developing Floodplain Mapping Guidelines documents and disbursement of funds to provinces, territories and local governments to update/develop floodplain maps.

- Most of the Canadian floodplain maps are now more than 25 years old and were developed using tools and datasets which are now fairly outdated. High-resolution LiDAR based new topographic datasets are now readily available and many state-of-the-art two- and three-dimensional numerical modelling tools have become available as well. These tools can provide relatively a more detailed picture of flood dynamics and risks for a given flooding situation/scenario.
- Canadian floodplain maps reflect a fixed standard-based approach, which does not explicitly take into account the consequences resulting from floods. This new paradigm of flood risk assessment is being considered across a broader flood risk assessment community internationally.
- Considerable variability exists in the designated/design flood level used for floodplain mapping across the country. For example, 100-year return period flood in Atlantic Provinces, Quebec and some parts of Ontario, versus 200-year level in British Columbia and 500-year level in Saskatchewan.
- Most of the floodplain maps show inundation extent and distribution of flood water depth in terms of floodway and flood fringe. Detailed spatial information about flood depth and velocities is available only for a few west and east coast communities, where new mapping initiatives were recently undertaken. This information is necessary if design specifications and flood-resilience is required at the building footprint level.
- Climate change informed flood maps are available only in a few parts of the country, mainly for selected west and east coast communities. A wide variability exists in projections depending on the emissions scenario, climate model used, and the downscaling approach. A harmonized framework for incorporating climate change information into floodplain mapping and future flood risk assessment is severely lacking in Canada. As well, there is lack of guidance on the choice of future time horizons for climate change projections.
- Shortage of readily usable data and approaches for converting projected climate-induced changes in other flood generating processes such as precipitation and evapotranspiration into flood magnitudes and information on future land use changes is another limiting factor.
- Supporting datasets for floodplain mapping are readily available in most parts of the country, though not from a single source as most reside with various contractors and service providers. Examples of these datasets are bathymetry, river cross-sectional information, hydraulic model calibration data, etc. Also, the quality of these datasets is not known. In some regions, datasets like LiDAR maps and aerial photographs of past flooding extents are available for purchase only. LiDAR data can be used to derive/verify other datasets such as drainage area, basin boundaries, cross-section geometry and DEMs.
- Floodplains in the Territories are not widely mapped. Maps do not exist for Nunavut and are currently being created for the Yukon Territory. In the Northwest Territories, paper maps are still in use, with no plans to update.
- Recently, community awareness to flooding has increased considerably, as was reflected in increased number of requests for updated maps. Consequently, various municipalities, regional entities and provincial government departments are interested in updating their respective floodplain maps but lack of consistent funding has been identified as a major impediment in this effort.

4 Path Forward for Flood-Resistant Design of Buildings and Infrastructure

Development of flood-resilient building codes require detailed information about spatial distribution of flood velocities and depths, corresponding to a selected design/regulatory flood, which is required for the entire floodplain, irrespective of coastal or riverine setting. This information is currently not available for most of Canada. Furthermore, floods are expected to be exacerbated by anticipated climate change due to the close connection between the land surface processes and atmospheric mechanisms. Thus, consideration of climate change impacts during development of flood resilient building codes becomes not only relevant but indispensable too. Some coastal and riverine communities, driven by the threat of climate change, have already started developing climate change informed flood maps. The majority of these maps show spatial distribution of flood depths, but not flood velocities. To fully incorporate impact of flood loads on buildings and CPI and to develop new codes and standards, it is important to also have information on the spatial distribution of flood velocities everywhere or at least for the most vulnerable flood sensitive communities across the country.

At the outset of this study, it was expected that the findings of the study will be useful for devising an appropriate line of action for developing climate-resilient codes and standards and the best possible ways of factoring climate change information into the floodplain mapping process. American Society of Civil Engineers Committee on Adaptation to a Changing Climate (Olsen 2015) states that "our engineered facilities and systems should adapt to changing climate, weather and extreme events". Certainly, adaptation to the changing climate will increase climate-resilience of the old and new buildings and CPI. However, climate science does not provide guidelines and a firm basis to alter our engineering practices and standards. Another important issue that needs serious attention from both the engineering and climate science community is "the targeted time horizon for future projections and the variable life span of various buildings and structures" because a single future time window or a specified average global warming scenario (e.g. 1°C, 1.5°C or 2°C) may not be suitable for all buildings and CPI systems. 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.

The synthesis of the collected information provided a strong basis for future research to support development of flood- and climate-resilient codes and standards. As the development of detailed floodplain maps to support derivation of flood loads may not be feasible economically, a number of documented case studies focusing on different building types and CPIs in riverine, urban and coastal settings, with a wide range of climate projections to address climate model and scenario related uncertainties, may provide a way forward to support development of flood- and climate-resilient building codes, standards and guides for future revision of the NBC.

5 Final Remarks

The findings of the national assessment of floodplain maps and supporting datasets presented in this paper are summarized based on individual studies conducted separately for each province and territory. For individual studies, some of 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 studies referenced above 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 floodplain mapping. Therefore, the assessment of flood maps and associated datasets is not of an exhaustive nature. It is hoped that similar efforts will continue in the future.

Existing Canadian flood maps were developed mainly for land use planning and development bylaws and therefore can provide only very limited information for developing flood-resistant codes and guides for structural design (retrofitting) of new (existing) buildings and infrastructure. Climate change informed flood maps are being developed, but are available only for a few west and east coast communities. Therefore, a comprehensive harmonized framework is required to be developed and implemented in order to address identified gaps and develop provisions for flood- and climate-resilience, including the impact of climate change, in the NBC.

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