Building Tomorrow's Society
Bâtir la Société de Demain

Fredericton, Canada
June 13 – June 16, 2018/ *Juin 13 – Juin 16, 2018*

HOLISTIC APPROACH TO FLOOD RISK MITIGATION IN NOVA SCOTIA

Fernandez, Victoria[1,2], Wilson, Alexander[1]
[1] CBCL Limited, Canada
[2] vfernandez@cbcl.ca (corresponding author email)

Abstract: The third United Nation World Conference on Disaster Risk Reduction recognized the importance of understanding disaster risks as result of the combination of not only natural hazards and infrastructure capacity but also social vulnerability, exposure levels, and emergency preparedness. Understanding these factors and their combined effect is fundamental for assessing risks, preventing disasters, mitigating damages and preparing for emergencies. In the case of Canada, flooding has been identified as the leading cause of emergencies. In this context, risk management requires not only understanding the hydrologic and hydraulic processes that result in extreme events but also recognizing that protection of infrastructure does not necessarily translate into the protection of public safety. In Atlantic Canada, more than 40% of residents live in rural and low budget communities. Populations at risks include First Nation communities and coastal settlements located in the Bay of Fundy (home to the highest tides in the world). Holistic flood risk management approaches in this region have focused on determining the priorities and needs of stakeholders, identifying vulnerabilities, evaluating the suitability of approaches such as retreat, protection and adaptation; and enhancing capacity for resilience. The implementation of such approaches in Atlantic Canada needs to be placed in the context of limited budget availability, complex environmental settings, limited historical data and uncertain future climate. This paper discusses the implementation of holistic flood management approaches and softer flood mitigation techniques in the province of Nova Scotia.

1 INTRODUCTION

Rural and urban communities in the peninsula of Nova Scotia are located within 70 Km of the coast and exposed to complex and diverse environmental settings. In the South Shore, for example, a deep natural harbour allowed the establishment of Halifax, now a densely populated urban center. Coastal developments are exposed to waves and storm surges from the Atlantic Ocean and are at risk of permanent inundation, as a result of sea level rise. In the Bay of Fundy, the world's highest tides inundated the coastal areas, creating nutrient rich soils that attracted agricultural development. Communities along these shores reclaimed coastal flooding areas through the construction of dykes and tide gates (aboiteaux) for flood protection. In recent times, many of these communities have experienced major flooding events caused by the overtopping of the dykes or stormwater backup (Nova Scotia Environment 2015).Throughout the province, communities at risk of flooding are exposed not only to flooding hazards of different nature but also to diverse socio-economical settings. These settings are relevant in defining a community's vulnerability and exposure to flooding disasters (Thistlethwaite and Henstra 2017).

Communities in Nova Scotia have traditionally relied on structural defenses from hazards up to a specific magnitude. The standard design criterion is generally the 100-year rainfall event (an event with an annual exceedance probability of 1%). On October 10, 2016, Thanksgiving Day, Sydney NS experienced a major flooding after a precipitation event of 225 mm of rain in 24 hours, an amount close to the 2000-year rainfall calculated with historical data in the area (Figure 1). The occurrence of events of magnitude above the infrastructure design threshold shows that structural defenses alone may not be sufficient to achieve effective flood management and disaster mitigation. A broader or holistic flood management strategy treats flood risks as a combination of multiple factors including hazards, emergency preparedness, environmental settings and socio-economic conditions. This paper discusses elements to consider when implementing an integrated approach to flood studies in Nova Scotia including exposure (the proximity of the community to the hazard), vulnerability (the environmental, social, and physical conditions that make a community susceptible to a hazard), and the limitations of human intervention when providing full protection against a flooding hazard.

Figure 1 Flood in Sydney NS on October 12, 2016. Two days after the storm (CTV News 2016)

2 PARADIGM SHIFT

Communities living in floodplains and along coastal shorelines have traditionally relied on flow control and storage (dams and reservoirs), channel enhancement and diversion, and structural defenses (levees and dykes) for protection against floods (World Metereological Organization 2009). This approach provided populations with access to areas naturally prone to flooding, but at significant long-term cost and risk. These include:

- the continuous need for infrastructure maintenance funds (Instittue for Sustainable Development 2013);
- performance limited to designs based on probability of occurrence (FEMA 2007);
- limited adaptability in the face of climate change (Blair and Thistlethwaite 2012);
- environmental damages associated with disconnecting the rivers from the floodplain (Tockner and Stanford 2002); and
- hidden risks associated with failures and additional developments (Managers 2007).

Recent estimates of flood-related economic loss indicate that effective flood management requires considering the limitations of structural defenses and the consequences of flooding (Thistlethwaite and Henstra 2017)

In the year 2009, the World Meteorological Organization called for a “paradigm shift” from this traditional approach to an integrated recognition of the dynamic nature of river and coastal systems (World Metereological Organization 2009).

In 2015, the Sendai Framework of Disaster Risk reduction, the most recent holistic guidance for global disaster management, identified four fundamental elements in the implementation of an integrated approach to disaster mitigation (United Nations 2015):

1. Understanding the Risks;
2. Strengthening disaster risk governance to manage the risks;
3. Promote public and private involvement; and
4. Enhance emergency preparedness

In the context of flooding, understanding the risks requires not only knowledge of the natural processes that cause flooding (rainfall, tides, snow melt, ice jams, storm surges) but also knowledge of the degree of exposure to the hazard and the degree of vulnerability. In this context, flood studies and floodplain mapping can provide a comprehensive description of the natural hazard and the extent of flooding.

Strengthening disaster risk governance for flood management involves the implementation of programs, plans, guidance, and regulations directed at managing the exposure to risk of flood-prone areas, strengthening emergency preparedness and response, and fostering resilience and recovery (United Nations 2015).

Increasing public awareness of flooding risks and the potential effects of climatic change on those risks should be included in public and private involvement and investment, with the goal of preventing the loss of life, reducing losses, and facilitating recovery. This also includes providing a mechanism for the public to establish its priorities for protection and potential needs during recovery. Citizen data collection also provides a platform to collect historical flood event information and creates awareness about the magnitude of hazards.

Enhancing emergency preparedness aims at fostering effective emergency response and identifying opportunities for implementing improvements when restoring or replacing damaged infrastructure. Generally, municipal, provincial, and federal authorities rely on emergency management plans outlining response strategies. In the context of flooding, calibrated hydraulic and hydrologic models, using rainfall and temperature predictions can potentially identify areas at risk. This would allow authorities to notify the public of the risk and prepare for extreme events ahead of time.

The following sections evaluate the implementation of a holistic approach to flood studies and flood management in Nova Scotia using the four elements identified in the Sendai Framework of Disaster Risk Reduction

3 UNDERSTANDING FLOODING RISKS IN NOVA SCOTIA

Floodplain maps are an effective tool for anticipating, preparing, and mitigating flood damage when based on updated weather and land use information (Henstra&Thistlethwaite, 2017). Between 1975 and 1996, under the Flood Damage Reduction Program (FDRP) more than 900 communities throughout Canada developed 1 in 20 year and 1 in 100 year flood maps aiming to identify areas vulnerable to floods and regulate development in those areas (Environment and Climate Chance Canada 2013). A study for the National Floodplain Management Framework of Public Safety Canada identified that by the year 2014, approximately 50% of flood maps in Canada were produced before 1996 (MMM Group Limited 2014) .

Since the FDRP ended,20 years of historical weather and hydrometric observations have become available through Environment Canada. Global models have increased their resolution and capability to project future climates (Le Treut, et al. 2007); computer modelling has evolved to allow hydraulic modelling in two and three dimensions (2D and 3D); and accurate gauging instruments have become available. In addition to this, community engagement (Natural Resources Canada 2017)and emergency preparedness plans (Public Safety Canada 2018) have become relevant in the evaluation of flood risks and vulnerability.

Several municipalities within Nova Scotia have conducted recent flood studies recognizing the value of updating their flood map information. These flood studies were based on the computer modelling of complex hydraulic and sediment transport processes in the Bay of Fundy or on simulations of a complex system of lakes, wetlands, river and hydraulic structures in the Halifax Regional Municipality (CBCL Limited 2016). However, despite the potential of the technological platform, which allows the assessment of flooding hazards, flood mapping in Nova Scotia faces the following challenges:

3.1 Lack of Historical Data

Advances in technology have included more complex computer models, high-resolution aerial imagery, and Lidar information availability allowing the simulation of complex hydraulic processes with a much greater degree of accuracy. However, evaluating the frequency of flooding and the probability of occurrence of extreme events requires an assessment of the local historical weather with a typical minimum of 20 years of records. In Nova Scotia, and generally in Atlantic Canada, this is limited by the low availability of gauging stations with sufficient historical records of rainfall amounts, water levels, and flow rates to conduct statistical analysis. For example, Figure 2 shows that very few rainfall stations over the province feature more than 20 years of record data within the last 50 years.

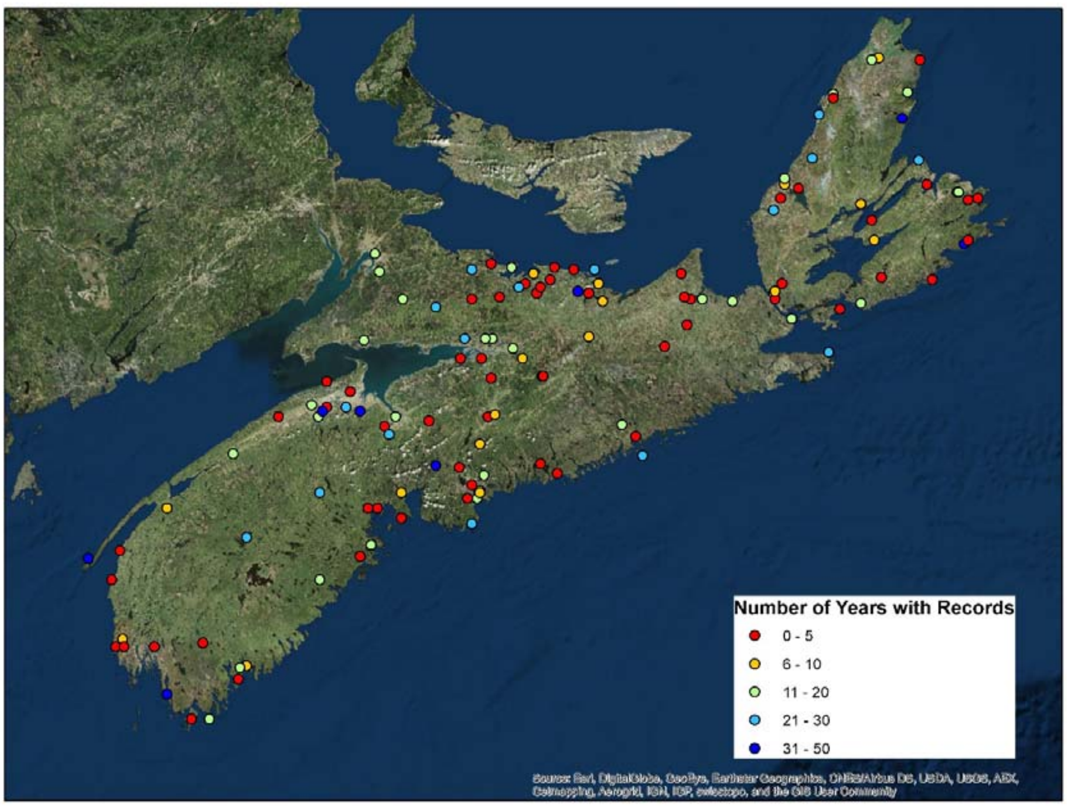

Figure 2 Environment Canada Rainfall Stations with Records since 1970

Overcoming the challenges associated with these information gaps requires a series of approximations and projections that may carry a certain degree of uncertainty and require additional validation efforts. For example, The Truro Flood Study required the development of a calibrated hydrodynamic model of the Bay of Fundy capable of projecting gauged water levels from Saint John Harbour to Truro (CBCL Limited 2014).

In the future, remote sensing records may offer an alternative to rainfall gauging stations for the calculation of rainfall intensity and duration curves (Marra, et al. 2017) which are typically used in the assessment of extreme stormwater flooding. In Nova Scotia, this methodology could be explored in the short term, as Environment Canada maintains rainfall radar data records, available from the year 2007 (Environment Canada 2018).

3.2 Complex Hydrodynamics

In the most recent flood studies in the region, advanced hydrodynamic modelling has provided insights into the complex combination of processes that result in flood risks (CBCL Limited 2016). For example, the interaction between the large tidal ranges in the Bay of Fundy with high rates of sediment transport and the network of dams and tidal gates (aboiteaux) result in temporal and spatial distribution of water levels, sediments, and flows that complicate field monitoring programs and model calibration. Figure 3 shows how more than one meter of sediment accumulated over a tide gauge during a field-monitoring program in the Bay of Fundy.

Figure 3 Sediment Accumulation Bay of Fundy at Tide Gauge Location (March 2013 Left, January 2014 Right). Credit: Alexander Wilson, CBCL Limited

3.3 Effect of Environmental Setting and Socio-Economic Conditions in Flood Mitigation Options

In the Bay of Fundy, sedimentation rates result in up to 2 meters of accumulation during the summer months and significant morphodynamical changes to river channels after the construction of hard infrastructure (Van Proosdij, et al. 2009). For example, the Truro Flood Risk study (CBCL Limited 2014) showed that under these conditions, the construction of protective infrastructure with limited life spans might require a significant capital investment to achieve minimal benefits, while increasing the risk of damage in case of failure. The study evaluated the implementation of more sustainable options including basin wide approaches that identify opportunities for avoiding exposure of key infrastructure to areas prone to flooding.

3.4 Limited implementation of nature-based approaches

Public awareness about the benefits of nature-based approaches for flood risk management is growing (World Bank 2017). The physical conditions of riverine and coastal systems are the result of the feedback between sediment transport, hydrodynamic processes and ecology. (Masselink and Hughes 2014). Nature-based solutions aim to reduce erosion issues, mitigate flood risks and improve water quality by mimicking processes of the natural environment. Benefits of this approach include adaptability, sustainability and low cost (NOAA 2015) .

Throughout the Province there are limited examples of flood mitigation approaches based on adaptation to natural processes. The capacity enhancement of Broad Brook in Yarmouth is one example of a flood mitigation approach that incorporates the functional features of adjacent wetlands and fish habitat (CBCL Limited 2016). The design is based on a system-scale perspective of the local socio-economic and environmental conditions after evaluating more than 10 combinations of infrastructure upgrade and stream enhancement. The project also includes considerations for adaptive management based on long-term monitoring.

4 FLOOD MANAGEMENT GOVERNANCE

In Nova Scotia, provincial and municipal governance includes the implementation of by-laws that regulate development within the 100-yearfloodplain (Nova Scotia Municipal Affairs 2002). Some municipalities such as the Halifax Regional Municipality require new developments to maintain peak runoff rates equal to those discharging from the site before development. Nova Scotia Environment regulates the environmental impacts that flood protection infrastructure may exert over adjacent wetlands and water courses (Nova Scotia Environment 2015). For approaches involving the construction of dams and water storage, Nova Scotia Environment requires a safety assessment based on the Safety Guidelines of the Canadian Dam Association. At the Federal level, the Department of Fisheries and Ocean requires the inclusion of fish passage considerations in the design and construction of any hard infrastructure within a watercourse. Therefore, an integrated approach to flood studies in Nova Scotia requires an understanding of the regulatory framework that governs the implementation of flood mitigation approaches. These regulations limit the implementation of traditional approaches that relied on extensive channel dredging, wetland reclamation, and river diversion.

5 PUBLIC AND PRIVATE INVOLVEMENT

A recent survey conducted by the University of Waterloo showed that about 94 percent of Canadians living in designated flood risk areas do not know they are at risk (Thistlethwaite et al. 2017). Effectively involving community residents in the floodplain mapping process is a critical component in establishing community-level awareness of flood risk (White, Kingston, & Barber, 2010).

Flooding studies for the Town of Mahone Bay in Lunenburg and for the Town of Truro, included public consultation at several stages of the project. The meetings unfolded through open house sessions that included “stations” to capture public feedback. Community members were directed to large maps where they could discuss their flooding experiences and concerns with the consultation team, illustrating their issues with markers and pens on the maps provided. The final station provided an opportunity for community members to rate priorities for flood protection. In both cases, this approach provided the community with updated information about flooding risks and allowed the development of mitigation recommendations taking into consideration the vision, values, needs, and priorities of each community.

6 FLOOD RISK MITIGATION AND EMERGENCY PREPAREDNESS

Flood risk mitigation in Nova Scotia requires recognizing the limitations of infrastructure-based protection approaches and recognizing the uncertainties associated with estimating the time and magnitude of the impacts of climate change. Reducing the risk of flooding under the complex environmental conditions of the Bay of Fundy, the socio-economic conditions of urban centers such as Halifax and Sydney and the physical characteristics of rural areas such as Yarmouth, may require combining strategies such as the following (Will and Leeds 2012, IPCC 2014):

- **Accommodate:** This approach involves changing land uses in exposed areas using infrastructure that can tolerate flooding. Examples of this approach include raising or flood proofing vulnerable infrastructure and using floating structures.

- **Retreat:** This long-term approach consists of relocating people and infrastructure away from hazardous coastal areas. Managed retreat involves selecting what to relocate and mitigating the environmental impacts of leaving infrastructure exposed to natural processes. Abandonment is another type of retreat that does not involve planning for relocation or for the impacts that abandonment may cause on the environment. Abandonment is not a beneficial adaptation strategy but may be necessary in cases of emergency.

- **Avoid:** This approach prevents development in hazardous coastal and riparian areas and locates critical infrastructure such as hospitals and emergency services in areas where risks of flooding are negligible.

- **Holding the line:** This approach maintains land uses and development in the vulnerable areas and relies in the design and maintenance of hard infrastructure to resist extreme events to a set level.

In Nova Scotia, selecting a suitable flood management approach requires an understanding of the regional setting that influences the scale of flooding risks, the characteristics of the population and the value of the infrastructure at risks. Flood mitigation options in areas of negative growth may require balancing the community outlook with the needs of their current residents. In addition, the occurrence of major flooding events such as the Thanksgiving storm in Sydney, shows the fundamental role of emergency preparedness as part of a integrated flood risk management strategy.

6.1 Expanding Emergency Preparedness in Nova Scotia

A wide range of factors, including availability of financial resources, physical constraints, and long-term unpredictability of the magnitude of the threat limits the effectiveness of human intervention in flooding risk protection (World Metereological Organization 2011). Therefore, emergency preparedness is a fundamental element in reducing the risk of life and infrastructure losses.

Flood mapping creates awareness about areas at risks and allows emergency management officers to implement general response plans. However, flooding maps are insufficient to account for the variability of timing, location, and magnitude of flood hazards. Therefore, the public and emergency response teams can benefit from the implementation of a flood forecasting and warning system.

Implementation of an effective flood forecasting and warning system requires consideration of multiple elements (World Metereological Organization 2011) including the type of expected flood (urban, seasonal, flash, coastal, estuarine, etc.); the size of the area to monitor, type of model (lumped or distributed), hydrological and coastal considerations. In Nova Scotia a fundamental consideration includes the simultaneous effect of multiple processes (rainfall, snowmelt, high tides, waves, and in some cases sediment transport) which can be better understood through computer modelling.

The availability of remotely sensed weather prediction, calibrated hydrodynamic models, and platforms for citizen data collection can potentially allow the anticipation of where and when a forecasted weather event is likely to cause more damage. Across Canada flood forecasting systems range from water level and flow monitoring to complex systems involving calibrated computer models.

In Nova Scotia, recent flood studies have developed calibrated computer models for a wide range of communities (CBCL Limited 2016). Some of these models can support real-time updates using weather and storm surge forecast. Environment Canada provides radar rainfall forecasting data from the High Resolution Deterministic Prediction System (HRDPS), a 2.5 Km resolution climatic model with up to 48-hour forecast period. NOAA and Deltares provide global and regional storm surge forecast. Webtide provides tidal predictions for the Atlantic. However, emergency preparedness programs based on flood forecasting using complex hydrodynamic models are not yet available in the Province (Natural Resources Canada 2014)

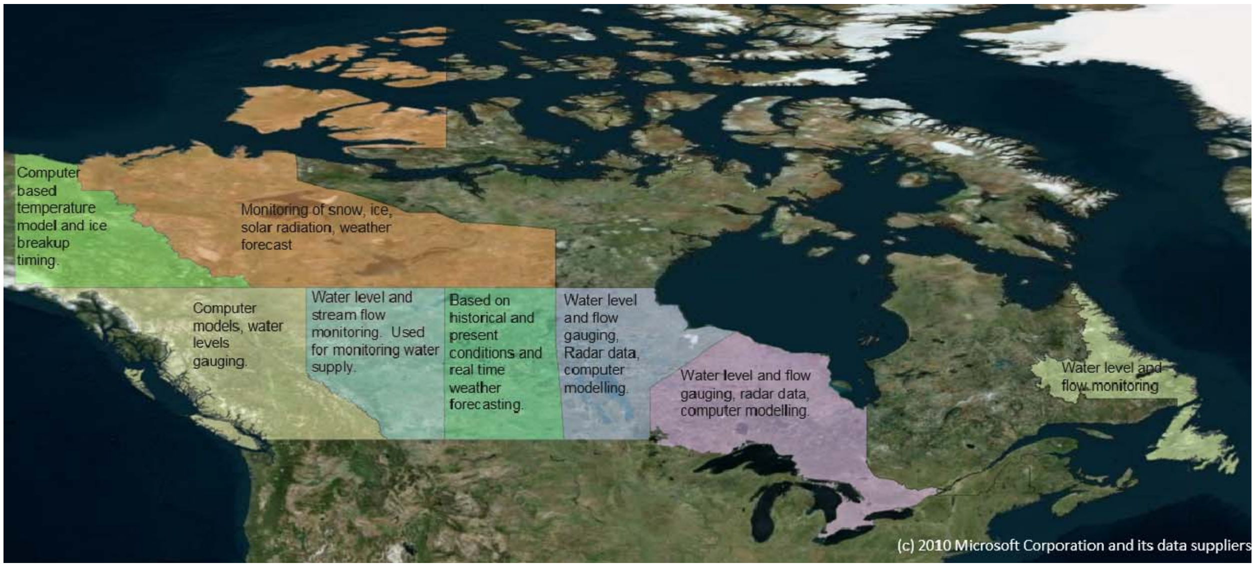

Figure 4 Flood Forecasting in Canada (Natural Resources Canada 2014)

7 CONCLUSIONS

Nova Scotia is no exception to the complexities of flood risk management that have been recognized and acknowledged worldwide in the face of climate change. The United Nations have developed a framework for disaster risk mitigation that aims to mitigate life and infrastructure loss and foster resilience. In the context of flooding, this framework and a holistic approach to flood risk studies can be implemented in Nova Scotia to define effective risk management strategies in vulnerable communities. An integrated approach to flood mitigation acknowledges the limitation of an infrastructure-based approach, takes into consideration the degree of uncertainty associated with climate change projections, recognizes that flooding events are the result of natural processes at a large scale, and identifies opportunities for improving the performance of the system as a whole.

Recent flooding studies in the province have used this approach in the evaluation and mapping of flooding risks under current climatic conditions and under the projected effects of climate change. These studies have provided recommendations that recognize the limitations of using hard infrastructure alone and have recognized the importance of community engagement as a source of information about historical events and the priorities and needs of vulnerable communities. The most recent studies have relied on complex computer modelling for producing flood maps identifying vulnerable areas. The availability of these models along with remote sensing information and weather forecast data provide an emergency preparedness strategies in the Province.

References

Blair, Feltmate, and Jason Thistlethwaite. 2012. Climate Change Adaptation: A Priorities Plan for Canada. Waterloo: University of Waterloo.

CBCL Limited. 2016. Assessment of Broad Brook Improvements. Yarmouth, NS: CBCL Limited.

CBCL Limited. 2016. Status of Flood Maps in the Atlantic Canadian Provinces. Halifax: CBCL.

CBCL Limited. 2014. "Truro Flood Risk Study for the Joint Flood Advisory Committe (County of Colchester, Town of Truro and Milbrook First Nation)." Halifax.

CTV News. 2016. Sydney, N.S., after Hurricane Matthew flooded the area, on Oct. 12, 2016. 10 13. Accessed 04 01, 2018. https://www.ctvnews.ca/canada/i-ve-lost-everything-insurance-coverage-in-question-after-atlantic-storm-1.3113324.

Environment and Climate Chance Canada. 2013. Flood Damage Reduction Program. 07 17. (https://ec.gc.ca/eau-water/default.asp?lang=En&n=0365F5C2-1).
Environment Canada. 2018. 1 11. http://climate.weather.gc.ca/radar/index_e.html.
FEMA. 2007. Design Guideline for Improving Critical Facility Safety from Flooding and High Winds. Washington DC: FEMA.
Instittue for Sustainable Development. 2013. Climate Change Adaptation and Canadian Infrastructure. Review of Literature. Winnipeg: The International Institute of Sustainable Development.
IPCC. 2014. "Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change." By V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.) C.B., 1132. Cambridge, United Kingdom and New York: Cambridge University Press.
Le Treut, H., R. Somerville, R. Cubasch, Y. Ding, and C. Mauritzen. 2007. Historical Overview of Climate Change. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
Managers, Association of State Floodplain. 2007. "Levees: the double-edged sword. ." Madison, WI.
Marra, Fracesco, Efrat Morin, Nadav Peleg, Yiwen Mei, and Emmanouil Anagnostou. 2017. "Intensity–duration–frequency curves from remote sensing rainfall estimates: comparing satellite and weather radar over the eastern Mediterranean." Hydrology and Earth System Sciences 2389-2404.
Masselink, Gerhard, and Michael Hughes. 2014. Introduction to Coastal Processes and Geomorphology. New York: Routledge.
MMM Group Limited. 2014. National Floodplain Mapping Assessment. Ottawa, ON: Public Safety Canada.
Natural Resources Canada. 2017. Federal Floodplain Mapping Framework. Ottawa: Natural Resources Canada.
—. 2014. Flood forecasting centres across Canada. 07 03. https://www.canada.ca/en/environment-climate-change/services/water-overview/quantity/floods/forecasting-centres.html.
NOAA. 2015. A Guide to Assessing Green Infrastructure Costs and Benefits for Flood Reduction. Charleston: NOAA Office for Coastal Management.
Nova Scotia Environment. 2015. "Guide to Altering Water Courses." Nova Scotia: Nova Scotia Environment.
—. 2015. Nova Scotia Flood Events from 1992 to 2015. December 15. https://fusiontables.google.com/DataSource?docid=1UwMP_E8K47cl2gcEpDfz660xa7Q3kit2czO6j7Lo#rows:id=1.
Nova Scotia Municipal Affairs. 2002. "Model Land Use By-Law." Halifax, July.
Public Safety Canada. 2018. "Canada's National Disaster Mitigation Strategy." Department of Public Safety and Emergency Preparedness . 01 31. https://www.publicsafety.gc.ca/cnt/rsrcs/pblctns/mtgtn-strtgy/mtgtn-strtgy-eng.pdf.
Thistlethwaite, Jason, and Daniel Henstra. 2017. "Municipal Flood Risk Sharinf in Canada: A policy instrument analysis." Canadian Water Resources Journal 349-363.
Tockner, Klement, and Jack Stanford. 2002. "Riverine Flood Plains: Present State and Future Trends." Environmental Conservation 308-330.
United Nations. 2015. Sendai Framework for Disaster Risk Reductoin . New York: United Nations.
Van Proosdij, Danika, Timothy Milligan , Gary Bugden, and Karl Butler. 2009. "A Tale of Two Macro Tidal Estuaries: Differential Morphodynamic Response of the Intertidal Zone to Causeway Construction." Journal of Coastal Research 772-776.
Will, McBain, and Arup Leeds. 2012. "Twenty-frist Centruy Flood risk Management." In Flood Risk: Planning, design and management of flood defence infrastructure, by ed. P.B. Sayers, 7-21. Oxfordshire: ICE.
World Bank. 2017. Implementing Nature-Based Flood Protection: Principles and Implementation Guid. Washington: The World Bank Group.
World Metereological Organization. 2009. Integrated Flood Management. 2009: World Meterological Organization.

World Metereological Organization. 2011. Manual on Flood Forecasting and Warning. Geneva: World Metereological Organization.