Rethinking Flood Risk Management

by

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This thesis consists of material, all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public

STATEMENT OF CONTRIBUTIONS

In the School of Environment, Resources and Sustainability, two forms of presentation of the

Findings from this dissertation are reported in three co-authored manuscripts:

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Chapter Four: Emami, P., de Loë, R.C. Manuscript. Rethinking governance of flood risk: lessons learned from the Port Lands Flood Protection Project, Water Policy.

These chapters have been prepared for submission to refereed journals.

I testify that I am the primary author of the manuscripts in my dissertation and that the work was dominated by my intellectual efforts.

ABSTRACT

Damages due to flooding have increased significantly in recent years and are predicted to rise globally despite many attempts by governments to mitigate flooding. Since 2015, global efforts to reduce the risk of flooding and to promote adaptation have gained momentum. These efforts include the development of the Sustainable Development Goals and the Sendai Framework for Disaster Risk Reduction. Despite the increase in global attention, there is evidence that the unpredictable impacts of climate change, combined with changes in social and economic trends, are not being adequately addressed in flood risk management strategies around the globe (FRM). A key concern is the roles played by natural or human-induced factors that directly or indirectly cause a change in the risk of flooding or the ways in which flooding is managed or governed. These are referred to as “drivers of change”. While the challenges and impacts of drivers of change on FRM are widely recognized by researchers and policymakers, very few studies have explored the impact of drivers of change on FRM at the global and local levels. Therefore, it is beneficial to study FRM systems in different social, economic, and environmental contexts to identify a global and local range of drivers of change, their impacts on FRM, and their implication for governance.

Examining drivers of change and studying their potential impact on flood management sheds light on pathways to change flood management approaches and to connect with broader social ecological systems to adjust to, cope with, or benefit from the impact of drivers of change. The overall purpose of this research is to identify and assess drivers of change and their influence on flood management. Four research objectives follow from this overall purpose: (1) build a conceptual framework that recognizes and accounts for impacts of drivers of change on flood management using insights from the Social-Ecological Systems (SES) Framework, institutional design and analysis, flood management, and broader water governance literature; (2) apply the conceptual framework to detect drivers of change and to understand the ways in which flood management and water governance literature have identified and addressed the influence of drivers of change on flood management; (3) use this framework empirically to examine flood management approaches concerning the influence of drivers of change in Ontario and the City of Toronto; and (4) identify ways in which institutional arrangements for flood management can be changed to reduce and manage the risk of flooding by accounting for drivers of change.

This dissertation used a mixed-method design that combined a systematic review of FRM literature with case study research in the City of Toronto, Ontario, Canada. A systematic review of peer-reviewed papers (n=170) was conducted to identify the most common and noted drivers of change. Using the systematic review, I explored FRM literature capacity to recognize or acknowledge the impact of drivers of change (Chapter Two). Case study research focused on the FRM systems in the City of Toronto, which is nested in the Ontario FRM system (Chapter Three and Four). In total twenty-eight key informant interviews were conducted. All participants had a managerial role in their organization and were purposefully recruited based upon their knowledge of FRM in Toronto, Ontario, Canada, and/or their involvement with the selected FRM systems. Personal observation and analysis of more than 230 documents provided additional data used in the analysis. Documents included statutes, case law, and reports from government agencies, the insurance industry, and other actors. The collected data described, explained, and exemplified the

scientific, engineering, policy, management, and governance approaches in FRM systems in the City of Toronto and Port Lands Flood Protection Project.

The empirical findings reveal that the most noted drivers are usually portrayed as global challenges outside the scope of FRM or governance, despite having a noticeable impact on the flood hazard and vulnerability at a local level. Defining and categorizing drivers of change facilitates identifying direct and indirect drivers that exist in different levels and scales (temporal and spatial). Identifying drivers of change is a necessary first step to rethink FRM approaches. This analysis also concluded that awareness of drivers of change and their impacts on FRM is increasing among people involved. The result from the systematic review reveals that drivers of change are emerging in five key categories: Environment (ENV), Policy (POL), Technology (TEC), Economy (ECO), and Social (SOC). The systematic review analysis also highlighted a gap in defining and categorizing drivers of change or weighing their impact on flood risk and vulnerability. To address this gap, I developed a conceptual framework that situates the select FRM system in the broader social-ecological systems and accounts for the pre-existing conditions in the system.

The conceptual framework, as a major contribution of this research, presents a new approach to identify the impacts of drivers of change on flood risk management using insight from the modified CIS (Combined Institutional Analysis Development and Social-Ecological Systems and a diagnostic approach. The conceptual framework follows a four-step analysis and supports high-level and in-depth research in the case study approach. In the four-step analysis, the first step is to define the action situation as clearly as possible. The second step, “spiralling inwards,” determines if a FRM perspective is appropriate. The third step critically reflects on the boundaries of the current action situation to facilitate the analysis' final step, which focuses on identifying opportunities to improve governance by accounting for drivers of change in the selected action situation. Together, the last two steps promote inquiry into interactions “external” to the selected action situation; they involve, which involves “spiralling outwards” to explore broader interactions and their impact on current FRM contextual factors. Using the four-step analysis, I explored the impacts of drivers of change on institutional arrangements to highlight opportunities and weaknesses in the selected action situation.

The case study research results highlight thirteen drivers of change relevant to FRM in the City of Toronto and five main drivers of change in the Port Lands Flood Protection Project. Further, this dissertation emphasizes a need for strengthening nested polycentric governance in FRM by engaging all levels of government. Further, examining drivers of change in the Port Lands Flood Protection Project provides a lens into the characteristics of an innovative institutional design that can adjust to, cope with, or benefit from the impacts of drivers of change. This innovative institutional design has enhanced collaboration among public and private actors while providing a strong business agenda to ensure the continuity of the projects and the plans. Finally, this dissertation makes scholarly and practical contributions. Scholarly contributions complement literatures on water and environmental governance, flood risk management, institutional analysis, and flexibility literature. Practical and policy contributions address the impacts of drivers of change on FRM in Ontario and the City of Toronto and build the case for more flexible institutional arrangements.

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DEDICATION

I dedicate my dissertation to my Parents, Soroosh, and Armin.

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Chapter 1

Introduction

1.1 Problem context and rationale

Globally, floods are recognized by the United Nations Office for Disaster Risk Reduction and the World Economic Forum as the most common natural disaster, accounting for 43% of all recorded events from 1995 to 2015 UNISDR (2015, 2). Floods are predicted to occur with higher frequency in the future (Winsemius et al. 2016). These global predictions highlight the escalating threats to global GDP (Gross Domestic Product); these threats can be exacerbated by the failure of climate-change mitigation and adaptation (Winsemius et al. 2016). The unpredictable impacts of climate change, combined with significant social and economic changes, invoke a shift in the landscape of water governance and flood risk management (FRM). Ecosystem degradation, climate change, and natural resource depletion are also challenges that have put pressure on water governance and environmental governance. The following section focuses on water governance and Flood Risk Management (FRM) challenges facing drivers of change. I conclude that there is a need to rethink water governance and FRM approaches to identify pathways for mitigation and risk reduction.

1.1.1 Water governance and changes to the nature of the risk

Increasing complexity and the scale of many environmental problems, accompanied by the development of new technologies, increasing urbanisation, changes in consumption, concerns about interconnected global risk, and increasing decentralisation have challenged current governance and management systems to provide flexible and sustainable solutions for environmental problems (Heikkila 2016, Skinner 2016, Baird and Plummer 2020).

Changes in the broader landscape of environmental governance have created an ongoing debate focused on re-examining governing structures in water governance and FRM to develop sustainable, flexible, and resilient solutions for social and ecological challenges (Egan and de Loë 2020, Baird and Plummer 2020). For instance, in flood management, sustainable, flexible and resilient solutions stem from the integration of structural and non-structural efforts (Alaerts 2019). These efforts include developing efficient land use, setting priorities in urban or socio-economic development, addressing climate change impacts, securing critical infrastructures, and resolving questions regarding responsibilities of direct and indirect flood management actors (Moudrak and Feltmate 2019, Raadgever, Booister and Steenstra 2018, Rollason et al. 2018, Morrison, Westbrook and Noble 2018b). To enhance the flexibility of flood management and manage the risk of flooding while addressing drivers of change, there is a need to revisit current institutional arrangements and interaction dynamics among various actors.

Changing current institutional arrangements and patterns of interaction among various actors who have an impact on water governance has proven to be challenging (O'Connell 2017). Efforts to develop flood risk management strategies are an example. Despite significant governance and management attempts at local, national, and global levels to reduce the negative impact of flooding, damages due to flooding have increased significantly and are predicted to rise globally (World Bank 2017, Ward et al. 2020). A number of scholars have recognized that

various persistent water-related failures can be linked to drivers of change in governance and management (Juhola et al. 2017, Butler and Pidgeon 2011, Owrangi, Lannigan and Simonovic 2014). I defined drivers of change in FRM as a natural or human-induced factor that directly or indirectly causes a change in the risk of flooding or the ways in which flooding is managed or governed. This perspective of drivers of change draws on insights from business and management (Perera 2017, Srdjevic, Bajcetic and Srdjevic 2012), organizational analysis literature (Borrás and Radaelli 2011, Whelan-Berry and Somerville 2010), biodiversity literature (Millennium Ecosystem Assessment 2005, Lewison et al. 2016), and deforestation and land-use changes literature (Geist and Lambin 2002, Rueda et al. 2019). These insights are further elaborated in Section 1.3.

Drivers of change, such as changes in weather patterns, are shifting the nature of risk. In Canada, water governance has been changing during the past decade. Changes in the landscape of water in Canada have been reactions to the impacts of these drivers of change (Jetoo et al. 2015, Bakker and Cook 2011, de Loë 2015). For example, urbanisation has introduced a different set of problems for flood management in Canada (e.g., sanitary sewer backup, stormwater and groundwater infiltration) relative to the ones that were addressed in traditional flood policy and plans, which focused on rivers and river banks (Henstra and Thistlethwaite 2017, Kovacs and Sandink 2013). These changes also led to the rise of new social-ecological issues (erosion and water quality degradation) that challenge current water policies and institutional arrangements. Studying drivers of change and their impact on current interaction dynamics and institutional coordination for flood management provides an opportunity to reduce and manage the risk of flooding in a flexible manner. Flexibility enables flood management to adjust to, cope with, or benefit from, a change while facing extreme weather events, conflicting interests, and different values (Baird and Plummer 2020, Difrancesco and Tullos 2015). Flexibility also supports innovative solutions to achieve water objectives in the changing landscape of water governance.

1.1.2 Drivers of Change and Flood Risk Management

To address the increasing risk of flooding and impacts of drivers of change, FRM has moved away from the traditional engineering approach to an integrated risk management approach (Hartmann and Driessen 2017). Globally accepted concepts such as integrated water resources management (IWRM) have directed FRM attempts around the world to integrate flood risk management concepts with traditional management approaches (Morrison et al. 2018b, Serra-Llobet, Conrad and Schaefer 2016). FRM policies in North America and the European Union have changed to incorporate various elements, including prevention, mitigation, preparedness, emergency response, recovery and learning processes (Raadgever et al. 2018, Serra-Llobet et al. 2016, Hartmann and Driessen 2017). Current flood risk management efforts include the promotion of appropriate land use, agricultural and forestry practices and mitigation policies that are focused on both structural and non-structural measures to reduce the likelihood of floods or the impact of floods in specific locations (Serra-Llobet et al. 2016, Newig et al. 2014).

In Canada, the movement away from traditional engineering approaches to flooding (e.g., designing single-purpose drainage systems, dams, and levees) gained momentum through the *Canada Water Act* (1970). By 1975, the Flood Damage Reduction Program (FDRP), a joint federal-provincial initiative, introduced systematic non- structural efforts focused on mapping to delineate and designate flood risk areas. After the withdrawal of the federal government in the

1990s, a return to the traditional approach to flood management without any commitment to damage reduction adversely impacted the program (de Loë 2000).

The division of policies and responsibilities among federal, provincial, and local governments also has impacted the success of flood management across Canada (Thistlethwaite 2017, Pomeroy, Stewart and Whitfield 2016). Institutional fragmentation, lack of clarity of flood management roles and responsibilities, the impact of drivers of change outside flood management systems, policy layering and competing mandates (favouring structural solutions to non-structural solutions, or to resistance and recovery solutions) have threatened current flood management systems (Shrubsole 2007). Experiences from Canada reveal that the success of flood risk management efforts is closely related to interaction dynamics and institutional coordination efforts on different levels and in different sectors of flood risk governance (Dieperink et al. 2016).

In the Canadian water governance context, the influence of drivers of change that were traditionally outside the water decision making process has become more evident when water issues arise (de Loë 2017, Chilima et al. 2013, Kelly et al. 2015). For example, extreme weather events in Alberta in 2011 and 2013 and flood events in Ontario (2013, 2017, and 2019) have challenged current flood management policies. Changes in patterns and intensity of precipitation, increasing the risk of flood damage due to urban development, and ageing infrastructures have altered the challenges that the flood management policies were facing previously. Increased overland flooding puts significant financial pressure on the Canadian economy. Financial pressure due to the frequent occurrence of extreme weather events (e.g., flooding) has emerged as a driver of change that is not usually seen as being within the scope of Canadian water governance (Chilima et al. 2013, Henstra and Thistlethwaite 2017).

Following the flooding event in Calgary (2013) and Toronto (2013, 2017, 2018), various actors (e.g., insurance, the private sector, urban planners) criticized current flood management approaches in Canada because of their inability to mitigate the increasing financial pressure and to reduce flood damages (Thistlethwaite 2017, Mann and Wolfe 2016, Pomeroy et al. 2016). Since 2013, various discussions and some changes have been commenced related to flood management. For example, The Federal government introduced the Federal Floodplain Mapping Guidelines Series (Public Safety Canada 2017) to address the increasing costs of flood damage. At provincial levels, Protecting people and property: Ontario's flooding strategy (MNRF 2020) was introduced to highlight the FRM as a shared responsibility among different actors (e.g., homeowners, local, provincial and federal governments) and clarify the core mandate of the Provincial government actors (e.g., Conservation Authorities).

Despite the need to change current flood management approaches in Canada, it is unclear in which ways current flood management approaches have changed or will change to address the impact of the increasing financial pressure and extreme weather events as drivers of change. The need to study current flood management in Canada with a focus on drivers of change guided this research to explore current FRM approaches are challenged to account for external factors that drive change in the FRM systems.

1.1.3 Rethinking approaches to flood management and governance

Changes in the landscape of water governance and the shortcomings of current approaches in recognizing and accounting for drivers of change and their influence in flood management point to the need to examine interaction dynamics and institutional coordination for flood management.

This perspective is essential because, as others have argued, changing policies to address the impact of a driver of change in isolation has the potential to increase risk and vulnerabilities, especially when insufficient attention is given to complex interactions between social and ecological systems (Räsänen et al. 2018, Wells et al. 2020, Guerriero and Penning-Rowsell 2021).

Growing concerns for flood damages, the failure of water governance to reduce the risk of flooding, and the increasing complexity of social ecological systems have led to calls for rethinking flood management and governance approaches (Dietz, Ostrom and Stern 2003, Folke 2006, Gupta and Pahl-Wostl 2013, Skinner 2016, Ingram 2008). In Ontario specifically, flooding is a costly natural hazard (Thistlethwaite 2017, Oulahen, Shrubsole and McBean 2015, Filatova 2014, Canadian Parliamentary Budget Officer 2016). These costs are expected to rise because climate change will lead to an increase in the frequency and intensity of rainfall (McDermid, Fera and Hogg 2015, 2, Pomeroy et al. 2016). Coupled with climate change, other socio-economic forces outside flood management and governance systems have increased the risk of flood damage in Ontario (Conservation Ontario 2013, Henstra and Thistlethwaite 2017, Henstra and Thistlethwaite 2016b, Auld 2008, Owrangi et al. 2014).

Drivers of change, including shifts in precipitation patterns (Conservation Ontario 2013), changes in public attitude about flood risk reduction (Mann and Wolfe 2016), and urbanisation (Sandberg, Wekerle and Gilbert 2013), all have put pressure on flood management and governance policies. These considerations are not usually seen as being within the scope of flood management in Canada, particularly in Ontario, where damages from flooding are increasing and current approaches to flood risk management are challenged to address these issues (Yumagulova and Vertinsky 2017, Grand River Conservation Authority 2014, TRCA 2017). Studying the influence of drivers of change on flood management in Ontario and exploring current institutional arrangements provides pathways to reduce and manage the risk of flooding. It also has the potential to advances understanding of innovative insititutional arrangments to enhance flexible flood management that accounts for various changes in the landscape of water governance to adjust to, cope with, or benefit from the impact of drivers of change.

Exploring drivers of change and their impact on flood management in Ontario, Canada, sheds light on ways in which current flood management and governance have changed or can change to move toward flexible flood management. This dissertation explores FRM systems and their interactions with broader social and ecological systems to understand drivers of change and their impacts in the landscape of water governance. In re-examining flood management to recognise and account for drivers of change, a number of questions arise.

1. How has flood management been organised during 2013-2021 in response to various drivers of change and their influence on flood risk reduction and management?
2. What are the current drivers of change that influence the flexibility of flood management to reduce and manage risk? How do institutional actors in flood management perceive the drivers of changes and their impacts? Are there interrelations between drivers of change?
3. To what degree does flood management recognise or acknowledge the impact of drivers of change and their influence on the flexibility of flood management to reduce and manage risk? What are proposed pathways to address these drivers to reduce and manage the associated flood risk?

4. In which ways can/ have flood management changed to accommodate drivers of change and their influence on flood risk reduction and management to guide the shift water governance toward flexible decision-making?

1.2 Purpose and objectives

The overall purpose of this research is to identify and assess drivers of change and their influence on flood management. In Ontario, where flooding threatens communities and their economic development throughout the year, there is a need to identify drivers of change and their influence on flood management to reduce risk. The International Joint Commission (2011, 3) also indicates that "there is a critical need to modify existing governance to strengthen coordination across jurisdictional lines to address [social] ecological challenges" to enhance the flexibility of flood management policies to reduce and manage the risk of flooding. Examining drivers of change and studying their potential impact on flood management sheds light on pathways to change flood management approaches and to connect with broader social ecological systems to adjust to, cope with, or benefit from the impact of drivers of change. Four objectives (see Table 1-1) guide this research toward reaching its purpose and answering the research questions.

1. Build a conceptual framework that recognizes and accounts for impacts of drivers of change on flood management using insights from the Social-Ecological Systems (SES) Framework, institutional design and analysis, flood management, and broader water governance literature.
2. Apply the conceptual framework to detect drivers of change and to understand the ways in which flood management and water governance literature have identified and addressed the influence of drivers of change on flood management.
3. Use this framework empirically to examine flood management approaches concerning the influence of drivers of change in Ontario and the City of Toronto.
4. Identify ways in which institutional arrangements for flood management can be changed to reduce and manage the risk of flooding by accounting for drivers of change.

The following table explains how these objectives are achieved across the chapters in this dissertation

Table 1-1: Research Objectives

Research objectives	Introduction	Chapters Two	Chapter Three	Chapter Four	Conclusion
1-To build a conceptual framework for analysis that recognizes and accounts for drivers of change	X	X	X	X	

2- To apply the conceptual framework developed in objective one to detect drivers of change		×	×	×	
3- To use this framework empirically to examine flood management approaches			×	×	
4- To identify ways in which flood management can/ have changed its institutional arrangements to reduce and manage the risk of flooding		×	×	×	×

1.3 Literature review and theoretical foundation

This section addresses four main topics: governance, flood management, drivers of change, and institutional design and analysis. These literatures provide a broad understanding of current flood management and water governance approaches in Canada, the influence of drivers of change on flood management trends, and potential ways to enhance response flexibility of flood management. The foundation of a conceptual framework is built on these selected literatures to re-examine the influence of drivers of change on flood management and to provide pathways for governance processes to recognise and account for these impacts.

Governance literature, with a focus on environmental governance and water governance, highlights the shortcomings of current water governance systems to account for drivers of change in broader social-ecological systems. Flood management literature sheds light on the current flood management approaches that aim to reduce risk and vulnerability resulting from uncertainty and the increasing complexity of social ecological systems. The drivers of change section is presented to provide a quick scan of broader literatures containing relevant ideas, including business and management (Perera 2017, Srdjevic et al. 2012), biodiversity literature (Gari, Newton and Icely 2015, Nelson et al. 2006, Svarstad et al. 2008, Millennium Ecosystem Assessment 2005), deforestation (Rueda et al. 2019, Geist and Lambin 2002), and institutional design literature in which drivers of change were defined and categorized to guide FRM approach. Institutional design literature includes Combined IAD (Institutional Analysis and Development) and SES (Social-Ecological Systems) frameworks (Cole, Epstein and McGinnis 2019), the diagnostic approach developed by de Loë and Patterson (2017a), and institutional design principles (Polski and Ostrom 1999, Huntjens et al. 2012). Institutional analysis literature facilitates investigating various institutional arrangements through which flood and water-related challenges can be addressed effectively. These fields provide a perspective on pathways to study current trends in flood management and potential future trends to account for the impact of drivers of change on FRM.

1.3.1 Environmental governance and Water governance

Governance as a process of governing is “rich and full of meaning” (Welch 2013, 255); the concept holds different interpretations in diverse disciplines. The malleability of governance as a concept in various theoretical and disciplinary settings, and the failure of centralised governments to address complex social and ecological issues, have increased the popularity of governance as a concept. This trend has created an opportunity to change the manner of governing (Bevir 2012, Kooiman 1993, Chhotray and Stoker 2009). Governance provides opportunities for goal-oriented and deliberate interventions in society (Kooiman 1993). It also can enable or constrain the success of conservation and environmental management (Bennett and Satterfield 2018)

Environmental governance and water governance are specialised branches of the broader field of governance that have addressed environmental issues and water-related challenges with direct implications for human societies (Young et al. 1999). Insights from a review of these specialised forms of governance facilitate understanding of the interconnectedness of social-ecological systems and highlight the convergent points in both environmental governance and water governance research. Both forms of governance are searching for solutions to address complex social and environmental problems by recognizing the influence of drivers of change that affect the ability, responsibility, power, and authority to guide, create, implement, and monitor environmental policies (Folke 2007, Berkes, Colding and Folke 2008, Rockström et al. 2014).

Environmental governance thinking emerges from a larger body of governance and has inherited a malleable concept of the term “governance” (Lemos and Agrawal 2009, Paavola 2007, Biermann et al. 2012, Glasbergen 1998, Bennett and Satterfield 2018). The major differences among conceptualizations of environmental governance hinge upon the degree of involvement of civil society, market, and government in addressing environmental problems (Newell 2008, Stoker 1998, Ansell and Gash 2008, Glasbergen 1998, Ostrom 2010, Newig and Kvarda 2012, Bennett and Satterfield 2018, Morrison et al. 2019). In economic approaches to environmental governance, the emphasis is mostly on market mechanisms (Ciplet and Roberts 2017), whereas political science emphasises participation, partnership, engagement, and the role of governments (Moss and Newig 2010).

According to Paavola (2007, 9), “environmental governance should be understood broadly so as to include all institutional solutions for resolving conflicts over environmental resources”. This definition of environmental governance accounts for the action component of addressing social ecological challenges using institutions in novel ways, but it does not highlight the importance of the rearrangement of institutional solutions accounting for the impact of external forces adequately. Thus, for the purpose of this research, environmental governance is understood as an attempt to address environmental challenges “through the establishment, reaffirmation or change of institutional arrangements” (Paavola 2015, 144).

Environmental issues have been examined using different perspectives of governance (e.g., the polycentric system of governances, multilevel governance, adaptive governance, global governance, or water governance). Insights from literature examining these different forms of governance (e.g., water governance and polycentric governance) help to address issues around external forces (e.g., driver of change) and their impact on governing environment issues (e.g., the risk of flooding) (Serra-Llobet et al. 2016, Räsänen et al. 2018).

Polycentric governance has been explored in a number of interdisciplinary contexts, including public administration (Araral and Hartley 2013), commons (Dennis and Brondizio 2020, McGinnis 2019), and water resource management (Lubell, Blomquist and Beutler 2020). In this study, polycentric governance is defined as "the organization of small-, medium-, and large-scale democratic units that each may exercise considerable independence to make and enforce rules within a circumscribed scope of authority for a specific geographical area" (Ostrom 2001, 2). Polycentric governance fits well in the management and governance of natural resources situated within broader social-ecological systems (Carlisle and Gruby 2019, Blomquist and Schroder 2019). Social-ecological systems are expanded beyond a particular scale and tend to be interconnected. To develop on the inherent potential offered by polycentric governance, there is a need to form sufficient insights into the impact of drivers of change on institutions and their arrangement to inform water governance and flood risk management theory and practice. In early water governance approaches, water management was isolated from a social-ecological context and was mainly focused on using water-centric perspectives and technical solutions (for instance, building higher dykes) (Breen, Loring and Baulch 2018, Karar 2017, de Loë and Patterson 2017c). Therefore, insights from fields beyond environmental governance, outlined below, are required.

The definition of water governance is built on providing opportunities for goal-oriented and deliberate interventions in society to develop and manage water resources (Jiménez et al. 2020, Engle and Lemos 2010). Water governance refers "to the range of political, social, economic and administrative systems that are in place to develop and manage water resources, and the delivery of water services, at different levels of society" (Global Water Partnership Technical Advisory Committee 2000, 18). Water governance has inherited characteristics of the term "governance". This allows various actors and disciplines to take different approaches to water governance since they have valued water differently (e.g., water as economic goods vs human rights/social goods). Each perspective favours a specific set of tools, instruments, and institutional arrangements to address water challenges (e.g., managing water demands by privatisations vs control of state government).

The persistent failures to resolve major water sustainability problems linked to poor governance have stemmed from various shortcomings, including the complexity of water problems, fragmentation of policy and jurisdictional decision making arenas, the path dependency of water-centric approaches, and lack of knowledge and institutional capacity (de Loë 2005, Pahl-Wostl et al. 2012, Dellapenna et al. 2013, Mollinga 2020, Dennis and Brondizio 2020, Baird and Plummer 2020). Traditionally, water resource management approaches were mostly focused on the "practical scope of causes, effects, and interests associated with a water issue," which is portrayed as "relatively clear, uncontentious, and bound by sector" (de Loë and Patterson 2017c). Changes in the landscape of water governance and emerging new perspectives (e.g., moving away from sole reliance on structural or control-engineered methods in water management or flood control) have introduced new sets of governance challenges. For example, to reduce the risk of flooding, flood risk management needs to account for spatial externalities, path-dependency and time lag between private investment decisions and consequences using various tools including taxation instruments, non-perverse subsidies, flood insurance, marketable permits, and transferable development rights (Filatova 2014).

Challenges in integrating water engineering and spatial planning, combined with significant social, economic, and environmental changes, mean that water governance is becoming

inordinately more complex. The influence of drivers of change in water governance, especially in flood risk management, is identified as an issue that leads to the failure of current governance efforts. A number of scholars highlight the impact of drivers of change when "many important water decisions are made or influenced by actors in government, civil society, and business outside the water sector" (Gober 2013, 956). Identifying drivers of change and the relative importance of various drivers of change is crucial for water governance to prioritise policies and coordinate institutional arrangements to reduce and manage the risk of flooding.

The relationship between drivers of change and water governance is complex and multi-scale. Drivers of change and new actors that come from academic, financial, industry, media and other sectors bring new thinking, innovative solutions, and conflicting interests to the water decision-making arena. These drivers of change and their influence outside of the typical scope of water governance can strongly affect and change water governance systems. Drivers of change can challenge water governance by increasing competing interests and creating an incompatible perspective to achieve desired outcomes (Bouwen and Taillieu 2004, Ansell and Gash 2007, Blomquist, Heikkila and Schlager 2004, Heikkila and Gerlak 2005, Huntjens et al. 2012).

Re-examining the water governance literature highlights the challenges and opportunities involved in developing an innovative institutional arrangement to meet the water needs (e.g., reduce the flood risk in the future). Water governance efforts aim to introduce specific incentives and institutional arrangements to integrate state and non-state actors in various spatial scales. Various scholars argued water governance is challenged in practice to coordinate institutional arrangements (Serra-Llobet et al. 2016, Hegger et al. 2016, Cook 2014, Watson 2014). These institutional arrangements are increasingly shaped by non-state actors, including NGOs, civil society, local businesses, intergovernmental organisations, transnational environmental organisations, market-oriented actors (e.g., transnational and multinational companies), and mid-size or small businesses (de Loë and Patterson 2017c, Gupta and Pahl-Wostl 2013, Biswas 2008, Biswas and Tortajada 2010). Therefore, insights from other fields that provide a clear understanding of flood management and its institutional analysis are required and outlined below.

1.3.2 Flood Risk management

Flood management is changing due to the awareness of experts, decision makers, and the public regarding climate change, increased risks of flooding, and the complexity of social and ecological systems. Traditionally flood management was focused on an engineering approach to flood control, which proved to be insufficient in dealing with hydraulic, hydrologic, social, economic, and environmental factors that impact flood management policies (Merz, Thieken and Gocht 2007, Hartmann and Driessen 2017). Moving away from hazard-based management toward flood risk management led to a search for non-structural solutions in countries around the world (see Table 1-2).

In Canada, the Flood Damage Reduction Program (FDRP), with the support of joint federal-provincial initiatives, was introduced in 1975 to facilitate both structural and non-structural approaches (de Loë 2000, Shrubsole 2007). The FDRP's non-structural approach aimed to map and delineate designated flood risk areas. Additionally, the FDRP prohibited federal and provincial governments from engaging in or providing assistance to various developments in designated high-risk areas. The program also provided various flood risk management strategies and tools. These strategies and tools include flood forecasting and warning, land acquisition,

public education, and structural measures (Shrubsole 2007). The success of the program was challenged by the lack of leadership at federal and provincial levels, limited funding for non-structural efforts, and favouring the traditional approach to flood management without any commitment to damage reduction

Table 1-2: Example of FRM efforts

FRM effort	Region	Descriptions	Sources
STARFlood	EU: Belgium, England, France, the Netherlands, Poland, and Sweden (2012-2016)	Project to assess flood risk governance arrangements from a combined public administration and legal perspective to make European regions more resilient to flood risks.	(Hegger, Driessen and Bakker 2018, Wiering et al. 2017, Hegger et al. 2016, Alexander et al. 2016)
The Room for the river	The Netherlands 2006-2015	Nature-based solution by giving more space to river addressing velocity of the flow	(Van der Most, Asselman and Slager 2018, Mens, Klijn and Schielen 2015, van den Hurk, Mastenbroek and Meijerink 2013, Zevenbergen et al. 2013)
The Bay Area Integrated Regional Water Management Plan	California, USA 2006- on-going	It is an effort to coordinate and improve water supply reliability, protect water quality, manage flood protection, maintain public health standards, protect habitat and watershed resources, and enhance the overall health of the San Francisco Bay.	(Serra-Llobet et al. 2016, Weissman, Varghese and Wood 2013)
The Federal Disaster Reduction Plan	Canada 1974- the late 1990s- The Federal Government left the joint agreement with the Provincial governments	Initiated a national shift away from reliance on flood control structures such as dams to the use of non-structural measures, including floodplain mapping and zoning.	(de Loë and Wojtanowski 2001, Public Safety Canada 2020)

To reduce the risk of flooding, the structural and non-structural solutions in flood management are working on the collaboration between spatial planning and water management (Hartmann and Juepner 2014). Current flood risk management efforts reflect some of the principles contained in the Integrated Water Resource Management (IWRM) approach (Serra-Llobet et al. 2016). IWRM aims to "promote the coordinated development and management of water, land and related resources in order to maximise economic and social welfare in an equitable manner without compromising the sustainability" (Global Water Partnership Technical Advisory Committee 2000, 18). A concept such as IWRM has directed FRM efforts around the world to move away from water-centric perspectives to account for broader issues, including land use planning, sustainability, and economics (Serra-Llobet et al. 2016). As a result, FRM has now shifted toward collaboration and integration of water engineering and spatial planning and has embraced the concept of flood risk (Hartmann and Driessen 2017, Francesch-Huidobro et al. 2017). This broad definition of FRM addresses a wide range of dynamic processes that aim to reduce the likelihood and/or the impact of floods by influencing flood hazards and vulnerabilities (Berndtsson et al. 2019).

Hazard, exposure, and vulnerability are key terms in FRM. These terms have been explored in various disciplinary and interdisciplinary contexts (Jurgilevich et al. 2017), including climate change (Cardona et al. 2012), risk assessment (Kalakonas et al. 2020), water resource engineering (Kalakonas et al. 2020). water governance (Baird and Plummer 2020, Plummer et al. 2018) and urban planning (Pirlone and Spadaro 2018). There are numerous reviews focusing on hazard, vulnerability, and flexibility; fewer studies are focused on exposure (Jurgilevich et al. 2017). Some scholars use vulnerability and exposure interchangeably by arguing that exposure can be viewed as a vulnerability of different sectors, groups or regions to the effect of climate change and globalization (O'Brien and Leichenko 2000, Pirlone and Spadaro 2018), while other scholars have argued the vulnerability is not just limited to climate change and globalization(Thomas, Jayalekshmi and Nagarajan 2020). Other factors, including other socio-economic-environmental drivers of change (e.g., poverty, land-use change, urbanisation, international trade, and policies), influence vulnerability and exposure. To create a converging point among the different audience (water resource engineering, water governance, insurance industry, and urban planners), this research focus on defining these terms (see Table 1-3) through the lens of water resource management and water resource engineering literature (Schanze 2006, Seegert et al. 2014).

The term "flood hazard" is defined by Schanze (2006, 2) as "the probability of the occurrence of potentially damaging flood events". Vulnerability, from a climate change perspective, is defined as the degree to which a system is susceptible and unable to cope with the adverse effects of climate change (IPCC 2007, 21). Flood vulnerability, in particular, is rooted "in how people or societies are likely to be affected by flood phenomena – that is, the sensitivity of the community or people to flooding considering the socio-economic, environmental and physical components" (Thomas et al. 2020, 202). Exposure is defined as the number of assets being present in endangered areas distinguished per typologies (Cutter et al. 2018, Hegger et al. 2016). Collectively, flood hazard, exposure, and vulnerability form the notion of flood risk (UNISDR 2009).

Changes in the nature of the risk (e.g., change in precipitation pattern) and emerging new perspectives (e.g., use of green infrastructure) have introduced new sets of governance and FRM challenges (Oulahen 2021, Aerts et al. 2018, Francesch-Huidobro et al. 2017). For example, to reduce the risk of flooding, flood risk management needs to account for social-economic factors

(e.g., increasing financial damages, mental health issues), path-dependency, time lag and different temporal scales between public and private investment decisions. Challenges in integrating water engineering and spatial planning, combined with significant social, economic, and environmental changes, mean that water governance is becoming much more complex. The influence of drivers of change in water governance, especially in flood risk management, is an issue that can lead to the failure of current governance efforts.

A number of scholars highlight the impact of drivers of change when "many important water decisions are made or influenced by actors in government, civil society, and business outside the water sector"(Gober 2013, 956). Identifying drivers of change and the relative importance of various drivers of change is crucial for water governance to priorities policies and to coordinate institutional arrangements to reduce and manage the risk of flooding (Berndtsson et al. 2019, Francesch-Huidobro et al. 2017, Winsemius et al. 2016). Therefore, the need for flexible responses in flood management is growing due to increasing flood damages and the growing complexity of social-ecological systems that introduce a range of uncertainties that cannot be mitigated or modelled in flood management strategies (Pomeroy et al. 2016). Flexibility as a concept is used in a wide range of disciplines (e.g., information technology, engineering, and biology) and interdisciplinary contexts (e.g., social-ecological systems, water resource management, manufacturing), as highlighted by DiFrancesco and Tullos (2014). For this research, flexibility (see Table 1-3) is defined through the lens of water resource management and water resource engineering. A flexible flood management approach has the ability to adjust to, cope with, or benefit from uncertainty and complexity caused by drivers of change (Baird and Plummer 2020, Difrancesco and Tullos 2015, Anvarifar et al. 2016). To move toward flexible flood management approaches, there is a need to rearrange current institutional structures and alter interaction dynamics among actors. A brief review of flexibility and its metrics is provided below to highlight the characteristics of a flexible institutional structure.

Table 1-3: Glossary of FRM terms and definitions

Terms	Disciplinary foundation	Definitions	Sources
Hazard	Water resource management and engineering	The probability of the occurrence of potentially damaging flood events	Schanze (2006, 2)
Exposure	Water resource engineering	The number of assets being present in endangered areas distinguished per typologies	(Cutter et al. 2018, Hegger et al. 2016)
Vulnerability	Water resource engineering	How people or societies are likely to be affected by flood phenomena – that is, the sensitivity of the community or people to flooding considering the socio-economic,	(Thomas et al. 2020)

		environmental, and physical components	
Flexibility	Water resource engineering	The ability to adjust to, cope with, or benefit from uncertainty and complexity caused by drivers of change	(Difrancesco and Tullos 2015, DiFrancesco and Tullos 2014, Anvarifar et al. 2016)

1.3.2.1 Flexibility in flood management:

Changes in the landscape of water governance and the impacts of drivers of change have put pressure on current flood risk management efforts. Despite ongoing efforts to reduce the risk of flooding around the world, damages due to flood events are increasing globally (World Bank 2017, Ward et al. 2020). To address these issues, recent literatures on flood risk management increasingly include a recommendation for more flexible management systems (Tempels and Hartmann 2014, Anvarifar et al. 2016, Difrancesco and Tullos 2015). Flexibility enables flood management to adjust to, cope with, or benefit from a change or a hazard caused by the impact of external drivers or increasing complexity (Baird and Plummer 2020).

The change toward flexible flood management provides opportunities to examine the extent to which drivers of change impact FRM systems' ability to reduce and manage risk. The term flexibility is defined as “accepting the risk and adapting to it” (Tempels and Hartmann 2014, 873); however, very little work has been done on what exactly it means to have a flexible flood management system. Therefore, more detailed insights from the literature are needed to provide a clear understanding of flexibility in flood management. Flexibility as a body of literature is not well studied in the context of flood management, in particular in Canada, despite the importance and frequency of recommendation for flexible flood management strategies (Self and Penning-Rowsell 2017, Baird et al. 2016). In general, flexibility literature provides insight into diverse characteristics of management systems and institutional structures. Flexibility enables the system to adapt and thrive while facing increased uncertainty without fully characterising the potential future conditions. The flexibility literature provides insights into the different metrics (e.g., slack, redundancy, connectivity, adjustability, compatibility, or coordination). These metrics can be used to examine flood management and its flexibility to reduce and manage risk while facing drives of changes and their impact (DiFrancesco and Tullos 2014).

Flexibility metrics tie flood management and water governance literature together and shed light on current water governance and flood management shortcomings to account for drivers of change. For example, climate change, population growth, urbanization, and change in land cover are usually noted by FRM scholars as drivers of change with negative impacts on the risk of flooding and increasing exposure and vulnerability. These drivers also challenge water governance by altering the conditions under which baselines, models, measurements, and policy are developed for FRM (Francesch-Huidobro et al. 2017, Gillon, Booth and Rissman 2016). Therefore, it is beneficial to review drivers of change in water governance, FRM and similar literature to get perspectives regarding definitions and characteristics of drivers of change.

To incorporate flexibility into decision making and to account for the impact of drivers of change, “adaptation pathways” are a promising approach in different interdisciplinary contexts

(Werners et al. 2021). Definitions and conceptualisations of adaptation pathways differ and depend on the disciplinary lens (e.g., climate sciences, water resource management, institutional analysis, economics). Nonetheless, these definitions converge around climate change discourse (Werners et al. 2021, Wise et al. 2014). In this research, adaptation pathways are defined as potential approaches to adaptation using different strategic approaches, goals, or outcomes (Gorddard et al. 2016). Pathways result in alternative states in the system of interest (Gorddard et al. 2016, Werners et al. 2021). This selected definition of adaptation pathway stress that needs to account for the social-ecological context and their interaction dynamic under which adaptation decisions are formed (Gorddard et al. 2016). There are different methods through which adaptation pathways have developed within the policy and decision making space to facilitate flexibility facing the impacts of drivers of change (Werners et al. 2021, Wise et al. 2014). This research explores flood management institutional arrangements facing drivers of change. The research presented by (Huntjens et al. 2012) offers potential approaches to adaptation using Ostrom on institutional design principles (see Section Institutional design and analysis) to deal with complexities and uncertainties related to the impacts of drivers of change (e.g., climate change).

1.3.3 Drivers of change

A review of drivers of change and FRM literatures reveals climate change, population growth, and urbanization were among the most common drivers of change that increase the risk of flooding. These drivers are usually portrayed as global problems that are outside the scope of FRM. Despite awareness around the impacts of drivers of change on flooding, a common definition of a driver of change was not found by a broad scan of the FRM literature. Therefore, to have a better understanding of drivers of change and an approach to categorize and assess drivers of change, a cursory review of similar literature is presented below (see Table 1-4).

Business and management literature has a wealth of sources regarding external forces and drivers of change (Fosher 2018, Perera 2017, Yüksel 2012) that impact companies, organizations, and management efforts (e.g., marketing, innovation, and customer satisfaction). Drivers of change are commonly defined in this literature as critical external factors that influence businesses operations and market competitiveness (Fosher 2018, Srdjevic et al. 2012, Yüksel 2012). One of the most used tools in this field is PESTEL (Political, Economic, Sociological, Technological, Environment and Legal) analysis. This analysis maps external factors that impact a business to create an understanding of the contextual environment in which the business is situated. Businesses use PESTEL analysis to identify risk in their risk assessment process to guide their growth strategies, investment policies and innovation expenditures to strengthen the competitiveness of the businesses or enterprises (Perera 2017). PESTEL analysis provides perspectives on social and environmental factors that impact the contextual environment, which enable the analysis to account for both hazard and vulnerability from an FRM perspective.

Organizational analysis literature also has its own definitions and assessment criteria to address the impacts of drivers of change in organizational and leadership settings (Whelan-Berry and Somerville 2010, Dumas and Beinecke 2018). The quick scan of this literature highlights two complementary ways of defining drivers of change. This body of literature uses “change drivers” as a term to account for drivers within the organization that can impact the system as a whole

(e.g., strong leadership or change in leadership style). Change drivers facilitate the implementation of change throughout the organization and facilitate individual adoption of change initiatives (Borrás and Radaelli 2011). The other use of the term identifies drivers change that gave birth to the desire or need for change in the organization (Whelan-Berry and Somerville 2010). Using a review of cases, organizational analysis literature has created a list of factors that impact change in organizational settings (e.g., accepted change vision, leaders' change-related actions, change-related communication, and change-related training). The selected criteria are solely focused on social issues in an organisational setting and do not consider issues in a natural environment.

Biodiversity literature has long recognized the impact of drivers of change in ecosystems and human health and performance (Millennium Ecosystem Assessment 2005, Nelson et al. 2005, Lewison et al. 2016, Svarstad et al. 2008). Therefore, there are tools to address drivers of change and their impact. This brief review focuses on two different approaches: the Millennium Ecosystem Assessment Framework and the DPSIR (Driver, Pressure, State, Impact, Response) Framework. In general, drivers of change are defined in these frameworks as any factor that changes an aspect of an ecosystem. However, there is a noticeable difference using each framework. The Millennium Ecosystem Assessment Framework categorises drivers of change into two groups: direct drivers of change and indirect drivers of change. The most important direct drivers of change in ecosystems are "habitat change (land-use change and physical modification of rivers or water withdrawal from rivers), overexploitation, invasive alien species, pollution, and climate change" (Millennium Ecosystem Assessment 2005, 14). The examples of indirect drivers of change include population change, change in economic activity, sociopolitical factors, cultural factors, and technological change (Millennium Ecosystem Assessment 2005, 19)

Table 1-4: Scan of Drivers of change definition and characteristics

Literature	Definition of drivers of change	strategies	Classification of drivers of change	Sources	Hazard or Vulnerability
Business	critical external factors that influence businesses and market competitiveness.	PESTEL analysis	Political, Economic, Sociocultural, Technological, Environmental and Legal	(Perera 2017, Srdjevic et al. 2012)	Hazard and vulnerability
Organizational analysis	Change drivers facilitate the implementation of change throughout the organization and facilitate individual adoption of change initiatives.	Review of cases	Accepted change vision Leaders' change-related actions Change-related communication Participation in change-related activities Aligned organization structure	(Whelan-Berry and Somerville 2010, Borrás and Radaelli 2011)	vulnerabilities
Biodiversity literature	A driver is any factor that changes an aspect of an ecosystem.	Millennium Ecosystem Assessment Framework	Indirect (e.g., Demographic) Direct (e.g., change in local land use and cover, climate change, species introduction)	(Millennium Ecosystem Assessment 2005)	Hazard and vulnerability
		DPSIR Framework	Drivers (e.g., population growth, economic) Pressure (e.g., climate change) State (e.g., change in precipitation pattern) Impact (e.g., food security) Response (e.g., change in land cover)	(Lewison et al. 2016, Gari et al. 2015, Svarstad et al. 2008, Borja et al. 2006)	Hazard and vulnerability
Deforestation literature	A driver of environmental change –, the usually complex set of actions, factors, and rationales involved in tropical deforestation	Review of cases	Proximate cause (e.g., agricultural and infrastructure expansion) Underlying driving forces: (e.g., Demographic, Economic, technological, policy and institutional)	(Geist and Lambin 2002, Rueda et al. 2019)	vulnerabilities

The DPSIR (Driver, Pressure, State, Impact, Response) Framework is another common framework in biodiversity literature used by Organization for Economic and Cooperation Development (OECD), the European Environment Agency, and UNEP to bridge scientific perspectives with policy and management (Svarstad et al. 2008). DPSIR components provide a categorization for forces that drive change in the social-ecological system. For instance, drivers are usually anthropogenic factors, and pressures are environmental parameters, impacts (Lewison et al. 2016). However, the lines between impact and pressure and states are less defined in the framework, and there is less consensus on drawing boundaries between these components. The complexity of the framework and lack of consideration for economic values and limited capacity of the framework for dealing with innovation are considered some challenges in using the framework in empirical settings (Lewison et al. 2016, Svarstad et al. 2008).

The final framework reviewed here emerged from deforestation and land-use change literatures. Geist and Lambin's (2002) framework examines the proximate causes and drivers of changes that impact tropical deforestation. Drivers of change are categorized as four broad clusters of proximate causes (e.g., agricultural expansion, wood extraction, infrastructure extensions) and five clusters of underlying causes (e.g., economic, policy, and culture). Proximate causes consider immediate human actions directly impacting forests while underlining causes are focused on fundamental changes in social, economic or environmental processes (Geist and Lambin 2002). This framework also provides opportunities to explore the interaction and feedback loops among different categories of underlying causes and proximate causes. By accounting for social and environmental factors, this framework has the capacity to address issues around hazard and vulnerability in FRM. However, in the case of flood management, the framework falls short for long-term human actions or the path dependency of FRM efforts that impacts the risk and vulnerability in FRM.

Reviewing these broad sets of literature enabled this research to develop a definition of drivers of change that capture characteristics of FRM and accounts for hazard and vulnerability in identifying drivers of change. I defined drivers of change in FRM as a natural or human-induced factor that directly or indirectly causes a change in the risk of flooding or the ways in which flooding is managed or governed. This definition helps develop strategies to identify and categories drivers of change and assess their impact on FRM efforts.

1.3.4 Institutional design and analysis

Understanding the influence of drivers of change on flood management requires a review of cross-scale flood management institutional arrangements. This review provides insights into the complex interactions of drivers of change with flood management and the impact of these interactions on the institutional configuration. This research focuses on institutions as conceptualised in institutional economics, leaving out the institution's conceptualisation from sociology and political sciences (e.g., Hall and Taylor 1996, Ostrom 1990)

In the field of institutional economics, the debate about the definition of an institution is still ongoing (Hindriks and Guala 2015, Hodgson 2006). For the purpose of this research, an institution is defined as "a cluster of rights, rules, and decision-making procedures that gives rise to a social practice, assign roles to participants in the practice and guides interactions among occupants of these roles" (Young, King and Schroeder 2008, xvi-xvii). The literature on New Institutional Economics (NIE) introduces diverse theories that provide insight into institutional

contexts, dynamics, and structures (Alexander 2005, North 1990, Huntjens et al. 2012, Polski and Ostrom 1999). Ostrom's (2011a) Institutional Analysis and Development (IAD) framework is one of the frameworks that is widely used in environmental governance and resource management. The IAD framework uses diagnostic research to understand the connections between diverse contexts in relation to resource sustainability and sheds light on the nature and the performance of institutional arrangements (Blomquist and deLeon 2011).

IAD literature explicitly recognises that "institutional configurations have an internal logic that directs their development, but all institutions are also exposed to external influences that also shape their development" (McGinnis 2016, 4). Ostrom's (2009) Social-ecological Systems (SES) framework, which is built on the premises of IAD, explains and describes the complex connections with social-ecological systems and their interactions. The SES framework, with its holistic approach, analyses social, economic, ecological, and policy forces using multi-tier variables (Ostrom 2009) and accounts for complex relationships among natural resources. First-tier variables include resource units (RU), resource systems (RS), governance systems (GS), and Actors/Users (A). These are developed around action situations, "in which individuals interact with each other and thereby jointly affect outcomes that are differentially valued by those actors"(McGinnis and Ostrom 2014, 30).

Action situations are the heart of the SES framework. Action situations are defined as "analytic concepts that enable an analyst to isolate the immediate structure affecting a process of interest to the analyst for the purpose of explaining regularities in human actions and results to potentially reform them" (Ostrom 2011b). In the SES framework, feedback paths link outcomes of action situations back to the contextual variables, thus conveying an explicitly dynamic structure that helps researchers to examine the influence of drivers of change on action situations.

By combining IAD and SES, Cole et al. (2019) present an analytical framework with the ability to map the changes in institutional processes using different variables and feedback loops that account for contextual factors and drivers that impact the decision making environment where individuals, organizations and actors interact to form their desired outcome (Cole et al. 2019). Exploring an empirical setting using CIF requires zooming in and out of a network of action situations (Cole et al. 2019) to find critical points with impact on current policy and governance processes. Despite the ability of the CIF framework to highlight and map the interactions relative to an action situation (e.g., flood management in Ontario), it does not identify drivers of the change prior to describing these interactions with an action situation or the network of action situation.

de Loë and Patterson (2017a) developed a diagnostic approach to address this shortcoming and to detect the driver of change by defining and redefining an action situation. According to de Loë and Patterson (2017a, 1), the diagnostic approach has the capacity to provide solutions that are considered valid for the defined project. The diagnostic approach pays attention to external factors (e.g., drivers of changes) "that are often neglected while being sensitive to the capacity constraints of policymakers and practitioners" (de Loë and Patterson 2017a, 1). The diagnostic approach provides a flexible framework through which the researcher is able to perform a cursory or in-depth analysis as appropriate in a given situation. These analyses have the potential to identify the drivers of change and their impact on current flood risk management.

The diagnostic approach consists of four steps. The first two steps of the diagnostic approach provide inquiry into interactions within a flood risk management action situation. This

involves defining the action situation as clearly as possible and "spiralling inwards" to determine if a flood risk management perspective is appropriate. The final two steps of the diagnostic approach promote inquiry into interactions "external" to a flood risk management action situation. This involves "spiralling outwards" to explore wider interactions and their impact on current flood risk management. These final steps can lead to reflecting and modifying action situation boundaries if necessary to clarify the boundaries in which flood risk management is operating.

The literature on institutional analysis has not produced concrete answers to ways in which necessary institutional change should be facilitated without imposing one size fit all solutions or blueprints that ignore the local conditions (Evans and McComb 2004, Huntjens et al. 2012). Polski and Ostrom (1999) identify a set of rules by studying the underlying institutional designs of those real-world experiments that have proved to be robust over time and have associated with successful outcomes in governing resources (Cox, Arnold and Tomás 2010, Baggio et al. 2016).

Polski and Ostrom (1999) identify eight design principles: (1) clearly defined boundaries; (2) proportional equivalence between benefits and costs; (3) collective choice arrangements; (4) monitoring; (5) graduated sanctions; (6) conflict-resolution mechanisms; (7) minimal recognition of rights to organize; and (8) nested enterprises. The design principles are selected to sustain long-term common-pool resource systems on a local scale and to establish or sustain a governance system to deal with the impacts of drivers of change (e.g., climate change, change in global trade demands and its pressure on local common-pool resources) in a complex, cross-boundary resource systems (e.g., Healey 2003, Huntjens et al. 2012, Polski and Ostrom 1999, Quinn et al. 2007, Ruttan 2006). The institutional design principles are used as a tool to identify pathways for adaptation in water governance by Huntjens et al. (2012). This research uses these principles to identify pathways for mitigation through which institutional change is proposed with respect to the action situation jurisdictional and geographical scale, complexity, and uncertainty.

Institutional analysis literature provides insight into interactions among drivers of change and flood risk management using the CIS framework and the diagnostic approach developed by de Loë and Patterson (2017a). The institutional analysis literature sheds light on the understanding of how the initial action situation is related to external actors, institutions, and drivers, or adjacent action situations (McGinnis 2011). This literature is selected to address water governance challenges in coordinating institutional arrangements that are increasingly shaped by external forces and non-state actors, including NGOs, civil society, local businesses, intergovernmental organisations, transnational environmental organisations, market-oriented actors (e.g., transnational and multinational companies), and mid-size or small businesses (de Loë and Patterson 2017c, Gupta and Pahl-Wostl 2013, Biswas 2004, Egan and de Loë 2020, Cole et al. 2019, Baird and Plummer 2020).

1.3.5 Summary

A broad review of governance literature, with a focus on environmental governance and water governance, highlights the shortcomings of current water governance systems to account for drivers of change in broader social-ecological systems. To address these shortcomings, there is a need to identify drivers of change and to examine drivers of change's influence on water governance efforts in flood risk management. Issues related to flood management and its institutional arrangements remain widely unanswered in water governance literature.

Traditionally flood management and flood protection were seen as engineering challenges designated to make land in floodplains usable (Hartmann and Driessen 2017). Therefore, insights from flood management, flexibility literature focused on flood management, and institutional analysis is provided for better understanding of flood risk management.

To adapt and thrive while facing increased uncertainty, there is a need to examine how drives of change influence complex relationships among governance systems, resource units, resource systems, and actors. The modified CIS (McGinnis and Ostrom 2014, Cole et al. 2019) and the diagnostic approach developed by de Loë and Patterson (2017a) are selected to examine the influence of drivers of change in institutional configurations and governing approaches to inform flood management and water governance theory and practice.

To identify pathways of change in institutional arrangments and dynamics that account for external forces (e.g., drivers of change) and their impacts, insights from flexibility literature and institutional design principles are provided. Flexibility metrics and various institutional design principles frame the changes in governance approach to guide alteration in institutional configurations and governance.

1.4 Research design and method

In this section, I describe the dissertation research design that combines a systematic review of literature and a qualitative case study. This foundation enables the research design to account for increasing complexity in social-ecological systems by focusing on both theory and practice. The foundation that is built on the social-ecological systems perspective enables proposed research to move from the idea of one size fits all to account for the local conditions while studying flood management in Ontario. Adopting these perspectives in developing a conceptual framework helps researchers identify solutions to environmental issues using iterative and problem-based methods. This section moves through two stages to meet the dissertation's purpose and objectives. The first component is introducing the conceptual framework (see Figure 1-1) (objective One). The second component highlights the need for case study analysis and empirical research to assess the developed framework (Objectives Two, Three, and Four) exploring flood management systems in different contexts (regional, local, project level).

1.4.1 The conceptual framework

The conceptual framework developed for this work has two parts. In the first part, the framework explores the flood management trends and water governance literature to identify current drivers of change and their influence through a systematic review of literature. The systematic review examined drivers of change in a regional/global context provides FRM professionals with the ability to determine the potential impacts of drivers of change on the risk of flooding. Following the first part of the conceptual framework, I collected and analyzed 170 studies from the European Union, the United States, and Canada and analyzed those using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), which resulted in identifying five categories of drivers of change (see Chapter Two).

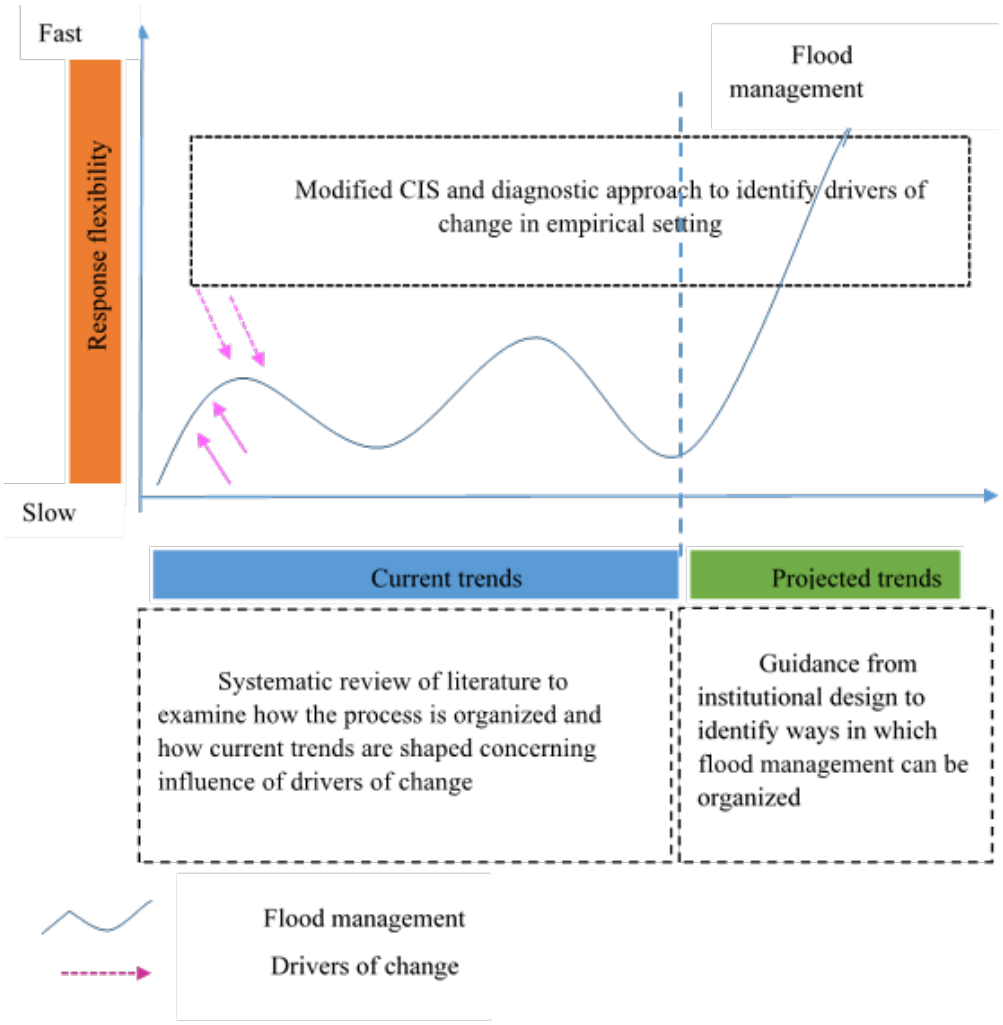

Figure 1-1: The conceptual framework

In the second part, a diagnostic framework is presented to provide both in-depth and cursory analysis of the empirical setting. To develop the second part of the conceptual framework, the modified CIS (Combined Institutional Analysis Development and Social-Ecological Systems (Cole et al. 2019) and the diagnostic approach developed by de Loë and Patterson (2017a) are merged together to examine the influence of drivers of change in institutional configurations and governing approaches to inform FRM (see Figure 1-2). These two parts independently have the capacity to account for drivers of change. The Social-Ecological Systems (SES) framework as a part of CIS provides a foundation to link social, economic, and political settings to social ecological systems. The SES framework enables the researcher to explore ways in which governance systems and actors in a system affect and are affected by the particular social, economic, and political settings and by characteristics of other related ecosystems. The diagnostic approach developed by de Loë and Patterson (2017a) pays particular attention to external factors that are neglected by actors and governance systems and provides a tractable tool to allow both in-depth and cursory analysis of the situation.

The conceptual framework situates the select FRM system in the broader social-ecological system by defining an action situation. It guided research to identify drivers of change by supporting both a high-level and in-depth analysis in a particular action situation following four steps (see Figure 1-2). The first step is to define the action situation as clearly as possible. The second step, "spiralling inwards," allows us to determine if a FRM perspective is appropriate. The third step critically reflects on the boundaries of the current action situation to facilitate the analysis's final step, which focuses on identifying opportunities to improve governance by accounting for drivers of change in the selected action situation. The last two steps promote inquiry into interactions "external" to the selected action situation, which involves "spiralling outwards" to explore broader interactions and their impact on current FRM contextual factors. Using the four-step analysis, I explored the impacts of drivers of change on institutional arrangements to highlight opportunities and weaknesses in the selected action situation. Action situations are defined as "analytic concepts that enable an analyst to isolate the immediate structure affecting a process of interest to the analyst for the purpose of explaining regularities in human actions and results to potentially reform them" (Ostrom 2011a, 11).

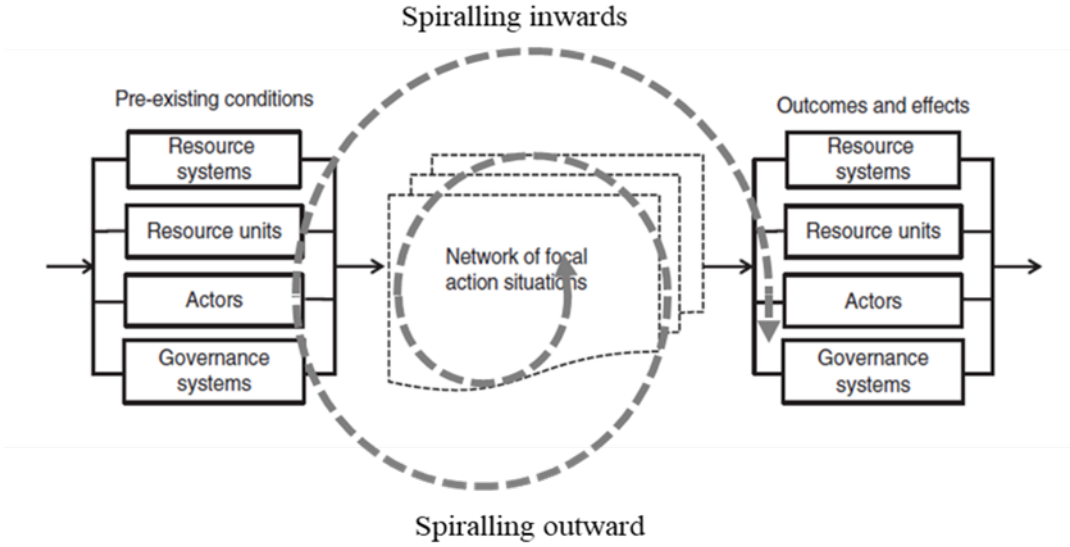

Figure 1-2: The combined frameworks the foundation for empirical analysis

Using this conceptual framework, I investigated the interaction of drivers of change with the flood management approaches in the context of a case study. In this section, the framework also draws on institutional design principles (see Chapter Three) and flexibility metrics (see Chapter Four) to explore pathways in which necessary institutional change can be facilitated to adapt to and cope with drivers of change and their influence in flood risk management.

The conceptual framework provided the theoretical guidance on drivers of change and their influence on flood management. Objectives Two, Three and Four, were addressed by conducting the four-step analysis as a part of the conceptual framework built on CIS and the diagnostic approach assessing the case studies. Case studies were reviewed in detail to bridge between theory and practice. The conceptual framework guides the research data collection and methods

of analysis. It also informs the selection of the case study and enables the researcher to focus on the understanding of the empirical context of the case (Yin 2009, 8)

1.4.2 Case study approach

A case study-based empirical analysis was used to examine drivers of change and their impact on Ontario's flood management. The case study method is well suited to exploring many aspects of the complex interactions between drivers of change and flood management in diverse social, economic, and environmental backgrounds (Yin 2009). I designed the case study to provide perspectives from the regional level to the local level by analyzing similar cases in the systematic review of the literature, followed by choosing the City of Toronto and a particular flood protection project within the City as the empirical cases for detailed analysis. The design of the case study has enabled this research to explore the concepts of levels and scale in analyzing drivers of change impact on FRM. Examining a case study provides an in-depth perspective of drivers of change that impact flood management in the context of Ontario. Case study analysis enables researchers to explain contemporary phenomena that are outside of researchers' control (Yin 2009).

The primary reason for selecting Ontario is that flooding, as a leading cause of public emergency in Ontario, has threatened economic development and public safety (Conservation Ontario 2013). In addition, changes in climate (e.g., increasing variability in precipitation), land-use (e.g., urbanization), economy (e.g., change in infrastructure spending), and geopolitics have presented several risks to flood management and water governance in the province. (Thistlethwaite 2017, Conservation Ontario 2013). The Conservation Authorities Act (1990) section C 27 delegated flood control to the conservation authorities (CAs) as a part of their responsibilities and roles. The Act indicates that to meet their designated roles and responsibilities, CAs need to work with municipalities, provincial government agencies (e.g., Ministry of Natural Resources and Forestry), and federal government agencies (e.g., Environment and Climate Change Canada).

Recent flood events in Ontario (see Table 1-5), changes in the institutional arrangement and responsibilities of CAs (Conservation Authorities of Ontario 2020, Environmental Registry of Ontario 2019), and funding cuts for flood risk management activities by the provincial government (Meckbach 2019) were deemed appropriate to build an evidence-based insight on drivers of change and their impact on flood risk management system in Ontario.

Table 1-5: Recent flood events in Ontario (IBC 2021)

Event data	Area	Description	Insured damages in million
22-Jun-15	Southern Ontario	The heavy rain in Toronto and London caused localized flooding.	$30
30-Apr-18	Ontario and Quebec	severe rain, heavy snow, and damaging winds	$85
14-Mar-19	Ontario	Winter storm, flooding, and ice jam	$53

15-Nov-20	Ontario	Storm Greater Toronto and Hamilton Area, Niagara region, Muskoka region, and the Lake Erie and Lake Ontario shorelines	$87
10-Jan-20	Ontario	Storm From Windsor to London, 60 to 70 mm of rain fell. In Toronto, 78 mm of rainfall was recorded	$95

In this dissertation, case studies are treated as action situations and were critically assessed using the conceptual framework through the first step of the analysis, which defines the action situation, and the second step, "spiralling inwards," which assesses the suitability of the currently defined boundaries. These two steps of analysis provide detailed insight on the flood management system and how it is situated in broader social-ecological systems, as well as a scan of actors and their connection to FRM systems. These two steps set the foundation for the in-depth analysis of drivers of change and their impact on the FRM system, which attempts to connect water governance and FRM in particular with broader social-ecological systems. This study follows various scholars' footsteps to identify drivers of change and forces outside water governance systems (Egan and de Loë 2020, Berndtsson et al. 2019, Muir 2018, Lewison et al. 2016, Winsemius et al. 2016). In Chapter Three, the presented action situation is focused on the City of Toronto and its flood management systems which are nested in FRM systems in Ontario. Chapter Four focuses on the Port Land Flood Protection Project within the city of Toronto.

1.4.3 Data collection

Guided by the conceptual framework, data for the case study analysis were collected from primary sources (semi-structured interviews) and secondary sources, including documents collected from governments, non-governmental organizations (NGOs), research organizations, municipalities, Conservation Authorities (CAs) and the private sector. Four data sources were used for the study: key informant interviews, document analysis, personal observations, and Twitter feeds. This section provides a summary of the collected data, which are explained more in detail in Chapters Three and Four, where the focus is the analysis of the selected case studies using the developed conceptual framework. In total, 28 in-depth interviews, 232 documents and 60 Twitter posts were collected between September 2018 and March 2021.

The data collection process was guided by 1) research design and 2) field execution. Research design relied on the literature to determine how many interviews were needed to reach data saturation. The literature suggests that between 20 to 30 one-on-one in-depth interviews were used in similar cases examining flood risk management issues (Wells et al. 2020, Dekker and Fantini 2020, Morrison, Noble and Westbrook 2018a). To collect a primary data set, I identified potential interviewees by sending a targeted email to 103 potential interviewees, including policymakers, NGOs, banks, insurance, municipalities, construction companies, news organizations, and technology companies, which resulted in 28 in-depth interviews. Furthermore, field execution presented some challenges which impacted the recruitment and willingness of actors to participate in the study. Changes in organizational arrangement (Ontario 2018), funding cuts (Meckbach 2019), the Covid 19 pandemic, and the occurrence of multiple flood events in the province (McNeil 2020) are examples of some challenges that occurred during data collection

The process of data collection was started by exploring flood risk management systems. Primary institutions and fundamental documents in the FRM system were identified through preliminary research and participation in key events (e.g., conference and workshops for practitioners). Through an iterative process, data were collected, and the conceptual framework was revisited to better account for a broader social-ecological context within which the cases are situated. Collecting different types of qualitative data concurrently from various sources facilitates the representation of various perspectives (e.g., academic and practitioners, regional, local and provincial scales, public and private sectors). In addition, it also contributes to the triangulation of data through a convergence of information from different sources of data (Heath 2015, Baxter and Jack 2008, Liamputtong 2013).

Data collection was conducted using mixed sampling methods, combining two methods used in qualitative research: purposive sampling and snowball sampling. The mixed sampling method identifies the eligible and knowledgeable individuals in flood management. Purposive sampling uses strategic choices to identify people who are the most knowledgeable about the subject of the study. The result of purposive sampling is a small pool of knowledgeable people. I used snowball sampling to increase the size of the pool of knowledgeable informants. Snowball sampling uses recommendations to find people with specific knowledge and expertise. The groups of informants who are identified by snowball sampling will be nominated by other participants as key informants with a profound insight into the subject of the study (see Table 1-6).

In total twenty-eight key informant interviews were conducted. All participants had a managerial role in their organization and were purposefully recruited based upon their knowledge in the context of Toronto, Ontario, Canada and/or involvement with the selected FRM systems and selected action situations (see Table 1-6). The interviews were conducted in person and over the phone and ranged from an hour to two hours. The participants were senior officials in their respective organizations: directors, managers in federal, provincial, and local governments, non-profits organizations, the private sector (including consultancies, an insurance industry, risk assessment organizations) and research groups and think tanks. Interviews were in-depth and semi-structured to guide the discussion towards the research objectives while also providing flexibility to enrich current perspectives on the FRM system and governance to facilitate the emergence of new themes.

Interviews were conducted in person, over the phone, and through virtual meetings using Skype. Interviews were recorded digitally with the interviewee's permission. When recording permission was not granted, detailed notes were taken. Interviews were transcribed and sent back to the interviewees for verification. The interview process was approved by a University of Waterloo Office of Research Ethics Committee (ethics clearance ORE #31920), in accordance with the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans. The interview guide and the consent are attached in Appendix A and Appendix B to provide an overview of the ethics process. As part of the ethics process, ensuring anonymity and evidence from interviews was implemented by assigning a number to interviews and transcripts that were unique for each participant.

Table 1-6: Interviews representation and data sampling examples

Level/ scale	Organization	# Interviews
International	International Joint Commission	1
Federal	Public Safety Canada	1
	Environment Climate change Canada	2
	Natural Resource Canada	1
	Finance Canada	0
Ontario level	Ministry of Natural Resources	1
	Ministry of Municipal and housing	1
	Ministry of Environment, Conservation and Park	2
	Ministry of infrastructure	0
City of Toronto	TRCA	4
	Municipal experts	5
	Municipalities (Parks Forestry and recreations)	1
	Municipalities (transportation)	0
	Office of Fire Marshall and Emergency	0
Other public and private actors at the local level		
NGOs		2
Research groups		3
Insurance companies		2
Consultancy (engineering)		2
Real-estate organizations		0
Total		28

Documents were collected through various sources, which were divided into two main datasets. Legal documents (e.g., statutes and case law) contain information regarding precedents for how the governance process is formed and operates. The other source included grey literature related to flood management in the context of Ontario's water governance. Grey literature also was included (e.g., documents from businesses, farming, industry resources published by private, NGOs, and activist groups). Document review guided analysis (Bowen 2009) to highlight drivers of change that directly or indirectly affect flood management, water governance, and

environmental decision making. The following table provides an overview of secondary sources of data used in each case study.

Table 1-7: secondary data sources used in each case study

Data sources and case studies	Document analysis	Personal observations	Twitter post
City of Toronto	170	8	0
Port Land Flood Protection project	62	5	60

The third set of data was collected via personal observation and field notes by participating in multiple public consultation meetings, workshops, practitioners' focused conferences in person or online regarding FRM systems in Ontario. Field notes were gathered on public reactions and comments in meetings. The fourth and final data source was a broad scan of Twitter posts focusing on the hashtags: #PortLands2024 #TRCA # TOwaterfront (60 posts) between 2019 up to 2021. The data contained Twitter posts, including comments and threads, analyzed and coded in content analysis. Personal observation and Twitter feeds provided ground truth and less intrusive ways to gain perspectives on different dimensions of the FRM system (e.g., informal discussions and personal opinions regarding the projects) not captured by the other two methods (Hollstein 2011). Detailed information regarding the events is presented in Chapters Three and Four.

1.4.4 Data analysis and integration

In this research, data were collected through guidance from the conceptual framework. Guided by the conceptual framework, results from the systematic review of literatures, interviews, personal observation, and document review were used to triangulate and develop emergent patterns and findings. The research identified drivers of change and their impact on the flexibility of flood management in the case study regions following the design of the conceptual framework. The step-by-step analysis is presented in each chapter that provides more detailed information on how data were analyzed, considering the characteristics of each action situation. Generally, this research used two different strategies: thematic analysis and content analysis

Thematic analysis (TA) is used as the method used to analyze in-depth interviews and documents. Thematic analysis works directly with the main content of in-depth interviews and documents (Liamputtong 2013). Using thematic analysis enables researchers to identify the more in-depth analysis of words, speech, pauses, changes or the presence of particular phrases (Boyatzis 1998), which are not detectable by other types of analysis (e.g., content analysis). Thematic analysis has the ability to present theme co-occurrence and graphically illustrate relationships between different phrases and themes.

In this research, interviews were transcribed and imported into Nvivo, as were selected documents, field notes, and Twitter feeds. The first step in the thematic analysis after reading each interview or document was coding. In the thematic analysis, an open coding style was used.

The open coding style was applied in this research using Code Toolkit in NVivo. Themes were identified by reading and re-reading the transcripts and using a comparative coding process (Liamputtong 2013). The coding scheme is based on categories that are designed to capture the dominant themes in the interviews (Liamputtong 2013).

In addition to thematic analysis, content analysis was also used to review of the literature (collected in the systematic review), interviews, documents, Twitter posts and personal observation as suggested by Liamputtong (2013) and Krippendorff (2004). Content analysis is a systematic and replicable technique for compressing large volumes of text into fewer content categories such as child nodes, parental nodes, and themes (Krippendorff 2004, Liamputtong and Ezzy 2005). Content analysis was used to describe the focus of the interviews, documents policies and legislation concerning flood management efforts in Ontario.

Integrating data and results from different sources facilitated the triangulation of data sources, collection, and analysis. Data integration followed by triangulation attempts to examine issues from different perspectives within the same method and across different methods to confirm the validity of the analysis (Liamputtong 2013). These steps support the reliability of the qualitative method by revealing information about themes coverage and reaching data saturation (Charmaz 2006). Data integration and triangulation helped to reach saturation and validity by ensuring that perspectives from different sources (e.g.., scientific literature, interviews, documents) were taken into account and presented as themes in the analysis. These themes were discussed in detail in Chapters Two, Three and Four, as well as Chapter Five, which provides a synthesis of the overall finding of the dissertation.

1.5 Empirical setting and Case study

In Canada, damage due to flooding is predicted to rise (see Figure 1-3) according to the Insurance Bureau of Canada, the Parliamentary Budget Office (PBO), which estimates that Canadian DFAA (Disaster Financial Assistance Arrangements) costs due to flooding could increase to more than CAD$670 million annually (Canadian Parliamentary Budget Officer 2016). Aon's Insurance's Global Catastrophe Recap noted flood damages estimates had passed US$8 billion from events globally in March 2019. Canada's portion of these economic losses caused by flooding in Ontario and Quebec between March 9-11, 2019, was estimated at up to C$150 million (US$110 million). Private actors, including insurers, paid up to C$60 million (US$45 million) in compensation. The increasing damage has drawn government attention to escalating threats to direct economic losses that can be exacerbated by factors outside flood risk management that impact flood hazards and vulnerabilities, such as changes in the social and economic characteristics of landowners.

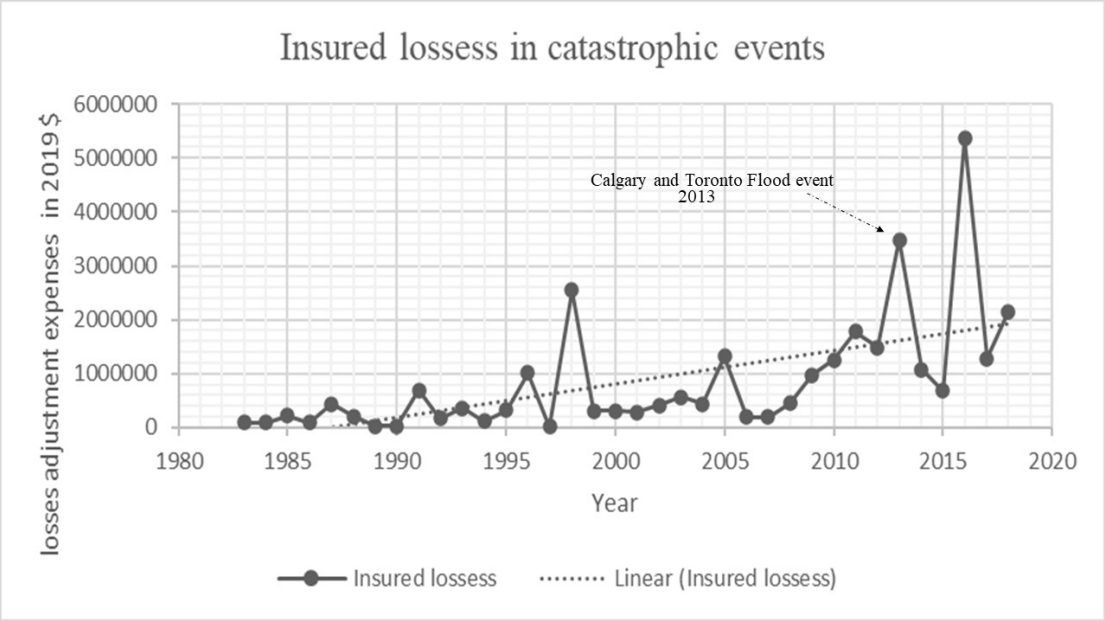

Figure 1-3: Trend losses in Canada data collected form (IBC 2020a)

To produce findings that inform decisions with regard to flood management and water governance in the broader Canadian context, I develop a set of selection criteria to identify the availability of cases well suited for the analysis. High flood reoccurrence (see Table 1-5), increasing flood damages, and the presence of strong multi-level flood management organizations (MNRF 2020, McNeil 2020) were the main selection criteria. The province of Ontario met all three selection criteria, and within the province city of Toronto was selected the action situation for exploring drivers of change and their impact on the FRM system.

The City of Toronto (see Figure 1-4) is the fourth largest city in North America and the largest city in Canada, with a population of approximately 3 million people. The City of Toronto generated approximately $186 billion in GDP (2018). The Census metropolitan area (CMA) GDP accounts for more than 18% of Canada's GDP in 2018 (City of Toronto 2021b). The city supports a labour force of more than 1.6 million with a population density of approximately 4,700 per square km. As the fastest growing city in Ontario, the City of Toronto has to deal with a host of issues, including increasing risk of flooding, infrastructure investment, and housing demands.

The City of Toronto borders Lake Ontario and contains the Humber, Don and Rouge Rivers. Recently, the City of Toronto has faced numerous flood events. The 2013 flood, with approximately $1 billion losses followed by the 2018 flood event with $80 million in insured damage, are recent and noted events because of the severity of the economic damages (Feltmate and Moudrak 2021, IBC 2014). In 2019, Toronto residents also experienced heavy rainfall, which impacted critical infrastructure (CI), including major highways and public transportation systems (IBC 2020). Historically, Hurricane Hazel (1954) dumped over 200 millimetres of rain in just 24 hours and made a long-lasting impact on the governance system’s approach to managing development along the river valleys (TRCA 2019b).

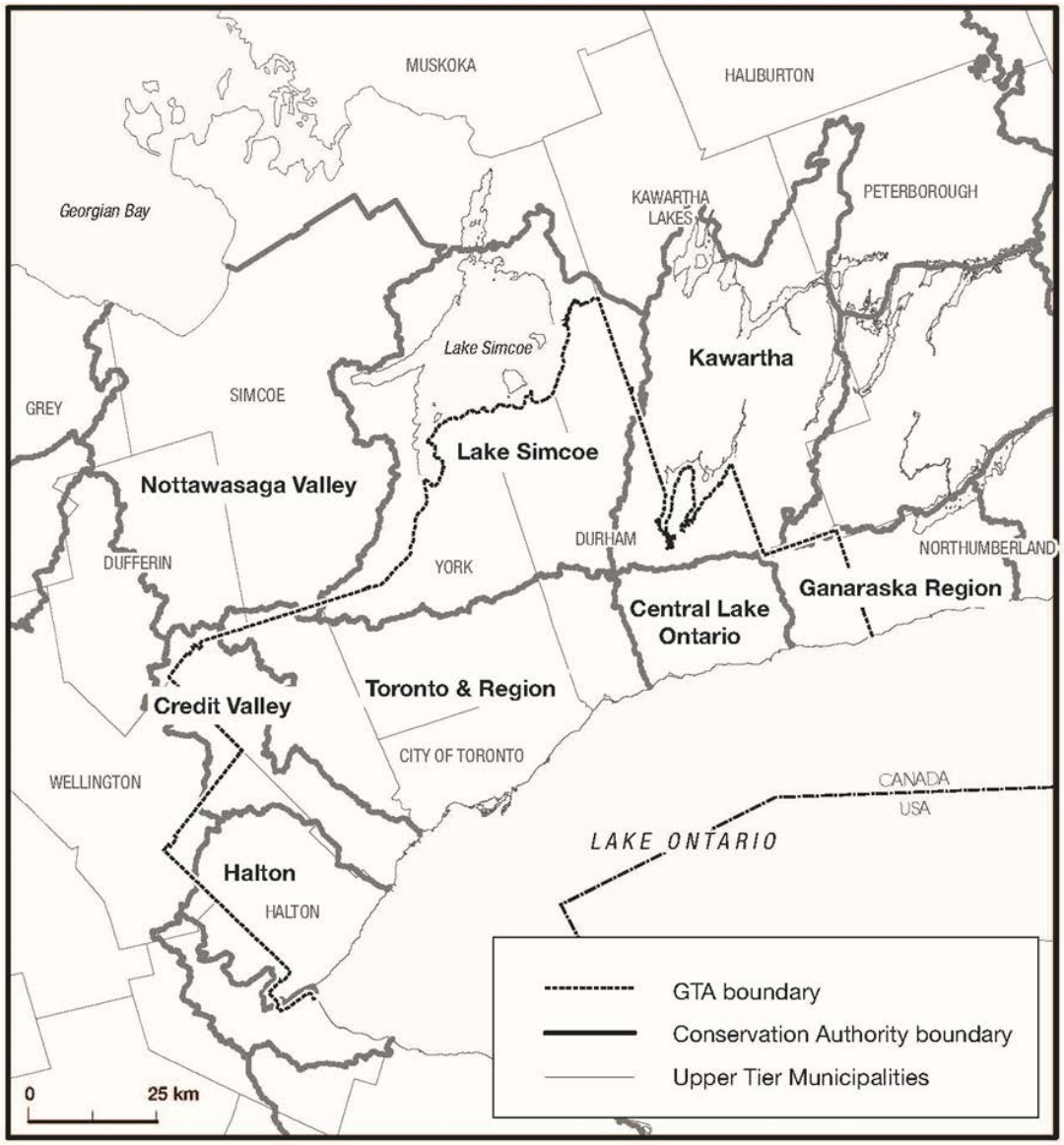

Figure 1-4: The case study: City of Toronto

The formation of the Toronto Region Conservation Authority (TRCA), which received its legislative authority under an amendment to the Conservation Authorities Act (1954), was a response to the devastation left behind by Hurricane Hazel. It should be mentioned that the formation of Conservation authorities was commenced by the Conservation Authorities Act (1946). At the time (1946), conservation authorities could be set up by resident requests and their willingness to contribute financially. The amendment to the Conservation Authorities Act (1954) has enabled Conservation Authorities to acquire lands for recreation and conservation purposes and to regulate that land for the safety of the community. The updated Conservation Authorities Act (1990) restated the core mandates of CAs to undertake watershed-based programs to protect people and property from flooding and other natural hazards and to conserve natural resources for

economic, social, and environmental benefits (MNRF 2020). Currently, the Province is conducting a consultation process to update the Conservation Authorities Act, which was announced by releasing a " Regulatory Proposal Consultation Guide: Regulations Defining Core Mandate and Improving Governance, Oversight and Accountability of Conservation Authorities, 2021" (Conservation Authorities of Ontario 2021). The implication of these changes on the role and responsibilities of CAs and their impact on FRM in Ontario are discussed by various actors (Mitchell, Shrubsole and Watson 2021, Conservation Authorities of Ontario 2021, Sandhu, Weber and Wood 2021).

In addition to the Conservation Authorities Act, to reduce the negative impact of flooding, the province also established using a two-tier zoning or Special Policy Area (SPA) approach. In this approach, the flood plain is divided into two major zones: floodways where new development is prohibited and flood fringes where new development can be permitted under specific conditions to address the risk of flooding (Conservation Authorities of Ontario 2010). SPAs mechanism activates a process through which various local levels (municipalities and Conservation Authorities) have to work with provincial partners, including the Ministry of Natural Resource and Forestry (MNRF) and the Ministry of Municipal Affairs and Housing (MMAF), to tailor a suitable approach for that area (City of Toronto 2015, TRCA 2008).

Currently, there are ten special policy areas in the City of Toronto (see Figure 1-5). The Lower Don: Don River, with the largest area, has been going under considerable planning initiatives since 1994. Attempts to the revitalization of the Don Mouth area resulted in securing $1.25 billion in shared funding announced by the governments of Canada, Ontario, and Toronto to flood-proof the area by supporting various flood protection projects. The result of these projects led to changes in the zoning of the current area according to the flood plain management planning policy approach. The ongoing effort of the City of Toronto to reduce the risk of flooding (e.g., a flood forecasting and warning system and stormwater management program) and to address different types of flooding (TRCA 2020b) and increasing flood damages present a strong rationale to assess FRM system in the City of Toronto.

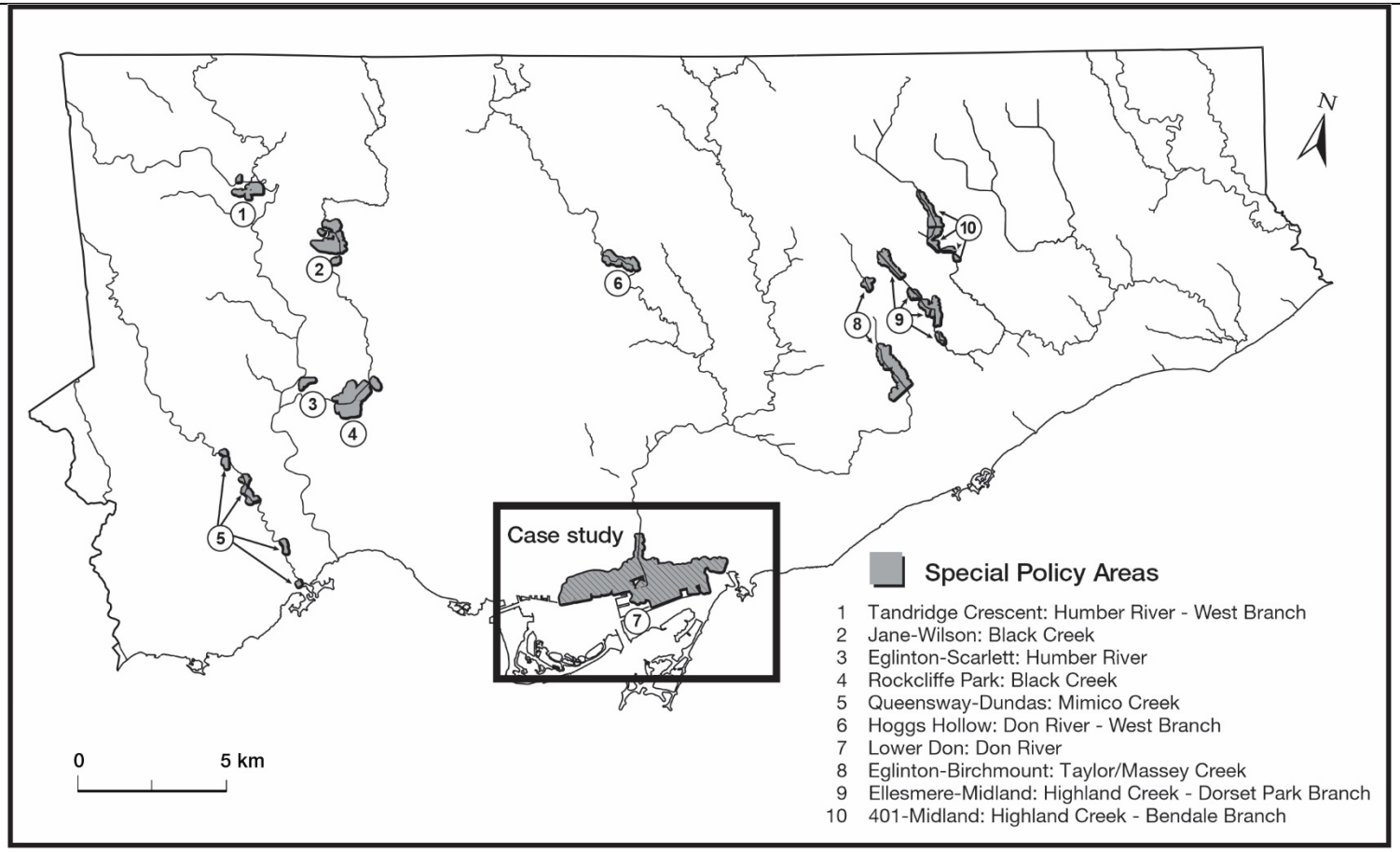

Figure 1-5: Special policy area in the City of Toronto

1.6 Organization of the dissertation

This dissertation is presented as three stand-alone manuscripts with an introduction section and a concluding synthesis chapter. The introductory chapter sets the stage for the dissertation. It introduced the developed conceptual framework that guides the research process, implementation, and reporting.

Chapter two, the first journal paper out of three stand-alone articles, presents a systematic review of the literature to characterize the current scientific and regional perspectives about FRM and drivers of change. Following the first section of the developed conceptual framework (see Figure 1-1), a systematic review of literature was conducted to identify drivers of change and assess their interactions to identify ways in which flood management can change its institutional arrangement for risk reduction and mitigation. This paper reflects on Objective One and Four (see Table 1-1). This chapter contains a manuscript titled “Global Drivers of Change in Flood Risk Management: A Systematic Review,” and it is going to be submitted to the Flood Risk Management journal.

Chapter Three is built on the conceptual framework using four-step analysis to empirically assess FRM systems to identify drivers of change (see Section 1.4.1). Building on the findings of Chapter Two, Chapter Three focuses on identifying drivers of change and assessing their impacts on the FRM systems to find opportunities for adaptation and mitigation. This chapter contains a manuscript title, “Identifying adaptation opportunities to account for drivers of change in a complex flood management system,” which will be submitted to Mitigation and Adaptation Strategies for Global Change. In This paper, I explored drivers of change in FRM in the City of Toronto, Canada, to provide an opportunity to examine pathways through which FRM can adjust to, cope with, or benefit from a better understanding of the role of drivers of change. In addition to exploring these drivers of change, our analysis sheds light on potential implications for water governance while identifying drivers of change and potential opportunities for adaptation and mitigation. This chapter contributes to reaching Objectives One to Four in the dissertation.

Chapter Four is the final stand-alone article and builds on the guidance of Chapters Two and Three. This chapter contains a manuscript title, “Rethinking governance of flood risk: lessons learned from the Port Lands Flood Protection Project”. It focuses on The Don Mouth Naturalization and Flood Protection Project (DMNP), one of the many flood risk management efforts conducted by the City of Toronto, Canada, along with other partners, to reduce the risk of flooding and to revitalize urban areas in the city (City of Toronto 2019, TRCA 2021b). The DMNP provides an excellent opportunity to examine the institutional arrangements which guide the diversification of FRM approaches to reduce the risk and probability of future flood events. Water Policy is the selected journal where this paper will be submitted. This chapter also explores the flexibility and the institutional arrangements in The Don Mouth Naturalization and Flood Protection Project (DMNP) in addressing drivers of change and their impacts.

Chapter Five provides a comprehensive perspective on four earlier chapters by highlighting the main findings from the empirical chapters as well as generalization of the overall approaches to address the impact of drivers of change. The value of identifying drivers of change and assessing their impact in FRM system is discussed to provide theoretical and policy-relevant contributions. In addition, the potential pathways and perspectives to better understand risk

mitigation and adaptation through changes in institutional arrangements are presented. Finally, some of the limitations of this study are outlined and potential opportunists to expand on this study are presented to conclude the dissertation.

Chapter 2

Global Drivers of Change in Flood Risk Management: A Systematic Review

2.1 Introduction

Globally, floods are recognized by the United Nations Office for Disaster Risk Reduction and the World Economic Forum as the most common natural disaster, accounting for 43% of all recorded events from 1995 to 2015 (UNISDR 2015). Floods are predicted to occur with higher frequency in the future (Winsemius et al. 2016). The negative impacts and damages due to flooding have increased significantly from 1995 to 2015, and are expected to rise globally (World Bank 2017, UNISDR 2015). The World Bank highlights that flood damages from property damage alone are estimated at US$120 billion US dollars per year (2017). Winsemius et al. (2016) suggest that the one trillion US dollar direct economic loss from 1980 to 2013 could be increased by a factor of 20 by the end of the century if no action in managing upcoming floods is taken. These global predictions highlight the escalating threats to global GDP (Gross Domestic Product), which can be exacerbated by the failure of climate-change mitigation and adaptation (Winsemius et al. 2016).

Our concern in this paper is with drivers of change in flood risk management (FRM). In this study, FRM refers to "government policies and programs that influence the decisions made by communities and individuals relating to floodplain location and use and their choice of actions to reduce flood risk and manage residual risk" (Shabman and Scodari 2014, 5). This perspective on FRM incorporates decisions that are made by all actors, including individuals and governments, and addresses actions that reduce the flood hazard, exposure, and vulnerability and which increase resiliency. We define drivers of change in FRM as a natural or human-induced factor that directly or indirectly causes a change in the risk of flooding or the ways in which flooding is managed or governed. Our perspective drivers of change draw on insights from business and management (Perera 2017, Srdjevic et al. 2012), organizational analysis literature (Borrás and Radaelli 2011, Whelan-Berry and Somerville 2010), biodiversity literature (Millennium Ecosystem Assessment 2005, Nelson et al. 2005, Lewison et al. 2016), and deforestation and land-use changes literature (Geist and Lambin 2002, Rueda et al. 2019). A combination of perspectives enables our analysis to account for the social, ecological, and economic aspects of FRM. To illustrate, drivers of change in FRM from the broad perspective we use include not only change in weather patterns but also the emergence of sustainable finance options at global to local scales (Alaerts 2019, Muir 2018).

Drivers of change can enable or constrain the success of management and governance efforts by altering the conditions under which baselines, models, and measurements are developed for FRM (UNWWAP 2009, Winsemius et al. 2016, United Nations Environment Programme 2007, Bloemen et al. 2018, Hartmann and Driessen 2017, Henstra and Thistlethwaite 2016a, Serra-Llobet et al. 2016). For example, change in access to real-time and high-resolution climate data (e.g., measured temperature and precipitation) for flood forecasting and changes in land use data (e.g., measured pervious vs. impervious surfaces) for modelling urban runoff act synergistically as drivers of changes in understanding of the probability of flood hazards and the

consequences of flood events (O'Connell 2017, Henonin et al. 2013, Booher and Innes 2010). These drivers can also influence policy and management interventions in cases where they misrepresent causes and effects; this can lead to negative impacts on monitoring, evaluation of the outcomes and future policy, and decision making (Van Buuren, Ellen and Warner 2016, Gillon et al. 2016, Aerts et al. 2018).

While the challenges and impacts of drivers of change on FRM are widely recognized by researchers and policymakers, very few studies have agreed on the definition of drivers of change in FRM, and a systemic review of these drivers and their impact on them in current FRM research does not exist. Therefore, it is beneficial to study FRM systems in various social, economic and environmental contexts to identify a global range of drivers of change, their impacts on FRM, and their implication for governance. We use a formal systematic review of the literature to answer two research questions: (1) What are the most common and most noted drivers of change that influence FRM? And (2) does FRM literature recognize or acknowledge the impact of drivers of change? In addition to exploring the research questions, the analysis shed light on potential implications for water governance to co-develop solutions to address the increasing vulnerabilities to flooding. Identifying drivers of change in the global context will provide insight into new approaches (e.g. new perspective on vulnerability assessment and risk ranking), innovative institutional arrangements, and potential partnerships among actors to improve FRM resiliency and effectiveness.

2.2 A brief review of FRM changes

In recent years, FRM has moved away from the traditional engineering approach to an integrated risk management approach (Hartmann and Driessen 2017). Globally accepted concepts such as integrated water resources management (IWRM) have directed FRM attempts around the world to integrate flood risk management concepts with traditional management approaches (Morrison et al. 2018b, Serra-Llobet et al. 2016). IWRM is defined as "a process which promotes the coordinated development and management of water, land and related resources to maximize economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems and the environment" (Global Water Partnership 2011). The concept of IWRM appeared in the development of the Water Framework Directive and the Floods Directive in EU countries, which provided funding and favoured nonstructural or soft structural measures in FRM, such as land-use controls and river and floodplain restoration (Serra-Llobet et al. 2016, Penning-Rowsell and Priest 2015, Hegger et al. 2014). In Canada, this shift gained momentum through the Canada Water Act (1970). By 1975, the Flood Damage Reduction Program (FDRP), a joint federal-provincial initiative, introduced systematic nonstructural efforts that focused on mapping to delineate and designate flood risk areas (de Loë 2000, Mitchell 2006, Watt 1995).

Recent changes in FRM approaches have aimed to control and reduce flood risk by enhancing technical and infrastructural capacity by designing non-structural solutions and developing flood warning systems (Raadgever et al. 2018, Bloemen et al. 2018, Rollason et al. 2018, Hartmann and Driessen 2017, World Bank 2017). FRM has increasingly focused on societal transformation and practical governance approaches by controlling behaviour (e.g., increasing risk awareness, implementing private flood protection measures, and promoting GI) using law and regulation (Rollason et al. 2018, Aerts et al. 2018, Mann and Wolfe 2016, Bubeck et al. 2015). To account for uncertainty and to accommodate the complexity of social-ecological

systems, FRM increasingly draws on an "adaptive management approach", which enables FRM to mitigate, cope with, and recover from expected and unexpected changes (Morrison et al. 2018b, Newig et al. 2014, DiFrancesco and Tullos 2014). This adaptive FRM approach focuses on continuous learning to enable the "adjustments or implementation of new rules, measures, or configurations to achieve a more sustainable state (e.g., managing risk and reducing damages)" of management and governance in response to drivers of change (Becker, Huitema and Aerts 2015, 1).

To address increasing global flood risks and the predicted effects of climate change on weather patterns and the intensity of precipitation, flood risk decision makers explore new perspectives to complement and adjust to the changing landscape of social-ecological systems (Hegger et al. 2016, Albano et al. 2015, Hegger et al. 2014). Resilience-based approaches have been adopted over the last two decades to build management systems that can absorb disturbances and which have the capacity to reorganize in the face of incremental or disruptive changes to retain their function, structure, and identity (Folke 2007, Morrison et al. 2018b, Baird and Plummer 2020). Governance approaches with the ability to consider the impact of broader social and ecological systems and to link policies, processes and relationships, can support appropriate strategies to reduce risk, increase resiliency, and transform the system into a desirable state (Hegger et al. 2014, Penning-Rowsell and Priest 2015, Petridou and Olausson 2017).

Projects and research initiatives across Canada, the EU, and the USA reveal that the success or failure of FRM efforts to address drivers of change is closely related to the governance system (Dieperink et al. 2016, Winsemius et al. 2016, Serra-Llobet et al. 2016). Examples include STARFlood in the EU (Alexander et al. 2016, Wiering et al. 2017); the Room for the River program in The Netherlands (Zevenbergen et al. 2013, Van der Most et al. 2018, Van Buuren et al. 2016); the Bay Area Integrated Regional Water Management Plan in California, USA (Serra-Llobet et al. 2016, Weissman et al. 2013); and Canada's FDRP (de Loë and Wojtanowski 2001, Public Safety Canada 2017) (see Table 2-1). Making changes to current approaches to reduce risk and increase resiliency may require new resources (knowledge, technology, and finances), new policies and regulations, and new institutional structures and organizations.

Identifying the most common drivers can enhance understanding of the role of drivers of change in shaping and reshaping our current and future FRM efforts and approaches. This was accomplished by reviewing the scholarly, peer-reviewed journal articles which addressed FRM and governance and drivers, forces, and external powers that impact FRM. This review sheds light on ways to categorize drivers of change while acknowledging their interactions and their coexistence on different scales to co-develop solutions to incorporate drivers of change their impacts in current FRM approaches and vulnerability assessments.

Table 2-1: Examples of flood risk management efforts

FRM effort	Region	Descriptions	Success and challenges	Sources
STARFlood	EU: Belgium, England, France, the Netherlands, Poland and Sweden (2012-2016)	Project to assess flood risk governance arrangements from a combined public administration and legal perspective to make European regions more resilient to flood risks.	Adapting a governance perspective on FRM Diversification FRM strategies Address issues around fragmentation by establishing bridging processes and mechanisms	(Hegger et al. 2018, Wiering et al. 2017, Hegger et al. 2016, Alexander et al. 2016)
			Challenges around financial recovery mechanisms Challenges around path-dependency in FRM Challenges around rules (e.g., private property rights)	
The Room for the river	The Netherlands 2006-2015	Nature-based solution by giving more space to river addressing velocity of the flow	Using an adaptive governance approach (multiple scenarios) Collaboration between public and private actors	(Van der Most et al. 2018, Mens et al. 2015, van den Hurk et al. 2013, Zevenbergen et al. 2013)
			Challenges around the availability of space Challenges around political will and collaboration	
The Bay Area Integrated Regional Water Management Plan	California, USA 2006- on-going	It is an effort to coordinate and improve water supply reliability, protect water quality, manage flood protection, maintain public health standards, protect habitat and watershed resources, and enhance the overall health of the San Francisco Bay.	Using IWRM (integrated water resource and management) Improve representativeness of nine counties' regional needs and priorities	(Serra-Llobet et al. 2016, Weissman et al. 2013)
			The lack of a central entity with the capacity and mandate for on-going coordination and region-wide risk assessments management Challenges to updating guidelines and requirements Adoption of the Bay Area IRWM Plan does not entail a direct commitment of resources and implementation of each project	

The Federal Disaster Reduction Plan	Canada 1974- the late 1990s- The Federal Government left the joint agreement with the Provincial governments	Initiated a national shift away from reliance on flood control structures such as dams to the use of non-structural measures, including floodplain mapping and zoning.	Collaboration among three levels of government Identifying and protecting environmentally significant areas Foundation for flood risk mapping • Lack of financial support • Cost of incorporating floodplain use restriction into Offical Plans • Cost of public land acquisition programs for flood-prone lands.	(de Loë and Wojtanowski 2001, Public Safety Canada 2020)

2.3 Method

Our analysis identified drivers of change highlighted by FRM and governance scholars in peer-reviewed journals, with article selection bounded by time and geographical location (see Figure 2-1: Distribution of journal articles over timeFigure 2-1 and Figure 2-2). A formal systematic review of literature was used to identify the major themes in large bodies of literature while searching to identify if there is a gap or opportunity for clarification in selected literature (in this case, flood risk management and governance). Data are summarized by theme using qualitative and quantitative methods; key studies are highlighted and compared to synthesize major findings (Crowther, Lim and Crowther 2010).

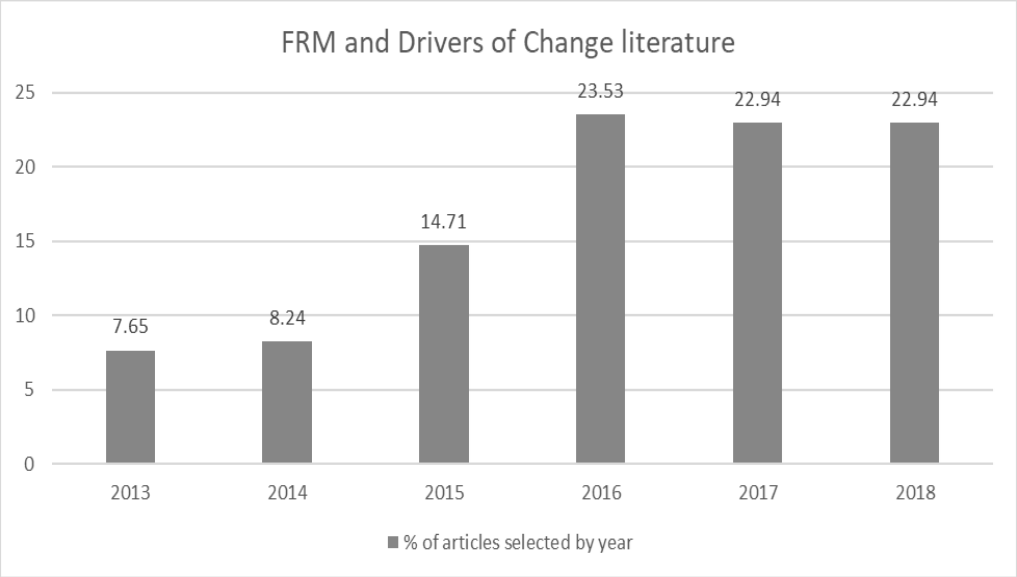

Figure 2-1: Distribution of journal articles over time

The process of retrieving data began by selecting two databases that are considered important in environmental studies research: Web of Science and Scopus. We used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) to ensure a transparent and complete reporting method. Using PRISMA to develop a systemic review contributes to replicability and helps to reduce bias (see Figure 2-2).

Using search terms (see Figure 2-2) to restrict articles to sensitive and specific studies, our searches yielded 815 articles; from these articles, 597 were from the Scopus database and 218 were retrieved from Web of Science. The search focus was on articles that discussed the management and governance of inland, fluvial, and pluvial flooding. During the screening, duplicate papers, non-English language articles, articles not relevant to the scope of our review, and papers that were not geographically bounded to the selected areas (the US, the EU and Canada) were excluded. This reduced the number to 380 relevant articles; see Figure 2-2 for

detailed information. It should be noted that in this study, the EU was composed of EU countries which formally included the United Kingdom and Schengen Area in 2018.

Systematic review selection criteria and search database				
Purpose	Identifying drivers of change in flood management			
Questions:	(1) What are the most common and most noted drivers of change that influence FRM? (2) Does FRM recognize or acknowledge the impact of drivers of change?			
Keyword search	*"("Flood Manage*" OR "flood Risk Manage*" OR "Flood govern*" OR "Flood Plan*") AND TS = ("driver* of change" OR trend* OR factor* OR "external force*")) AND LANGUAGE: (English) AND DOCUMENT TYPES: (Article) AND 5YEAR*			
Databases		Web of Science	Scopus	Total
	Date of Search	September 8th 2018	September 21th 2018	
	Searched results	218	597	815
	Full text included			170
Estimate Item after cleaning the data		130-180 articles		
Location		Canada, USA, and EU		
Timeline		From 2013 –To 2018		
Method to conduct the systematic review		Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)		

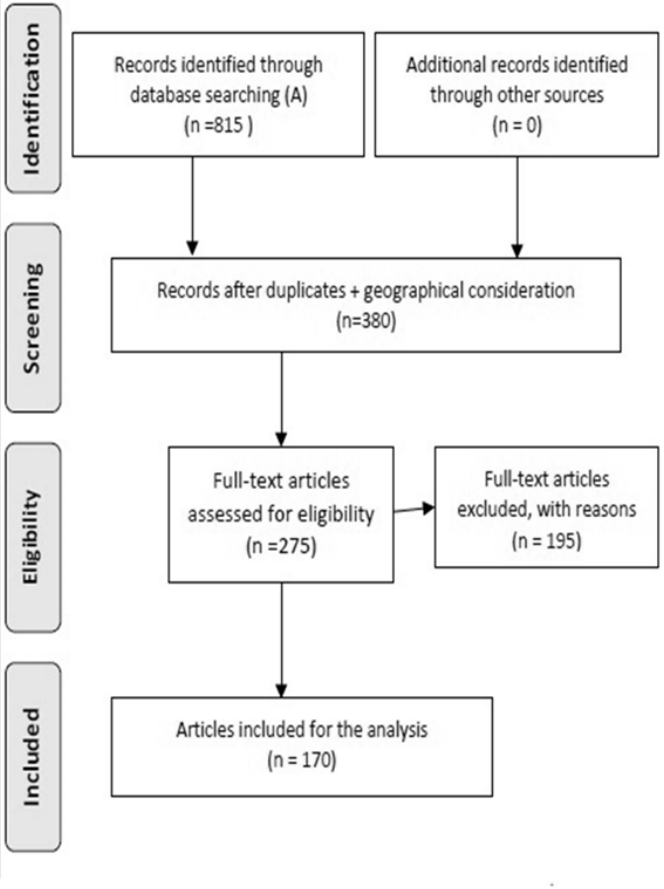

Figure 2-2: PRISMA analysis

The remaining 380 articles were manually examined by reviewing keywords, titles, abstracts, and full text to identify papers discussing FRM and governance with consideration of change, or which included water or land governance issues related to flooding which addressed drivers of change, external forces, or exogenous factors, e.g., Owrangi et al. (2014), Penning-Rowsell and Priest (2015). Articles that focused on detailed engineering, ecology, or agricultural practices were excluded. For example, articles addressing computation design (Kumar et al. 2015), engineering design or ecology (Hanley et al. 2017), or agricultural practices and technology (Pedersen, Perata and Voesenek 2017) were excluded. Articles that solely focused on ocean level rise leadings to coastal flooding were also excluded from the process.

The 170 articles which passed the eligibility screening (see Figure 2-2) were included in the final qualitative analysis conducted using QSRNvivo version 10. The coding process involved a four-step analysis. The first step used a text search query to identify whether a definition for drivers of change (or other similar keywords exogenous forces and external factors) was mentioned by the authors directly. For example, it was common for authors to discuss climate change as a driver of change in the abstract of their papers yet not provide detailed connections to the identified drivers or their direct impact on the subject of study. After reading the full article, we excluded such articles from the process (see Figure 2-2- eligibility section).

The next step involved a detailed thematic analysis of the full text to capture themes using an iterative, mixed deductive, and inductive procedure. As noted in the introduction, our perspective on drivers of change drew on bodies of literature that have a more detailed understanding of “drivers”. For instance, it is common in the business literature to identify external political, economic, sociocultural, technological, legal, and environmental factors that influence business operations and market competitiveness (Perera 2017). From the perspective of ecosystem sciences, the Millennium Ecosystem Assessment Framework (UN-Water 2018, Lemos and Agrawal 2009) focuses attention on a broad range of direct and indirect drivers of ecosystem change. From this broad perspective, each article was analyzed using a coding strategy. Codes contained three elements: 1-a manifestation of an impact on FRM or the potential to change the flood management system. 2- a manifestation as an on-going challenge or future threat to FRM, and 3- a manifestation as multi-organizational or multi-actor concerns. If the code satisfied these three elements, it was considered as a driver of change. For example, several authors stated that specific political views had altered flood management and governance incrementally or disruptively (Becker et al. 2015, Teicher 2018). However, these authors did not directly identify the political views as drivers of change, despite identifying population growth and/or climate change as influential drivers.

Following completion of the thematic analysis, drivers of change with a similar domain of influence or origin were clustered together to create broad categories including, Environment, Policy, Technology, Economic, Social and behavioural change. This step was conducted to report the results in a way that is compatible with the FRM approach in addressing vulnerability and risk assessment (Fernandez, Mourato and Moreira 2016, Sandink et al. 2016). If new categories emerged while coding recent articles, the previously coded articles were re-read and, if necessary, recoded to tailor to the concept so that they represent the finding of all primary. To verify the coding process, a random set including five articles was coded by another researcher using the developed codebook. The results that emerged from the coding were compared to the author

coding; despite some minor variation in codes, the final clusters by both researchers were consistent.

In the final step of the analysis, we assessed interactions between all pairs of drivers of change. Interactions between pairs of drivers were estimated based on the strength of their overlapping articles: no/loose connection contains less than ten overlapping sources; a moderate connection had 10 to 20 overlapping sources; a strong connection had more than 20 sources in common between two drivers of change. For example, there could be a moderate connection between the shift in role and responsibilities (POL1) and an increase in financial pressure (ECO1). In this case, a moderate connection was identified because these themes shared ten common sources, although it should be noted that this does not draw any conclusions with respect to correlation or causation of this interaction or connection in detail (Rollason et al. (2018), Bubeck et al. (2015).

In the process of identifying drivers, two issues emerged. The first issue occurred when there was an overlap among identified drivers. To resolve the issue, the article was carefully reviewed to identify the main driver. If the overlap was unresolvable, the paragraph in the article was coded for both drivers of change. The second issue was related to the depth of the connection and interaction between two drivers of change. In these cases, the coding process could identify the interaction between two drivers of change, but the depth of the impact or interaction of these drivers on the actual FRM could not be measured. Categories and their interactions are presented in the Results section of this paper.

2.4 Result

A total of 170 peer-reviewed journal articles published between 2013 and 2018 were selected using the PRISMA method (see Figure 2-1 and Figure 2-2). There was a gradual increase in the number of published articles since 2013, with approximately 60% of the articles being published after 2016. FRM has attracted more attention in recent years because it provides new ways of addressing change through the lens of new discourses such as adaptation, risk management and resiliency (Rollason et al. 2018, Aerts et al. 2018, Bubeck et al. 2015, Morrison et al. 2018b, Penning-Rowsell and Priest 2015, Van Buuren et al. 2016, Plummer et al. 2018, Serra-Llobet et al. 2016). The results of our research are presented here in three parts. The first part focuses on the most noted drivers that are directly linked to the increased risk of flooding identified by the text search query (see Figure 2-3). The second part examines five categories that emerged through thematic analysis, which can be interpreted as drivers of change in FRM (see Figure 2-3). The third part examines the connection and interaction between pairs of drivers of change.

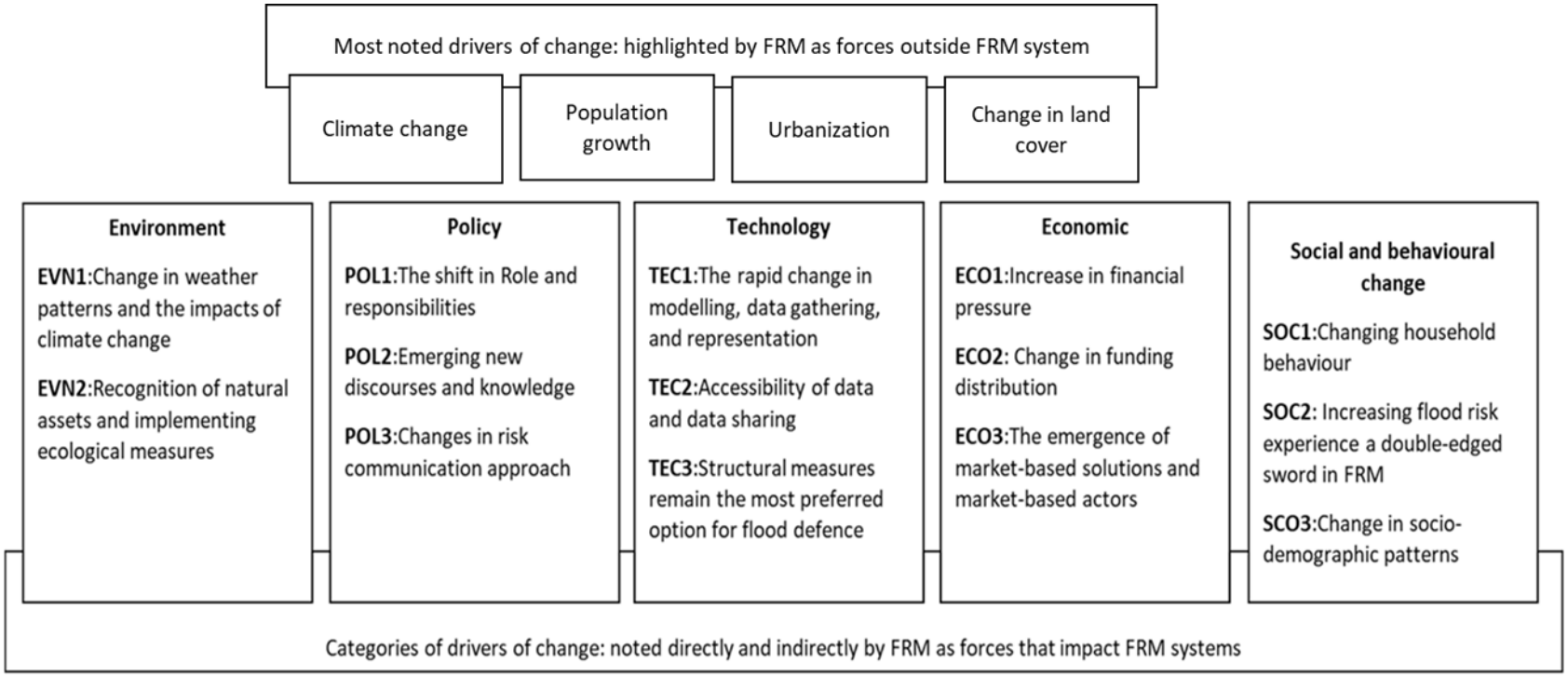

Figure 2-3: Direct and indirect drivers of change

2.4.1 Most commonly noted drivers of change

Drivers of change were directly identified in 95% of the 170 articles examined. Climate change (including changes in weather patterns, rainfall events, and precipitation intensity) is the most recognized driver of the risk of flooding in 89% of the articles. Population growth (46%), urbanization (27%), and change in land cover (including land-use change, increase in permeable land cover, and loss of vegetation) (18%) were the most noted drivers of change after climate change (see Figure 2-3). The result of the search term analysis showed that the most noted drivers are portrayed as "global challenges" since they posed a threat to all selected regions, including the EU, the US, and Canada. In addition, drivers of change were identified as factors that negatively impacted the risk of flooding by increasing exposure and vulnerability in several articles (Shao et al. 2017, van der Pol, van Ierland and Gabbert 2017, Francesch-Huidobro et al. 2017). Frequent use of keywords such as "factors," "forces," and "drivers of change" revealed an existing awareness and recognition of drivers of change and their impact on FRM. Importantly, in the FRM literature analyzed in this study, a common definition or a set of characteristics that could provide a more precise description of drivers of change was not identified.

2.4.2 Categories of drivers of change

From the broad perspective of drivers of change that underpins the study, we analyzed the 170 articles to identify factors that should be considered drivers of change but were not specifically identified as such by the study authors. Fourteen distinct drivers of change emerged from our thematic analysis of the 170 articles. These are organized into five key categories based on their similarities in topics and subjects (see Table 2-2).

Table 2-2: Drivers of change- categories and themes

Categories	Number/ Percentage	Drivers of change	Description of the driver of change and domain of influence	Scale of influence	Number/ Percentage
Environment	92%(156)	ENV1: Change in weather patterns and the impacts of climate change	Change in patterns of a rainfall event, temperature, severity of rainfall events and peak flows Increasing uncertainty, The impact is distributive	Global Regional	**155 (91%)**
		ENV2: Recognition of natural assets and implementing ecological measures	Acknowledging the role of vegetation and natural assets in the water cycling process in developing new technologies and strategies. Barriers and uncertainties of using new technologies The impact is more incremental	Local	**25 (14%)**
Policy	88% (149)	POL1: The shift in roles and responsibilities	The change in the influence of the state, river basin organization, local level government and private property owner in FRM The impact of this driver is incremental.	State to local	**69 (40%)**
		POL2: Emerging new discourses and knowledge	FRM as an integrated approach (spatial planning and engineering) works with new discourses, adaptive governance and resiliency The impact of this driver is incremental.	Global to local	**63(37%)**
		POL3: Changes in risk communication approach	The nature of the risk is changing Sharing relevant information (time, location, and type of incident) and providing Participation opportunities The impact can be both incremental and disruptive	Local	**50 (30%)**

Technology	72%(122)	TEC1: The rapid change in modelling, data gathering, and representation	New sets of modelling, data collection, new ways of mapping. Selection of models and combining models to reduce uncertainty The impact can be both incremental and disruptive	Global to local	**49 (28%)**
		TEC2: Accessibility of data and data sharing	Degree of information to share among different actors Data transformability and accessibility The impact can be both incremental and disruptive	Global to local	**65 (38%)**
		TEC3: Structural measures remain the most preferred option for flood defence	Structural measures usually win the rebuild design for flood defence, especially after an event There are more public trust in the conventional management approach The combination of water management strategies can reduce the risk of failure of structural measures	State to local	**80(47%)**
Economic	66%(112)	ECO1: Increase in financial pressure	Increase insured and uninsured damages The pressure might/had impacted the higher-level scale of the international and national financial situation The impact can be both incremental and disruptive	Global to local	**80 (46%)**
		ECO2: Change in funding distribution	Change in State strategies in funding FRM measures Limited budget of the lower-level government. The need for smart investment and return on investments The impact can be both incremental and disruptive	Global/state to local	**74 (43%)**
		ECO3: The emergence of market-based solutions and market-based actors	Designing an effective flood insurance Creating a self-regulating arrangement between private actors (banks, lenders, developers, and property owners) and levels of government The impact is more incremental	Global to local	**56 (33%)**

Social Behavioural change	53%(90)	SOC1: Changing household behaviour	The need to change household behaviour to have better risk awareness by Providing incentives Participation in community engagement The impact is more incremental	Local	**60 (36%)**
		SOC2: Increasing flood risk experience a two-edged sword in FRM	The degree and extent of a flood can impact the way in which households react to floods. The impact can be both incremental and disruptive	Local	**30 (18%)**
		SOC3: Change in socio-demographic patterns	An ageing population coupled with Immigration and multiculturalism. Socio-economic conditions (e.g., willingness to take the risk) The impact is more incremental	Global to local	**40 (23%)**

2.4.2.1 Environment

"Environment" is the most frequently noted category and was identified by more than 92 % of the articles reviewed in this study (see Table 2-2). There are two major drivers of change in this category: change in weather patterns and the impacts of climate change (91%) and recognition of natural assets and implementation of ecological measures (14%).

Change in weather patterns and the impacts of climate change (ENV1 in Table 2) is characterized differently among the articles. For example, Francesch-Huidobro et al. (2017, 3) defined the concept of climate change as "the variation of a zone's weather pattern, which is attributed directly or indirectly to human activity". In contrast, Gocht and Meon's (2016, 1) study of the impact of climate change on FRM and reservoir management defined climate change as lowering the confidence "in numerical projections of changes in flood regimes". The lack of consistency in these and other similar articles highlighted the need to define or categorize drivers of change in FRM. A consistent definition facilitates developing clear benchmarks and metrics to evaluate the impact of drivers of change in FRM and governance (Gocht and Meon 2016, Albano et al. 2015, Bubeck et al. 2015, Penning-Rowsell and Priest 2015, Teicher 2018, Bloemen et al. 2018).

Recognition of natural assets and implementation of ecological measures (ENV2) is gaining prevalence in the discourse of resiliency and adaptive governance (Bloemen et al. 2018, Morrison et al. 2018b). Alternative approaches (green infrastructure, green-blue approaches) have been developed utilizing natural assets (e.g., retention capacity of river floodplains, wetlands, and urban forests) and new engineered green technologies (e.g. green roofs, engineered wetlands, permeable surfaces). In our research, we observed these approaches were always complementary to structural methods in addressing the risk of flooding. Cases in Canada and the US promote the combination of structural and alternative approaches in reducing the risk of flooding. (Baird et al. 2016, Waylen et al. 2018, Halbe et al. 2018, Huq 2016, Plummer et al. 2018). To encourage these approaches and manage trade-offs, the support of governance in developing policies that prioritize the use of alternative approaches (e.g., EU Water Framework Directives and EU Flood Directive) is critical (Halbe et al. 2018, Huq 2016).

2.4.2.2 Policy

"Policy" is the second most noted category, with 88% of articles identifying policy-related drives that impact FRM. Within this category, a shift in role and responsibilities (69%), emerging new discourses and knowledge (63%), and risk communication alteration (50%) were identified as the three main drivers of change (see Table 2-2).

A shift in role and responsibilities (POL1) highlights the increase of the pressure on harnessing the abilities of river basin organizations, local level governments, and private property owners to address the risk of flooding. (Penning-Rowsell and Priest 2015, Plummer et al. 2018, Van Eerd, Wiering and Dieperink 2017, Serra-Llobet et al. 2016). For example, German states that have a central role in FRM used initiatives, change in power and delegating the responsibilities, and funding from the EU Water Framework Directives and the EU Flood Directive to create various governance models in which municipalities, water management

agencies, and other public and private actors within or neighbouring a river basin district collaborate to implement FRM plans (Hartmann and Spit 2016).

Emerging new discourses and knowledge (POL2) accounted for 63% of articles. These addressed persistent failures caused by viewing flood risk management from a pure engineering approach, as well as increasing tangible and non-tangible damages. This driver of change highlights the empowerment of new discourses (resiliency, adaptive governance, and risk management), new technologies, and approaches to reduce risk and exposure (Morrison et al. 2018b, Bergsma 2018, Bloemen et al. 2018). These discourses have validated a specific set of knowledge, practices, governance models, and power relations that have impacted FRM (Bergsma 2016, Rollason et al. 2018, Van der Most et al. 2018, Waylen et al. 2018).

Changes in risk communication methods (POL3) were noted by 50% of articles presented as drivers of change. Methods and tools through which risk information has been disseminated are constantly evolving and causing difficulties for FRM practices. FRM are challenged to select and use fast, reliable, cost-efficient platforms or tools to communicate with their audience (Benson, Lorenzoni and Cook 2016, Buchecker et al. 2013, Haer, Botzen and Aerts 2016, Seebauer and Babcicky 2018). Being up-to-date and keeping up with the change in platforms and tools for communication has proven to be challenging and costly for some river basin organizations and local level governments (Seebauer and Babcicky 2018, Haer et al. 2016). Nonetheless, clear, timely, and accessible information creates knowledge-sharing opportunities between public and local governments and helps to build trust while facing a high degree of uncertainty and risk (Rollason et al. 2018, Seebauer and Babcicky 2018, Mann and Wolfe 2016, Haer et al. 2016).

2.4.2.3 Technology

"Technology" is a very broad category in FRM. It should be noted that the scope of the selected articles was focused on governance, policy, and management. Considering the scope of data collection, the detailed engineering advancements and techniques related to flood defence and structural measures (e.g., geotechnical enforcement of levees) stayed outside the scope of our research. The three main drivers of change that emerged in this category are the rapid change in modelling, data gathering and representation (49%), accessibility of data and data sharing (38%), and structural measures remain as the most preferred option for flood defence (47%) (Table 2).

The rapid change in modelling, data gathering, and representation (TEC1) is linked to the rapid advancement in sensing, transmitting, computing, and data analysis technologies that allow capturing the status of the natural environment to be captured in great detail (e.g., monitoring river water levels in real-time) (Albano et al. 2015, Bloemen et al. 2018, Zevenbergen et al. 2013, Hino and Hall 2017, O'Connell 2017, Thorne et al. 2018). Advancement in hydro informatics resulted in detailed hazard maps in Canada, the US and the EU. In addition, the EU Flood Directive promotes the shift towards FRM in practice by introducing new instruments such as FRM plans (Hartmann and Driessen 2017, Hartmann and Spit 2016).

Accessibility of data and data sharing (TEC2) highlights the rising concerns over raw data collection (crowdsourcing, third party collection, self-reporting), quality of the data, ownership of data, privacy, transformability (open source, storage option, backup) and cybersecurity (Dessers et al. 2015, Krieger and Demeritt 2015, Demeritt and Nobert 2014, Albano et al. 2015, Morrison et al. 2018a, Merz et al. 2015). Finally, structural measures remain the most preferred option for

flood defence (TEC3), which sheds light on the concerns around the uncertainty of using new methods and the unknown risk attached to their use. This driver highlights the fact that among all the technological advancements and new approaches in FRM, reliance on solutions focusing on structural measures (47%) is still the most preferred option for flood defence following a flood event (Becker et al. 2015, Bergsma 2018, Dessers et al. 2015, Gralepois et al. 2016, Buchecker, Ogasa and Maidl 2016). Reliance on using only structural measures calls for robust governance efforts to promote policies and co-produce solutions that include both structural measures and new approaches (Francesch-Huidobro et al. 2017).

2.4.2.4 Economic

The "economic" category contains drivers of change that have emerged from changes in policy instruments to address increasing tangible and intangible loss and financial pressures. Three drivers of change were identified, namely an increase in financial pressure due to flood damages (46%), changes in funding distribution and rethinking the use of available funds (43%), and the emergence of market-based solutions and market-based actors (33%) (Table 2).

An increase in financial pressure due to flood damages (ECO1) arises in both insured and uninsured losses and represents a major challenge to FRM. At the same time, the projection does not show any relief in losses, as they have been estimated to increase more than twofold in some cases (Henstra and Thistlethwaite 2017, Penning-Rowsell and Priest 2015, Penning-Rowsell and Pardoe 2015, Filatova 2014). To manage the growing financial pressures, governments have diversified FRM funding and tried to develop governance systems that share the risk of flooding among public and private actors (Thorne et al. 2018, Dieperink et al. 2016, Vojinovic et al. 2016, Alexander et al. 2016, Plummer et al. 2018, Surminski and Thieken 2017).

Changes in funding distribution and rethinking the use of available funds (ECO2) discuss how funds have been redistributed from state-provided structural protection funds to public and private funds focusing on climate adaptation and resiliency (Thaler and Levin-Keitel 2016, Penning-Rowsell and Pardoe 2015, Thorne et al. 2018, Dieperink et al. 2016). While these funds cover flood mitigation and risk reductions at a local or municipal level, the diversification of alternatives, limited budget, and lack of resources have put pressure on localized FRM (Alexander et al. 2016, Rollason et al. 2018, Francesch-Huidobro et al. 2017, Penning-Rowsell and Priest 2015, Albano et al. 2015). To implement alternative measures, which include land use and spatial planning, relocation from flood hazard areas, flexible infrastructure design, collaboration with the insurance industry, forecasts, early warning and communication, and updating building codes, localized FRM actors need to rethink the structure of their financial resources. This driver of change conveys implications for flexible governance arrangements that can mobilize funding’s and allocate financial resources among different alternatives in an efficient, transparent and timely manner (Rollason et al. 2018, Seebauer and Babcicky 2018, Surminski and Thieken 2017, Krieger and Demeritt 2015, Penning-Rowsell and Pardoe 2015, Filatova 2014, Todini 2017, Pathak and Eastaff 2014).

The emergence of market-based solutions and market-based actors (ECO3) highlights the need to rethink localized FRM budgeting and financial systems, which have provided momentum for creating a self-regulating arrangement between private actors (banks, lenders, developers, and private property owners) and various levels of government to reduce exposure and implement flood damage mitigation measures (Petridou and Olausson 2017, Hegger et al. 2016, Milman and

Warner 2016, Krieger and Demeritt 2015, Penning-Rowsell and Priest 2015, Hegger et al. 2014). The UK FRM approach formed around solutions that utilize the financial capacity of both public and private actors to cope with trends in flood risk (Filatova 2014, Plummer et al. 2018, Baird et al. 2016, Surminski and Thieken 2017, Penning-Rowsell and Pardoe 2015, Botzen and van den Bergh 2008). Nonetheless, the lack of information and a limited number of successful and replicable cases to support the cost-effectiveness of private flood damage mitigation limits the implication for FRM (Filatova 2014, Hino and Hall 2017).

2.4.2.5 Social and behavioural change

"Social and behavioural change" is identified as a driver in 53% of articles. This category is gaining momentum in climate change adaptation and resiliency literature (Penning-Rowsell and Priest 2015, Osberghaus 2017). Changing household behaviour (36%), increasing flood risk experience as a two-edged sword (30%), and change in socio-demographic patterns (40%) are the three drivers of change identified in this category (Table 2).

Given that the nature of risk is changing, 36% of articles noted that household behaviour (SOC1) needs to be adjusted to increase resiliency (Slavikova 2018, Oulahen et al. 2015, Penning-Rowsell and Pardoe 2015). The need to change household behaviour to withstand mounting uncertainties has put pressure on FRM strategies to develop policies and programs to help households understand the benefits of risk reduction measures, to raise awareness on various types of flood hazard (e.g., riverine, sewage backup, flash floods), and to implement preparedness measures to address the risk (Aerts et al. 2018, Becker et al. 2015, Thaler et al. 2017, Osberghaus 2017). Changes in household behaviour are closely linked to understanding an individual's risk perception. Risk perception is the individual’s assessment of a threat with respect to its probability and potential damages. Several articles argued that the way in which an individual takes action and reacts to a flood event depends on the individual's risk perception (Seebauer and Babcicky 2018, Mann and Wolfe 2016, Milman and Warner 2016, Oulahen et al. 2015, Merz et al. 2015). Assessing the individual’s risk perception has implications for risk communication and identifying the most vulnerable groups with the least knowledge or ability to undertake mitigation measures (Osberghaus 2017, Aerts et al. 2018).

With the overall increase in flooding, the number of households that experience a flood event is also on the rise. Increasing flood risk experience as a two-edged sword (SOC2) is a driver of change that has impacted flood policy and management, with 30% of articles noting that increasing the flood risk experience is a two-edged sword. This is because flood experiences are not always considered as a positive factor in FRM and the severity and extent of a flood event or flood damages will impact the way in which households react to a flood in the future. Several studies showed that if the flood experiences/emotions/ memories were too hard to confront, households were either less reactive to the situation, or they felt helpless and were unable to take any action to reduce the risk or recover from the event (Aerts et al. 2018, Haer et al. 2016, Bubeck et al. 2015, Fuchs et al. 2017, Hopkins and Warburton 2015, Krieger and Demeritt 2015).

Changes in socio-demographic patterns (SOC3) alter social risk and vulnerabilities, particularly in urban areas. Several studies connected socio-demographic factors such as age, gender or income, previous flood experience, and risk perception as impacting household behaviour with respect to judging flood risks, evaluating their coping abilities, and taking action, which has important implications for vulnerability and risk assessment and governance (Aerts et

al. 2018, Krieger and Demeritt 2015, Filatova 2014, Kellens, Terpstra and De Maeyer 2013, Mann and Wolfe 2016).

2.4.3 Interaction among categories and themes

The fourteen drivers of change identified in Table 2 do not exist independently of each other; they coexist and interact across levels and scales (e.g., temporal or spatial). Thus, we examined interactions among these drivers of change and their categories (see Figure 2-4). Interactions between pairs of drivers of change were explored by examining the number of shared articles in the analysis. These interactions shed light on the dynamics, connection pattern, coherence, and commonality of the drivers of change in a social-ecological system (see Figure 2-5). The analysis includes eleven interactions with "strong connection", which means two drivers were mentioned in 20 or more common sources. Fifteen interactions were categorized as having a moderate connection, which means two drivers shared between ten to twenty common sources. The remaining interactions between the two drivers of change had "no or loose connection", meaning that they shared less than ten common sources.

Among drivers of change, the change in weather patterns and the impacts of climate change (ENV1) had the strongest connection with other drivers of change (see Figure 2-5). Numerous articles highlighted that changes in weather patterns and the impact of climate change have a strong connection to at least one of the other identified drivers, including Bergsma (2018), Aerts et al. (2018), Henstra and Thistlethwaite (2017), Francesch-Huidobro et al. (2017), Hino and Hall (2017). Changes in weather patterns and the impacts of climate change (ENV1) shift the nature of risk and alter trends in policy, economic and social and individual behaviour. An increase in financial pressure (ECO1) had the most interaction with other drivers of change emerging in policy, technology, and social/ behavioural change categories (see Table 2-2). Several studies linked the increase in financial pressure to growing pressures on current FRM systems to probe new policies, discourses, or alternative approaches to develop community resilience and reduce risk (Ran and Nedovic-Budic 2016, Difrancesco and Tullos 2015).

Recognition of natural assets and implementation of ecological measures (ENV2) was usually discussed from a physical point of view (e.g., the benefits of natural retention processes or as a tool to reconnect and increase the area available for flood water storage). However, a limited number of articles drew connections between ENV2 and other drivers in policy, social/ individual behaviour, and technology (see Figure 2-5). For example, Fraser and Storie (2016) tied the physical concept of using wetlands as natural assets in FRM to socio-economic dimensions. Besides the physical characteristics of the soil, land and location, the cost of land, and the collaboration between landowners, flood managers, and the local level administration also impacted the implementation of ecological measures to reduce risk in FRM (Vojinovic et al. 2016, DiFrancesco and Tullos 2014).

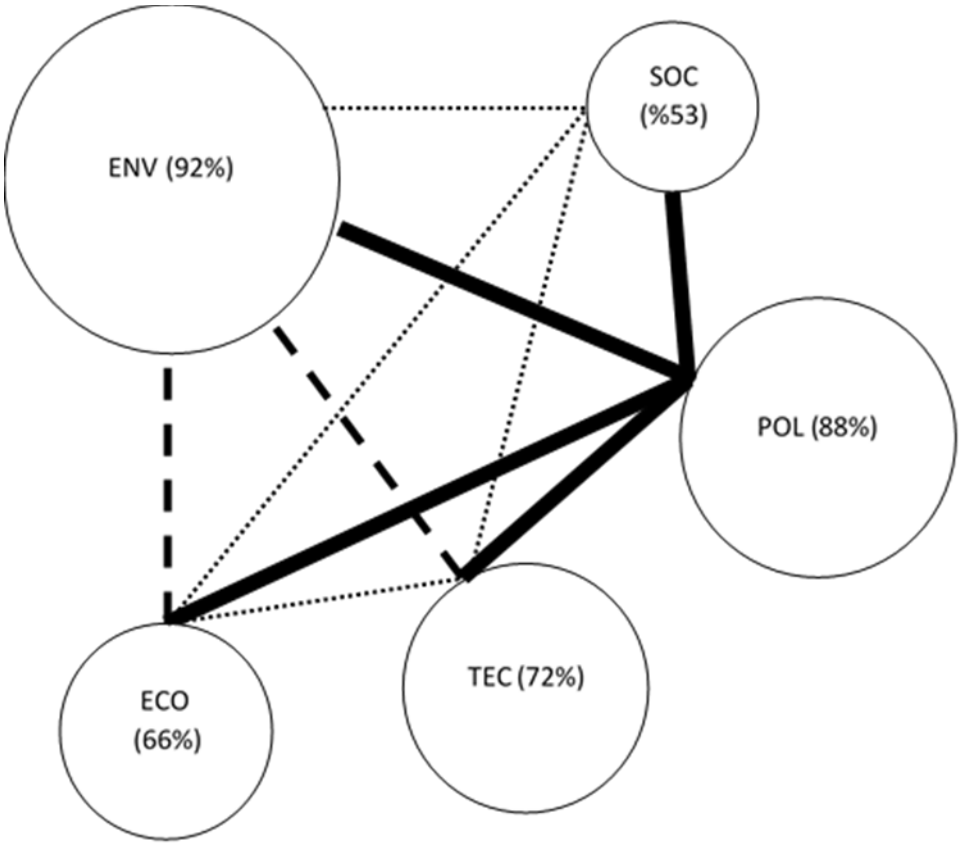

Figure 2-4: Interaction between each two categories

Rapid changes in modelling, data gathering, and representation (TEC1) is an example of a driver with low interaction (see Figure 2-5). This driver was mostly focused on the disciplinary point of view and technological advancement to improve quantitative risk assessment and flood forecasting. The lack of interaction between TEC1 and drivers of change in the policy category suggests that this is an area for potential opportunities to integrate the TEC1 with policy and social dimension FRM in a research and policy setting. Examining the interaction dynamics between two drivers of change shed light on various dimensions of FRM and highlight disconnectedness or lack of integration between these dimensions in the governing system and among actors. Understanding interaction dynamics provides a holistic view through which the resources and funds can be mobilized and collaboration with public and private actors can be strengthened to reduce risk and vulnerability.

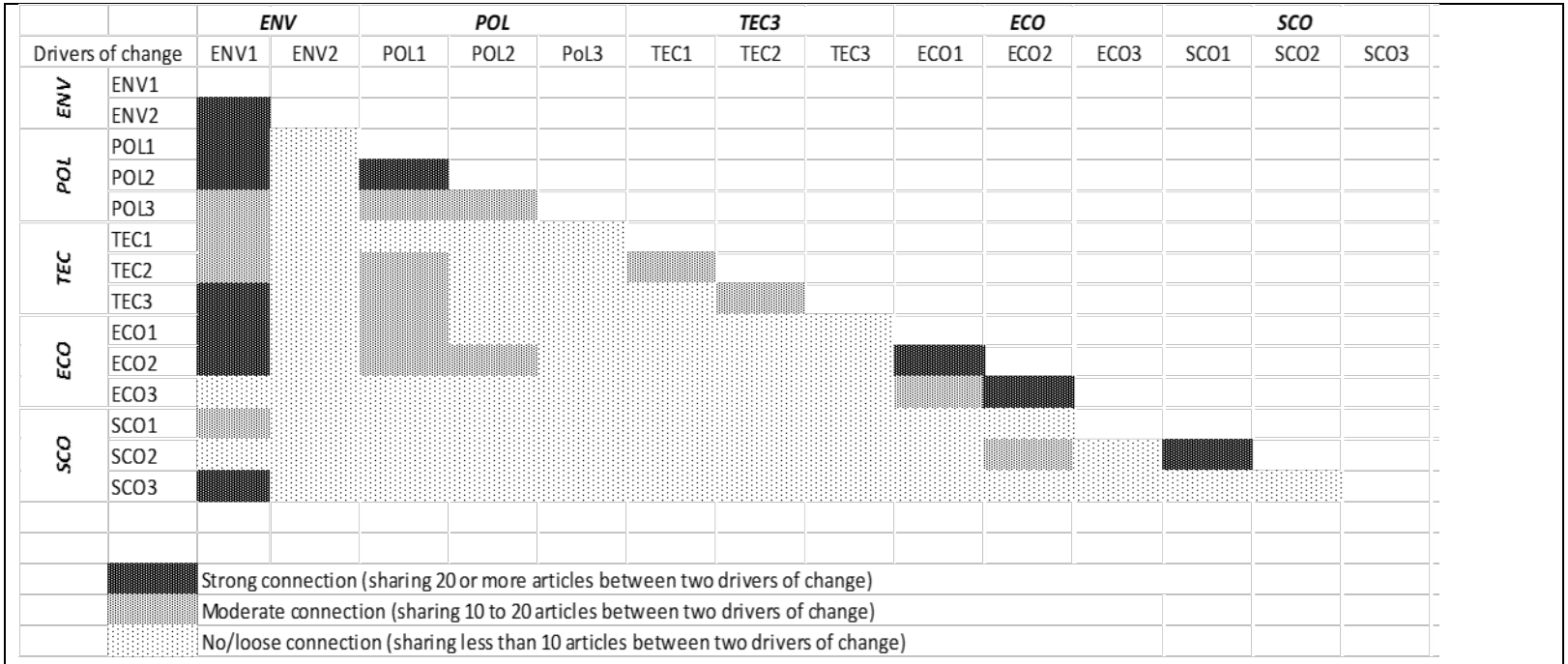

Figure 2-5: Interaction between pairs of drivers of change

2.5 Discussion

This analysis highlights that FRM literature directly points to the most noted drivers of change, including climate change, population growth, urbanization (see Figure 2-3). The most noted drivers are usually portrayed as global challenges outside the scope of FRM or governance, despite having a noticeable impact on the flood hazard and vulnerability at a local level. Defining and categorizing drivers of change facilitates identifying direct and indirect drivers that exist in different levels and scales (temporal and spatial). Identifying drivers of change is the first step to explore pathways to account for them and their influence considering current FRM capacity. This analysis also concluded that the awareness of drivers of change and their impacts on FRM is increasing. The increasing awareness can be leveraged to co-develop solutions using governance approaches according to current FRM efforts (see Table 2-3).

2.5.1 Increasing awareness and drivers of change impact

Our analysis shows that 95% of authors acknowledge the influence of drivers of change in their work and practice. However, the ways in which these drivers or their influence can be addressed by FRM was often outside the scope of these papers; this is a limitation of FRM research, as pointed out by (Bloemen et al. 2018, Thaler et al. 2017, Wiering et al. 2017, Serra-Llobet et al. 2016, Huq 2016). The emergence of most noted drivers highlights those drivers of change are deeply intertwined with FRM systems in social, economic, and environmental contexts. Our analysis also sheds light on significant gaps in defining and categorizing drivers of change or weighing their impact on the probability of the flood hazards or the consequences of the occurrence of flood events. Identifying drivers of change, their influence, and their evolution will assist in constructing these external issues into more defined problems that specify the source of the problems, as well as assisting in identifying the courses of action that can be addressed by FRM.

Most noted drivers of change (e.g., climate change and changes in land cover) are altering the nature of flood risk (Morrison et al. 2018a, Hino and Hall 2017, Gralepois et al. 2016). Problems become apparent when hazards and damages are increasing despite having adequate flood management in place (ECO1). An increase in flood damages puts pressure on the limited available funds and also divides policymakers, voters, and engineers when choosing between various scenarios (e.g., leaving the flood-prone areas to build and strengthen dykes, levees, and other structural measures) and deciding who should bear the responsibility (PO1). Although much progress has been made in integrating the consideration of broader issues into FRM policy and decision making, many countries and cities are still heavily investing in structural measures for flood defence (TEC3). Path-dependency in mitigating the risk of flooding and the impacts of drivers of change both hinder the ability of FRM to address future flood events (Wiering et al. 2017, Van Buuren et al. 2016, Filatova 2014).

The success or failure of FRM is closely related to an understating of the level of risk across various layers of social-economic systems and an understanding of how individuals perceive and respond to the risk (SOC1 and SOC2). Emerging discourses that focus on adaptive governance and resiliency (PO2) emphasize the fact that solely being aware of drivers of change is not sufficient; flood risk must be viewed from a perspective that considers drivers of change in the

context of complex social-ecological systems. To develop a holistic approach that absorbs undesirable changes in these complex social-ecological systems, acknowledging drivers of change is an important first step (Winsemius et al. 2016, de Loë and Patterson 2017c). Researchers and decision makers should have a nuanced understanding of how drivers of change can shape and alter social-ecological systems incrementally or disruptively, which can present potential implications for governance in co-developing more concrete and more solution-oriented approaches (see Table 2-3) to FRM (Lewison et al. 2016, Chapman 2014).

2.5.2 Co-develop solutions by understanding drivers of change

To transform the existing awareness of drivers of change in FRM into action in institutional and policy settings and to understand their potential implications, an important step is to establish a common approach to the definition of these drivers. A clear definition will allow researchers to categorize drivers in various forms, develop indicators, and evaluate and examine drivers and their impact on FRM systems (see Table 2-3). Our analysis using a systematic review of FRM articles in Canada, the US, and the EU offers a possible definition for a "driver of change" and one way of identifying and categorizing drivers of change. Identifying, describing, and categorizing drivers of change is the first step to conducting an in-depth analysis. The next step is then to develop qualitative or quantitative indicators that can be measured and compared in temporal and spatial scales. After developing these indicators, a third step is the evaluation of the interaction among drivers of change and social-ecological systems, which has direct implications for governance, including identifying and supporting approaches to share information and compare successful and replicable cases to support cost-effectiveness, resilient, and adaptive solutions to flood damage mitigation (see Table 2-3).

Conducting a full examination of the impact of drivers of change on FRM institutions and policies in specific places will be a lengthy process considering the complexity of FRM systems. The complexity of FRM systems is reflected in the diversity of FRM literature, which covers a broad spectrum of subjects in social and physical sciences (Morrison et al. 2018b). There are many disciplinary, multi-disciplinary, and transdisciplinary research projects underway which seek to understand multiple dimensions of FRM. In our analysis of the interactions among drivers of change, we identified disconnectedness between FRM studies. For example, there is no/loose connection between drivers of change in technology and drivers of change from economic categories. Specifically, there is a strong disconnect between the second theme in the environment category (ENV2: the recognition of a natural asset and the implementation of ecological measures) and change in social and behavioural change. At first glance, this disconnectedness can be viewed as a separation of research on social and physical subjects (Morrison et al. 2018b). However, there is a need for an in-depth analysis of these interactions because, in some cases, efforts to reduce the risk of flooding seem contradictory and are not supported by all actors in FRM. The examples of these problems emerge in selecting flood defence policy and tools as well as other cases which are included in (Thorne et al. 2018, Osberghaus 2017, Babcicky and Seebauer 2017, Penning-Rowsell and Pardoe 2015)

Table 2-3: Example of a co-development process

First step			Second step	Third step
Category	**Driver of change**	**Scale of influence**	**Potential indicators**	**Pathways to address the impact of drivers of change in FRM**
Policy	POL3: Changes in risk communication approach	Local	Identifying the most used mode of communication (e.g., cellphone or printed media) The potential rate of change in the mode of communication in the community The potential rate of change to the tools which is used the mode of communication (e.g., the emergence of different apps and rate of uptake by community members for cellphone) The cost of updating current methods risk communication (e.g., the cost of printing vs the cost of having and operating a website or social media accounts	Adding these as outreach challenges to vulnerability assessment. Creating flexible flood risk communication, the can work in multiple platforms targeting diverse audiences by collaborating with the tech industry and community leaders
Economic	ECO2: Change in funding distribution	Global/state to local	Categorizing funding distribution for each program. Funding characteristics for mapping and modelling: i: sources (public, private); ii- timeline (long-term- midterm, short terms); iii- stability of funding (government funding which can be eliminated by the next election, private fund which is related to market performance); and iv-the probability of change (what are the chances of losing/fund reduction).	Providing a vulnerability assessment for the flood-related programs and their funding. Providing business cases (e.g., generating funds for reinvestment and linking costs to revenues) for each program and their impact on potential financial damages

The review of projects and research initiatives across Canada, the EU, and the USA (see Table 2-1) sheds light on the fact that water governance is equipped with the tools and means to address some of the emerging conflict aggravated by drivers of change (Raadgever et al. 2018, Bergsma 2018, Morrison et al. 2018b, Seebauer and Babcicky 2018, Hartmann and Driessen 2017, Henstra and Thistlethwaite 2016a, Serra-Llobet et al. 2016, Thaler and Levin-Keitel 2016). For instance, governance actors have provided solutions for the conflict between the public preference for structural flood defence investments (TEC3) instead of long-term non-structural and ecological measures (ENV2) (Buchecker et al. 2016, Buchecker et al. 2013). A governance perspective can offer insights for FRM systems with respect to bridging gaps between identified silos, integrating diverse and complex considerations, and developing definitions and metrics to examine the impact of drivers of change (Räsänen et al. 2018, Raadgever et al. 2018, Aerts et al. 2018, Morrison et al. 2018b, Serra-Llobet et al. 2016, Dieperink et al. 2016).

By working with institutions and actors in a wide range of political, social, economic, technological, and administrative systems to develop and manage resources, governance has delivered policy objectives and built flood resiliency at different scales. In EU research initiatives (e.g., FLOODsite, Flood Risk Management Research Consortium, STARFlood), analysts highlight the importance and potential room to increase the role of governance (see Table 2-1) in reducing risk in FRM and address the impact of drivers of change (Wiering et al. 2017, Hegger et al. 2016, Alexander et al. 2016). These research initiatives can also facilitate the development of typology to understand current FRM systems and how they are impacted by forces outside the systems (e.g., climate change). With this, water governance approaches can be developed to guide adaptation strategies to face drivers of change and enhance the efficacy of available policy instruments through which actors, institutions, and strategies can be bridged (Bergsma 2018, Morrison et al. 2018b, Francesch-Huidobro et al. 2017, Serra-Llobet et al. 2016).

2.6 Conclusion

The landscape of FRM is rapidly changing, and pressure from drivers of change adds to the complexity and uncertainty (Hartmann and Driessen 2017, Henstra and Thistlethwaite 2016a). Drivers of change are emerging in diverse categories to impact FRM (Winsemius et al. 2016, Francesch-Huidobro et al. 2017, Hino and Hall 2017, Gocht and Meon 2016, Zevenbergen et al. 2013). Current and future drivers of change (e.g., change in weather patterns and the impacts of climate change), as well as their interactions with other drivers of change in various scales, are still poorly understood. This analysis shows there is awareness of the impact of drivers of change within the FRM research community, particularly over the five years between 2013-18, and specifically with respect to how drivers of change have posed challenges to FRM institutional structures, modelling, and planning. Our analysis also reveals changes in economics (change in funding) and engagement strategies (more substantial presence of market-based actors) in organizing institutions and supporting FRM implementation. Furthermore, our research reveals the lack of integration among drivers of change and FRM research and suggests a method to better understand drivers of change that can be achieved by examining other disciplinary and interdisciplinary research such as ecology and management studies.

To address the increasing risk of flooding and to account for the impact drivers of change, FRM must bridge social, economic, environmental, technological, and political (policy)

dimensions to reduce tangible and intangible damages of flooding. By transforming the existing awareness of drivers of change to action, FRM has the potential to achieve the "desired outcomes of resilience, efficiency and legitimacy" using water governance approaches (Hegger et al. 2018). To be successful in transforming the drivers of change awareness, understanding the changing nature of the risks and their drivers are essentials. Developing consensus-based definitions for drivers of change and using interdisciplinary and transdisciplinary approaches to build indicators to evaluate both the physical and social dimensions of FRM can facilitate the transformation. In addition, to move beyond raising awareness on drivers of change, collaborating with actors, experts, politicians, and the public while revisiting current FRM institutions, procedures, rules, and resources to account for drivers of change and their impact can reduce risk and increase resiliency in affected communities.

Chapter 3

Identifying adaptation opportunities to account for drivers of change in a complex flood management system

3.1 Introduction

The risk of flooding in urban areas is worsening due to increasing impervious surfaces, property values, and intensification (Alaerts 2019, Berndtsson et al. 2019). Despite governance and flood risk management (FRM) attempts to reduce tangible (financial losses) and non-tangible (e.g., mental health issues) damages, the water-related challenges are persistent and property values at risk of flooding are increasing (IBC 2020b, IBC 2014). Recently, the Province of Ontario and the City of Toronto have faced numerous flood events (McNeil 2020). The 2013 flood, with approximately $1 billion losses, is the most noted event because of the severity of the economic damages (Feltmate and Moudrak 2021). In 2019, Toronto residents also experienced heavy rainfall, which impacted critical infrastructure (CI), including major highways and public transportation systems (IBC 2020).

Scholars and practitioners have linked challenges and shortcomings in governance and FRM to key drivers of change and their impacts that usually stay outside FRM and governance systems (Owrangi et al. 2014, CWN 2018, Morrison et al. 2018a). In broad terms, we define drivers of change as a natural or human-induced factor that directly or indirectly causes a change in the risk of flooding or the ways in which flooding is managed or governed. Drivers of change alter conditions (e.g., winter frost timelines) and baselines (e.g., lake levels) that enable or constrain FRM and governance efforts (Winsemius et al. 2016, United Nations Environment Programme 2007, Bloemen et al. 2018, Serra-Llobet et al. 2016).

Addressing increasing damages and values at risk are significant challenges for FRM in cities. Researchers and decision makers involved in FRM in the private and public sectors have questioned the success of current flood management approaches to mitigate the increasing financial pressure and to reduce flood damages (Thistlethwaite 2017, Oulahen 2021, Mann and Wolfe 2016, Halbe et al. 2018, Cutter et al. 2018). This paper is the second part of a broader research project that examines drivers of change and their impacts on FRM to shed light on ways to restructure actors' interactions and to contribute to better accounting for risks. The first part of the research project (Chapter Two) is a systematic review of literature in which definitions and categories of drivers of change emerged. It provides the foundation for this paper, where we explore drivers of change in FRM in the City of Toronto, Canada, and examine pathways through which FRM can adjust to, cope with, or benefit from a better understanding of the role of drivers of change. In addition to exploring these drivers of change, our analysis sheds light on potential implications for water governance while identifying drivers of change and potential pathways for adaptation and mitigation.

3.2 Drivers of change and FRM

Drivers of change (e.g., population growth or climate change) alter hazard and vulnerability and thus affect the chances of success for governance and management efforts (Berndtsson et al. 2019, Halbe et al. 2018, World Bank 2017). Drivers of change are having a noticeable impact on

the flood hazard and vulnerability at a local level. Traditionally, flood management and flood protection were water-centric and seen as engineering design challenges (e.g., dams, flood levies) to make land in floodplains usable (Hartmann and Driessen 2017). Water-centric approaches are mostly focused on the “practical scope of causes, effects, and interests associated with a water issue,” which is portrayed as “relatively clear, uncontentious, and bound by sector” (de Loë and Patterson 2017c). Controlling floods using an engineered system of dams, dikes, and levees is an example of a water-centric approach. Increasing financial damages and growing concern around extreme rainfall and change in weather patterns have challenged FRM and water-centric approaches.

Concepts such as integrated water resources management (IWRM) have directed FRM attempts around the world to integrate flood risk management concepts with broader issues, including land use planning, sustainability, and economics (Serra-Llobet et al. 2016). As a result, FRM has now shifted toward collaboration and integration of water engineering and spatial planning and has embraced the concept of flood risk (Hartmann and Driessen 2017, Francesch-Huidobro et al. 2017). From this perspective, we define FRM as "the mix of federal and non-federal government policies and programs that influence the decisions made by communities and individuals relating to floodplain location and use and their choice of actions to reduce flood risk and manage residual risk. The term also covers the decisions made by all levels of government and by individuals to implement actions to reduce flood hazard, exposure, and vulnerability as well as to increase resiliency" (Shabman and Scodari 2014, 5). This broad definition of FRM addresses a wide range of dynamic processes that aim to reduce the likelihood and/or the impact of floods by influencing flood hazards and vulnerabilities (Berndtsson et al. 2019).

Hazard, exposure, and vulnerability are key terms in FRM. The term “flood hazard” is defined by Schanze (2006, 2) as “the probability of the occurrence of potentially damaging flood events”. Vulnerability, in general, is defined as the degree to which a system is susceptible and unable to cope with the adverse effects of climate change (IPCC 2007, 21). Flood vulnerability, in particular, is rooted “in how people or societies are likely to be affected by flood phenomena – that is, the sensitivity of the community or people to flooding considering the socio-economic, environmental and physical components” (Thomas et al. 2020, 202). Exposure is defined as the number of assets being present in endangered areas distinguished per typologies (Cutter et al. 2018, Hegger et al. 2016). Collectively, flood hazard, exposure, and vulnerability form the notion of flood risk (UNISDR 2009).

Changes in the nature of the risk (e.g., change in precipitation pattern) and emerging new perspectives (e.g., use of green infrastructure) have introduced new sets of governance and FRM challenges (Oulahen 2021, Aerts et al. 2018, Francesch-Huidobro et al. 2017). For example, to reduce the risk of flooding, flood risk management needs to account for social-economic factors (e.g., increasing financial damages, mental health issues), path-dependency, time lag and different temporal scales between public and private investment decisions. FRM must also address the consequences of using a wide range of tools, including taxation instruments, non-perverse subsidies, flood insurance, marketable permits, and transferable development rights (Aerts et al. 2018, World Bank 2017, Filatova 2014). Current FRM approaches are challenged to account for external factors that drive change in the FRM systems. Therefore, it is beneficial to examine FRM and its governance system to identify drivers of change and assess their impacts to develop adaptation opportunities for flood risk reduction and mitigations.

To identify and account for drivers of change, it is critical to understand broader social-ecological systems in which the FRM systems are situated; this is essential to build management flexible management systems that can adapt to, cope with, or benefit from uncertainty and complexity caused by drivers of change (Anvarifar et al. 2016, Difrancesco and Tullos 2015). Numerous frameworks have been developed to study the linkages among institutions and ecosystems. Among these, analytical frameworks that are built on Ostrom's IAD (Institutional Analysis and Development) and SES (Social-Ecological Systems) frameworks have been used in various water resource management situations to understand the dynamics in complex social-ecological systems, including water resource management, natural flood risk management, and fisheries management (Wells et al. 2020, Cole et al. 2019).

The Combined IAD and SES (CIS) framework (see Figure 3-1) presents an analytical framework with the ability to map the changes in institutional processes using different variables and feedback loops that account for contextual factors and drivers that impact the decision making environment where individuals, organizations and actors interact to form their desired outcome (Cole et al. 2019). By mapping the linkages among institutions and the ecosystem, CIS provided this research with systematic and strategic ways to identify and evaluate drivers of change. An attempt to explore external factors and their impact on a diagnostic approach builds on Ostrom's approach with a focus on assessing the internal and external factors that impact governance systems and have emerged recently in water governance literature (Egan and de Loë 2020, Garrick et al. 2013, Ferguson, Brown and Deletic 2013). Diagnostic approaches are designed to "unpack the complexity of a problem, allowing an analyst to explore patterns of interactions that produce outcomes" (Cox 2011, 346). In our research, we used a combination of CIS and a diagnostic approach to facilitate the identification of drivers of change and assessment of their impact on FRM systems (see Data and Methods section 3.1).

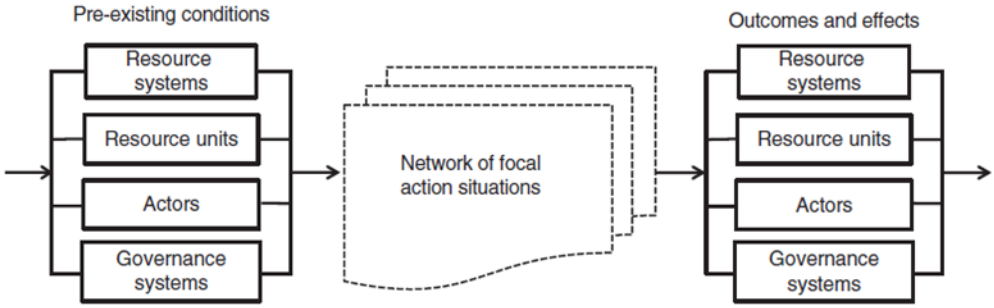

Figure 3-1: CIS framework (Cole et al. 2019)

Identifying drivers of change and their impact on the governance system can help to address persistent water-related challenges. Various scholars argue that the awareness of drivers of change and their impacts on FRM is increasing (Breen et al. 2018, Muir 2018, Winsemius et al. 2016). The increasing awareness can be leveraged to rethink institutional design to help FRM systems deal with complexity and uncertainties by developing adaptation and mitigation strategies. To guide adaptation efforts, necessary institutional change should be facilitated

without imposing one size fit all solutions or blueprints that ignore local conditions (Baggio et al. 2016, Huntjens et al. 2012). Polski and Ostrom (1999) identify a set of rules for studying the underlying institutional designs of those real-world experiments that have proved to be robust over time and have been associated with successful outcomes in governing resources (Cox et al. 2010). Huntjens et al. (2012) proposed a modified version of the institutional design principle to account for climate change adaptation in complex water governance systems. The designed principle adopted by Huntjens et al. (2012) contains eight principles, including 1. Clearly defined boundaries, 2. Equal and fair (re-)distribution of risks, benefits, and costs 3. Collective choice arrangements, 4. Monitoring and evaluation of the process, 5. Conflict prevention and resolution mechanisms, 6. Nested polycentric governance, 7. Flexible process, and 8. Policy learning. These refined institutional design principles provided a strong framework to explore institutional arrangement weaknesses and opportunities relating to drivers of change.

3.3 Data and Methods

To identify drives of change, it is critical to consider rulemaking organizations (McGinnis and Ostrom 2014) as well as the broader context that impacts the FRM system or other factors of a social-ecological system. The modified CIS (Combined Institutional Analysis Development and Social-ecological Systems (Cole et al. 2019) and the diagnostic approach developed by de Loë and Patterson (2017b) are selected to examine the influence of drivers of change in institutional configurations and governing approaches to inform FRM (see Figure 3-2).

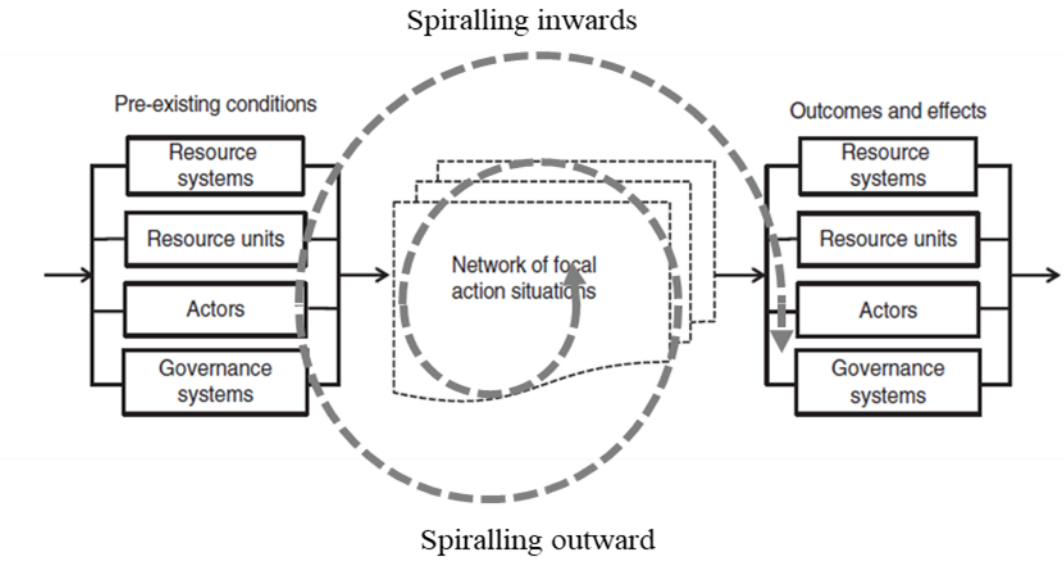

Figure 3-2: The conceptual framework

The conceptual framework situates the select FRM system in the broader social-ecological system by defining an action situation. It guided research to identify drivers of change by supporting both a high-level and in-depth analysis in a particular action situation following four steps (see Figure 3-2). The first step is to define the action situation as clearly as possible. The

second step, “spiralling inwards,” allows us to determine if a FRM perspective is appropriate. The third step critically reflects on the boundaries of the current action situation to facilitate the analysis's final step, which focuses on identifying opportunities to improve governance by accounting for drivers of change in the selected action situation. The last two steps promote inquiry into interactions “external” to the selected action situation, which involves “spiralling outwards” to explore broader interactions and their impact on current FRM contextual factors. Using the four-step analysis, we explored the impacts of drivers of change on institutional arrangements to highlight opportunities and weaknesses in the selected action situation. Action situations are defined as “analytic concepts that enable an analyst to isolate the immediate structure affecting a process of interest to the analyst for the purpose of explaining regularities in human actions and results to potentially reform them” (Ostrom 2011a, 11).

The conceptual framework also guided data collection. It informed the selection of institutional arrangements and helped identify actors whose insights have proven useful for this research (see Section 4.1). Data were collected from primary (e.g., semi-structured interviews) and secondary sources in governments, non-governmental organizations (NGOs), research organizations, municipalities, Conservation Authorities (CAs), and the private sector. Three data sources were used for the study: key informant interviews, document analysis, and personal observations.

In key informant interviews, twenty-eight participants who have a managerial role in their organization were purposefully recruited based upon their knowledge in the context of Toronto, Ontario, Canada and/or involvement with the selected FRM systems. The interviews were conducted in person and over the phone and ranged from an hour to two hours. Interviews were audio-recorded and transcribed, and the transcripts were returned to interviewees for review on their requests. Among participants, 10 out of 25 declined to be directly quoted, while they shared their opinion to enrich the result of this research. Fieldwork coincided with a change in government in Ontario that led to significant organizational changes in the public service (Ontario 2018) and funding cuts (Meckbach 2019). Additionally, fieldwork took place during multiple flood events in the province (McNeil 2020). Together, these circumstances made it challenging to recruit key informants. Despite these challenges, it was possible to recruit a satisfactory number of senior participants. Additionally, a research design that also prioritized other data sources ensured that the necessary data were secured.

Documents were collected from various sources (N=170). Regulations, statutes, and official reports were selected based on recommendations from participants, workshops, and most noted references in various reports. In addition to documents and interviews, data were collected in the form of field notes taken during personal observations in different events at public meetings, seminars, workshops, online webinars, and open houses for public meetings organized by Waterfront Toronto and Toronto Region Conservation Authority (TRCA).

The qualitative data analysis software QSRNvivo version 10 was used to facilitate the analysis, triangulation and subsequent reporting of data from semi-structured interviews, document review and personal observations. Data triangulation among these three sources was used to ensure rigour, accuracy, and validity. Data analysis was conducted using two methods: content analysis and thematic analysis (see Table 3-1). The content analysis focused on a textual analysis by weighing and counting word frequencies and collocations with emphasis on variation,

e.g., similarity within and differences between parts in the collected data. Content analysis was divided into two iterative stages (Finfgeld-Connett 2014).

The first stage, the development of data segments and coding, was followed by a reflection using memoing on factors that impacted/ will impact FRM systems and was guided by a systematic review of literature (see Chapter Two) FRM (see Table 3-1). This stage included an iterative and inductive identification of phrases that are separated into similar or dissimilar themes and subthemes. The final stage of the analysis involved note-taking for a clear "audit trail" as data analysis progressed, note-taking on immediate reflections of phrases and codes within studies, and then on themes across studies (Finfgeld-Connett 2014). This stage resulted in the creation of categories of drivers of change relative to the case. Development of the categories was guided by the first part of the research, "*Global Drivers of Change in Flood Risk Management: A Systematic Review*" (Chapter Two). The identified drivers of change with a similar domain of influence or origin were clustered together into one of five broad categories: Environment (ENV), Policy (POL), Technology (TRC), Economic (ECO), and Social (SOC). These categories are used in the results section to present the results in a way that is compatible with the FRM approach in addressing vulnerability and risk assessment (Fernandez et al. 2016, Sandink et al. 2016).

Thematic analysis was conducted through the lens of the modified institutional design principles and a global review of drivers of change and their categories (see Table 3-1). A thematic analysis identifies patterns for detailed coding and analysis from within the larger body of text that "at minimum described and organized the possible observations and a maximum interpreted aspect" of the FRM institutional arrangement in which drivers of change can be acknowledged or addressed effectively. By comparing data that focused on FRM organizational roles, responsibilities, regulations, and policies, we were able to recognize common features in institutional interactions and dynamics, which were coded as themes. A set of logical themes and associated characteristics was deduced using open coding. The initial patterns of coding incorporate a hybrid approach using a deductive, theoretical process and a bottom-up, inductive, data-driven process (Liamputtong 2013, Swain 2018). The second round of coding involved *posteriori* coding further to refine the categories from the first round of analysis. The final round of coding provided us with the ability to conceptualize a system of interactions between themes that are presented in the result section.

Table 3-1: Examples of coding and variables

Type and purpose of the analysis		**Example of codes**	**Consideration**
Content analysis guided by literature on drivers of change in FRM	Identifying drivers of change	Change in a weather pattern a shift in role or responsibilities change in risk communication new models and data financial pressure change in household behaviour	The scale of influence (global-local) Influencing hazard or vulnerability

Thematic guided by the modified institutional design principle	Identifying their impact on the FRM system	Clear boundaries defined role and responsibilities risk-sharing options alternatives collaboration and multilevel governance robustness conflict resolutions process	Enabling and constraining factors (policy, funding, vision, acceptance, technical constraints, natural constraints, opportunities)

In the next section, the FRM action situation in the City of Toronto is explored using the conceptual framework, focusing on the first two steps of analysis: (1) identifying the action situation, followed by (2) "spiralling inwards" to determine if a FRM perspective is appropriate by exploring actors and broad perspectives on FRM in the City of Toronto. This stage of the analysis provides a foundation for a detailed review of identified drivers of change and assessment of their impact on FRM. By building on evidence from triangulated data and using that evidence to highlight potential adaptations, opportunities and mitigation strategies drawn from FRM and water governance literatures are identified and assessed using the final two steps of analysis, which is discussed in the result section

3.4 Action situation: The City of Toronto FRM system

The first step in the analysis is identifying the action situation. The City of Toronto (Figure 4), the fastest growing city in Ontario, is located along Lake Ontario and the Humber, Don and Rouge Rivers. The city contains an 11,000 ha ravine system. Over half (5700 hectares) of ravine system land is publicly owned parkland, and some parts of the ravine system are protected under the Ravine and Natural Feature Protection Bylaw (City of Toronto 2020). The river systems in the city have changed (e.g., channelization) and will continue to change (e.g., naturalization programs, pressure from the growth of the city, and climate change). Large storms have altered and will continue to change the river systems in the city. For example, Hurricane Hazel (1954) dumped over 200 millimetres of rain in just 24 hours and made a long-lasting impact on the governance system's approach to managing development along the river valleys (TRCA 2019b).

Through conducting step two of the analysis, spiralling inward, we explored and assessed the current FRM systems. The FRM system starts with the formation of the Toronto Region Conservation Authority (TRCA), which receives its legislative authority under the Conservation Authorities Act (1990). The Conservation Authorities Act (1990) was a response to the devastation left behind by Hurricane Hazel. After Hurricane Hazel, TRCA initiated plans for flood control, erosion prevention, and land acquisition and conservation. Two major dams, including G.Ross Lord Dam on Don River and Claireville Dam on the Humber River, as well as small dam and flood control channels throughout the watershed, are the main flood structures in the city (City of Toronto 2020, TRCA 2018). TRCA developed other programs over time, including a flood forecasting and warning system and stormwater management program to address different types of flooding (TRCA 2020b).

The further analysis highlights that TRCA collaborates with various partners on different scales (international, federal, provincial, and local), including the City of Toronto, in developing

plans to mitigate flood hazards and reduce the risk of flooding. A broad scan of actors and governance systems involved in FRM shed light on the complexity of FRM efforts in the City of Toronto (see Figure 3-3). The analysis shows that FRM is a shared responsibility among different actors. Thus, the FRM systems fit the definition of a polycentric governance system as “the organization of small-, medium-, and large-scale democratic units that each may exercise considerable independence to make and enforce rules within a circumscribed scope of authority for a specific geographical area” (Ostrom 2001, 2). TRCA's collaboration with various partners (see Figure 3-3) has created a foundation for strong polycentric governance; however, current changes in organizational arrangements, authority, and funding of TRCA have a noticeable impact on the current system (Meckbach 2019, Feltmate and Moudrak 2021, Conservation Authorities of Ontario 2021).

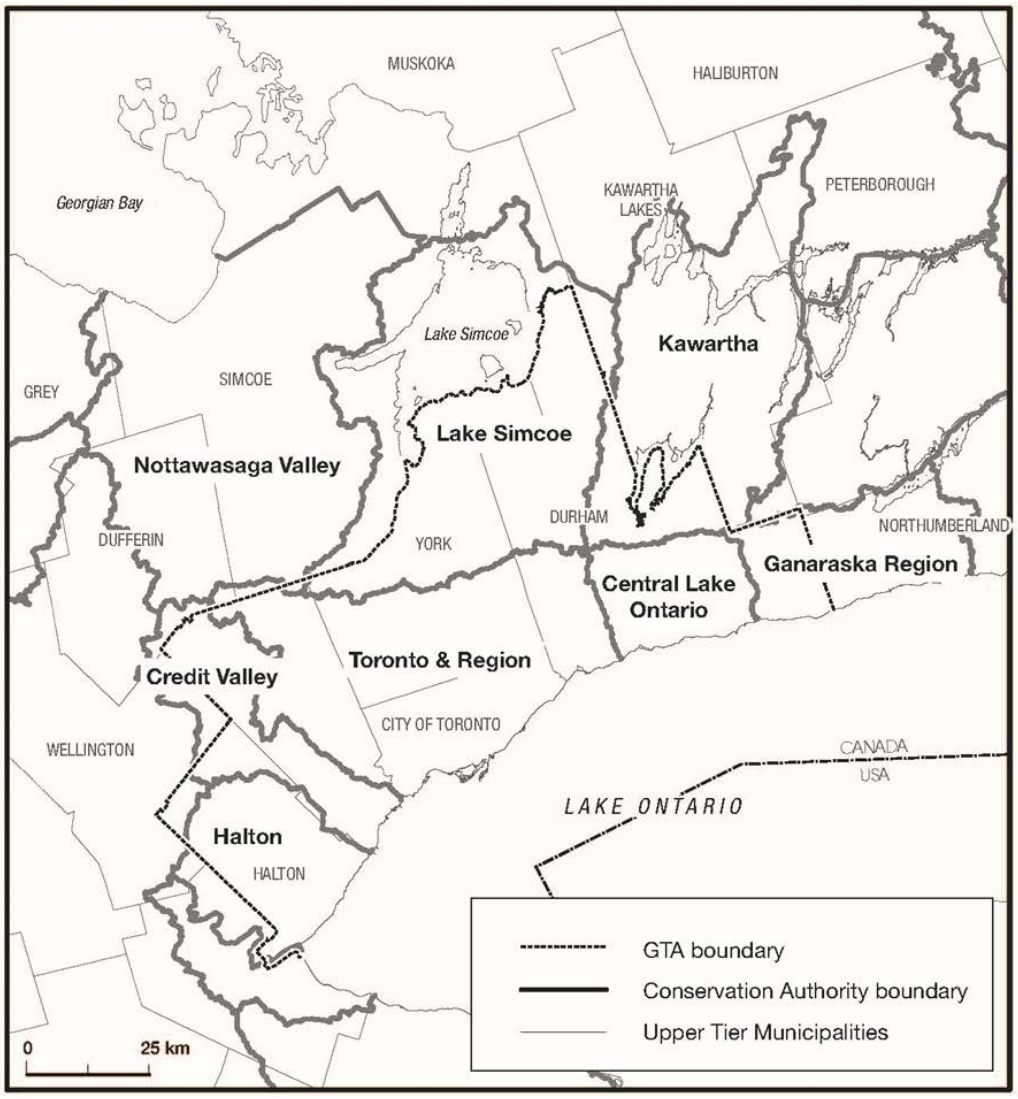

Figure 3-3: Selected action situation: City of Toronto

Despite significant efforts to reduce the flood hazard, damages due to flooding have increased over time. In the 2013 flood incident, the City of Toronto faced $60 million in flood

damage, in addition to exceeding $1 billion in losses that were absorbed by the insurance industry (Blakelock 2017). Subsequent incidents in 2017 (Toronto Island flood and high-water levels), 2018 (August torrential rain), 2019 (July heavy rain and high water levels) had a wide range of negative impacts on private properties and public infrastructure. To tackle these growing concerns, the City of Toronto and TRCA conducted the Toronto Flood Risk Ranking (TRCA 2019b) to assess hazard, exposure, and vulnerability to consider factors such as socio-economic characteristics of communities that impact the risk of flooding. This is a step toward connecting FRM with broader social-ecological systems. Nonetheless, there is very little attention devoted to underlying drivers that can alter these characteristics and pre-existing conditions, and how drivers of change have impacted risk, actors, institutions, and the FRM system (see Figure 3-4). Therefore, it is timely to study the selected action situation (the city to Toronto FRM system as a case study) to identify drivers of change, examine the impact of identified drivers of change on the current FRM system to suggest opportunities for FRM adaptation and mitigation.

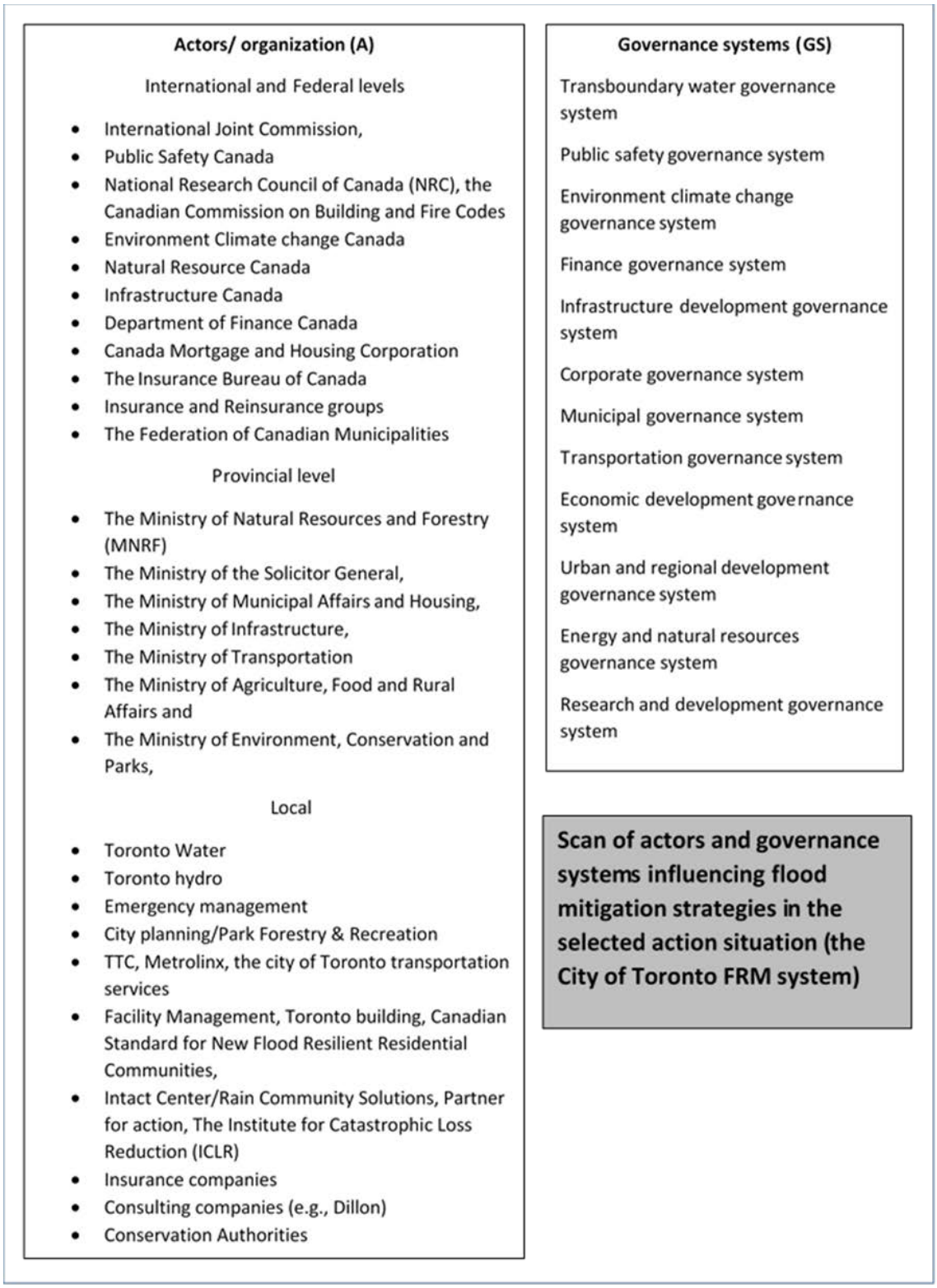

Figure 3-4: Actors and governance system influencing FRM in the City of Toronto

3.5 Identifying and assessing the impacts of drivers of change

This section presents findings from the analysis using the third and fourth steps of the conceptual framework: an inquiry into interactions "external" to the selected action situation. Findings build on the systematic review in Chapter 2 and are organized under the five broad categories that were identified through the analysis of the data (section 1.3): Policy (POL), Economic (ECO), Technology (TEC), Environment (ENV), and Social (SOC). Within each broad category, between one and four specific drivers of change were identified during the coding. In this section, findings relating to each of the five broad categories are presented in two parts. The first part focuses on the *identification* of drivers of change, while the second part presents an *assessment* of the impacts of drivers of change on FRM.

Together, these two parts provide guidance to explore opportunities for identifying mitigation and adaptation strategies. Opportunities are additional or adjusted institutional design principles introduced by institutional analysis and water governance literature that can provide solutions for challenges or enable opportunities that are identified in the assessment process for each driver of change. For completeness, summary tables for each broad category below address all three concerns: identification, assessment, and pathways. After identifying available opportunities, the three most influential design principles that were presented as opportunities for each driver of change are explored in detail in the discussion section.

3.5.1 Policy (POL)

Identification: This category includes a single driver of change: *"Clarifying roles and responsibilities"* (POL1) – see Table 3-2. FRM is a shared responsibility among actors and levels of government in the City of Toronto (see Figure 3-4). After the Calgary (2013) and Toronto (2013, 2018, and 2019) flood events, the need to clarify the roles and responsibilities was a concern mentioned by twenty participants from different levels of government, researchers, and risk analysts. This need became more evident in addressing urban flooding (pluvial flooding) due to ongoing lawsuits, a lack of regulated roles in the province, and a lack of a clear funding mechanism that ensures actors in their respective roles can react to urban flooding (Oulahen 2021, IBC 2020b, McNeil 2020). All levels of government (federal, provincial and municipal) are changing their FRM policy in an attempt to clarify their roles; this concern was raised by 25 interview subjects and confirmed by document analysis (Public Safety Canada 2017, MNRF 2020, City of Toronto 2019b).

Senior provincial and federal government officials, NGO directors, and CA staff indicated that the federal government had expanded its short-term and medium-term FRM efforts (see Table 3-2) to strengthen its proactive role in FM and to ease the pressure on its reactive role in emergency management. At the provincial level, the recent flood events highlighted the issue around types of flooding and jurisdictional gaps that currently exist in addressing urban flooding. This concern was discussed by ten representatives and also was revealed in the document analysis (e.g., McNeil 2020, Muir 2019, Blakelock 2017). The issues around types of flooding and change in weather patterns highlighted the need to update acts, policy statements, regulations, and technical guidelines. The attempt to update related acts and strategies coincided with a change in elected government and the introduction of a new policy approach to identify the core mandate for current FRM systems in place (see Table 3-2). The new policy approach began with a division of responsibility, funding reduction, and altering current systems in place. As a result of these

changes in FM policy and funding, Ontario's flood preparedness and the ability to limit flood risk decreased noticeably between 2016- 2019 (Feltmate and Moudrak 2020). Finally, at the city level, the City of Toronto has developed its first Resilience Strategy to account for long-term risk management. By making reference to it, the City of Toronto is able to steer the decisions, programs, and plans in different divisions, sectors while working with various partners to adapt to changing climate and reduce increasing flood damages highlighted by urban planners and CA staff (PA# 11, 9, 18, and 3).

Assessment: The most noted challenge in the policy category was the commitment of government actors (see Figure 3-4) to priorities other than adaptation and risk reduction. All participants pointed out that flood events opened a window of opportunity to push for risk reduction policies and funding and that a lack of long-term resilient development visions can lead to disaster recovery action that is the short-term solution and will result in ineffective adaptation. A government official (PA# 24) pointed out that "there is a huge mismatch between fast-paced extreme events, long term decision making and planning for flood, and the reaction of elected officials to the extreme event recovery plans". The temporal mismatch between long-term adaptation and risk reduction and the commitment of government actors (see Figure 3-4) has long been a challenge that FRM and water governance have been confronting in addressing water-related issues (Berndtsson et al. 2019, Egan and de Loë 2020).

Developing strategies with the provision of guiding short-term actions toward long-term adaptation emerged from the analysis as a key opportunity to facilitate recognition of, and adaptation to, drivers of change. For example, the Flood Resilient Toronto Project brought together more than 20 major agencies working on Toronto's roads, electricity, transportation, construction and environmental policies "with a pledge to reduce urban flooding as the city struggles to absorb extreme rainfall" (City of Toronto 2019a, 3). This initiative promised to "for the first time, see the city and provincial offices break out of their traditional silos and collaborate to fast-track innovative flood-protection projects" (Welsh 2019, 1). Breaking traditional silos and guiding collaboration efforts can be facilitated by strengthening nested polycentric governance (Lubell 2015) as an opportunity to flood risk mitigation.

Table 3-2: Policy drivers of change

<table>
<tr><th colspan="2">Assessment steps</th><th colspan="3">Drivers of change relative to the case study action situation: Policy category</th></tr>
<tr><td rowspan="2">Identification</td><td></td><td colspan="3">POL1</td></tr>
<tr><td></td><td>Federal:
National Disaster Mitigation Program (NDMP)
An additional 15% Disaster Financial Assistance Arrangements (DFAA)
Green Infrastructure Fund (GIF, 2009-2021)
The Municipal Asset Management Program (MAMP 2017-2025)</td><td>Provincial:
The Building Better Communities and Conserving Watersheds Act – Bill 139 (Ontario 2017)
Ontario proposed changes to the Planning Act</td><td>Local government:
The first Resilience Strategy
The Flood Resilience Toronto Project (2019)</td></tr>
<tr><td rowspan="4">Impact assessment</td><td>Scale</td><td colspan="3">Federal to local</td></tr>
<tr><td>Impact</td><td colspan="3">Vulnerability</td></tr>
<tr><td>Challenges</td><td colspan="3">Conflicting commitments and temporal miss match
Lack of communication among levels of government and reinforcement of power asymmetries</td></tr>
<tr><td>Opportunities</td><td colspan="3">Strong interest to develop inter-divisional and inter-sectoral groups to address the risk of flooding</td></tr>
<tr><td colspan="2">Adaptation opportunities</td><td colspan="3">Strengthening nested polycentric governance</td></tr>
</table>

3.5.2 Economic (ECO):

Identification: This category has four major drivers of change (see Table 3-3), including increasing damages, negative impacts on the economy, and increasing value at risk (ECO1); market-based solutions (ECO2); diversification of funds (ECO3); and return on investments of FRM projects searching for financial sustainability (ECO4).

Increasing damages, negative impacts on the economy and increasing value at risk (ECO1) highlight financial pressure on public and private actors (see Table 3-3). The scope of damages is growing, as reflected in property values soaring by almost five-fold (comparing detached house prices since 2013). An insurance advisor (PA# 1) argued that household wealth (e.g., increasing finished basements) and inequality result in increasing vulnerability and value at risk. Increasing vulnerabilities and value at risk in the city was supported by five other participants and by the

document analysis (e.g., City of Toronto 2021, RBC 2017). Property loss and damage, lower revenues, business interruption, increased debt, and higher insurance costs were also highlighted in documents analysis as examples of direct losses immediately after the event (IBC 2020b, Feltmate and Moudrak 2020).

Market-based solutions (ECO2) are emerging tools to address increasing flood damages. A Director Manager of a risk assessment firm (PA# 8) highlighted that traditionally market-based solutions were presented as insurance products. Examples include sewage backup insurance, commercial flood policies, municipal insurance, and new overland flooding insurance introduced in Canada in 2015. In addition, seven FRM representatives discussed recent attempts to introduce other solutions, including updating Canada's building codes, introducing home flood protection programs, and connecting with banks, mortgage lenders and mortgage insurers internally or publicly to limit the development of high-risk.

Diversification of funds (ECO3) to support the local level government is another driver of change emerging in the economic category. The emergence of funding opportunities under different funding streams has boosted current FRM. Despite the diversity of funds, NDMP (2013-2022) is the fund most used or applied to by local actors in Ontario (see Figure 3-4). In addition, among funds secured for FM, there are competing interests that were mentioned by more than seven urban planners and CA staff. Two CA staff members (PA#11 and 18) illustrate examples of these competing interests: updating infrastructure, updating maps, building a better communication system, data collection, updating analysis systems, updating or expanding current stormwater management systems, emergency response, and green infrastructure in which existing FM funds at the local level can be invested.

Return on investments of FRM projects searching for financial sustainability (ECO4) is the last driver of change in this category (see Table 3-3). The lack of long-term and consistent funding streams at federal, provincial and municipal levels directly dedicated to FM, and high competition for available funds, was identified by six participants from different levels of government, researchers, and risk analysts. As confirmed in the document analysis, this trend has put pressure on municipalities to focus on risk and return on investment measures (Public Safety Canada 2020, TRCA 2019a). The ability to assess the return on investment helps proposals for projects meet federal government requirements for DMAF or Climate Lens requirements and the NDMP stream and allows them to be consistent with provincial requirements such as the Growth Plan for the Greater Golden Horseshoe (Public Safety Canada 2016, Infrastructure Canada 2017, Consolidation 2020, Government of Ontario 2020).

Assessment: Changes in funding mechanisms and the temporal mismatch of funding systems among different levels of governments have challenged FRM in Ontario (see Table 3-3). Participant # 3, a city staff member, argued that "[t]he funding changes and issues related to that can be less of a problem in large municipalities, but other CAs with smaller municipalities are depending on this funding." Through the document analysis and participation in workshops, it was evident that in CAs with smaller municipalities are dependent on government funding and other resources to enable the CA's flood management abilities (e.g., Conservation Authorities of Ontario 2021, McNeil 2020). NDMP, as of 2015, has enabled many CAs to tackle various issues that fit in defined funding streams, including Flood Risk Assessment, Flood Mapping, Flood Mitigation Planning, and Non-structural and small-scale structural measures (Public Safety Canada 2020, Public Safety Canada 2016). Nonetheless, CA staff, provincial government

officials, and city managers (PA# 5, 11, 23) noted several challenges, including a mismatch of funding timelines and provincial budget cycles, which were also highlighted by the evaluation of NDMP by the federal government (Public Safety Canada 2020). Furthermore, “most Provincial and Territorial representatives stated that Public Safety did not meet its approval timelines, which resulted in project delays” (Public Safety Canada 2020, 15).

An opportunity presented by drivers of change in this category was growing interest among the diverse public and private actors to collaborate and bundle different projects to reduce risk and increase the return on investments was explained by a CA staff person (PA #5). This opportunity also emerged from personal observations at CatIQ's Canadian Catastrophe Conference 2019 and was supported by document analysis (e.g., Consolidation 2020, TRCA 2019b, CWN 2018). TRCA is partnering with actors such as IBC, Intact Center, and Electrical safety Authority at Hydro One to run an open house and inform residents, which shows the emergence of this opportunity in the Flood Risk Outreach Program. The CA staff argued that “people found this event helpful because they [partners and private actors] can provide a little bit more information beyond just the risk information.” To enhance collaboration with current and emerging actors, strengthening nested polycentric governance is one opportunity for adoption. Promoting equal and fair (re) distribution of risks, benefits and cost and flexible processes are recognized as two additional opportunities in sharing responsibilities, funding commitments, and cost burdens in the process of adaptation and risk mitigation (Penning-Rowsell and Pardoe 2015, Butler and Pidgeon 2011) (see section 1).

Table 3-3: Economic drivers of change

Assessment steps		**Drivers of change relative to the action situation: economic category**			
Identification		ECO1: Private actors and insurance industries are facing reputational and financial challenges Canadian homeowners bear 75% of the financial burden of uninsured flood damages	ECO2: Two primary insurance providers, Co-Op and Aviva, introduced the first overland flooding in 2015 The emergence of home flood protection programs The attempt to update Canada's building codes	ECO3 Funding opportunities presented by the federal government under Public safety Canada, Infrastructure Canada, Federation of Canadian Municipalities, the Climate Action and Awareness Fund	ECO4 The emergence of return on investment tools(The Risk and Return on Investment Tool Requirement for applying for other funding, including DMAF, NDMP, and provincial requirements
Impact assessment	Scale	Local	Global to local	Federal to local	Federal to local
	Impact	Vulnerability	Vulnerability	Vulnerability	Vulnerability
	Challenges	Increasing financial pressure on local level government and assets	Emergence of new actors in the FRM system with diverse interests	Lack of long term funding's	Competition challenges due to lack of funding and incentives
	Opportunities	Reassessing local natural and built assets	The emergence of approaches to tackle the risk	Relying on various large-scale or small-scale funds and grant	Bundling projects to increase the return on investments
Adaptation opportunities		Equal and fair (re) distribution of risks, benefits and costs	Strengthening nested polycentric governance Flexible process	Equal and fair(re) distribution of risks, benefits and costs Strengthening nested polycentric governance	Equal and fair (re) distribution of risks, benefits and costs Flexible process

3.5.3 Technology (TEC):

Identification This category focuses on both information technology and broad technical solutions (see Table 3-4) and includes three drivers of change: *data collection, modelling, and data gaps* (TEC1); *data sharing and issues around privacy* (TEC2); *preferred structural solutions combined with Green Infrastructure-GI* (TEC3).

Data collection, modelling, and data gaps (TEC1) as drivers of change evolves, based on advancements in technologies and modelling and the needs of municipalities (see Table 3-4). Innovations in remote sensing, satellite imagery, and real-time data collection (TRCA 2020a) have reduced the costs of data acquisition, as highlighted by seven government officials, NGO directors, CA staff members. Meanwhile, document analysis points to the increasing complexity in modelling that has increased the demand for extensive data sets and affects the type, resolution, format and price of data (TRCA 2019b, Muir 2018, CWN 2020b).

Data sharing and issues around privacy (TEC2) are highlighted as drivers of change because the extent of up-to-date information on flood risk or hazard is dependent on municipalities' needs and requirements (see Table 3-4). Two CA staff members (PA #18,11) argued that there is a broad spectrum on the availability of data and information on flood risk and hazards between municipalities serviced by the same CAs (McNeil 2020). This broad-spectrum approach created challenges in data sharing and neighbouring municipalities' ability to address the risk of flooding, as discussed by urban planners and CA staff members (see Table 3-4).

Preferred structural solutions combined with Green Infrastructure-GI (TEC3) is emerging as a driver of change, although structural solutions are still the most trusted, as noted by five urban planners and CA staff members and confirmed by document analysis (Waterfront Toronto 2021a, Thorne et al. 2018, Waterfront Toronto 2016b). There is disagreement among groups (e.g., Ontario professional engineers, the wastewater and stormwater industry, and many Ontario municipalities) regarding the use of GI as a sole solution to reduce the flood risk (Muir 2019). Scenarios that predominantly consist of structural solutions while adding some GI to achieve higher flood control benefits that satisfy public policy regarding climate adaptation and funding priorities for infrastructure investments (Muir 2019, TRCA 2019a). This driver of change highlights the concerns around the uncertainty of using new methods and the unknown risk attached to their use.

Assessment: One of the biggest challenges noted was the rules governing access to risk hazard or vulnerability information that varies among municipalities and CAs (CWN 2020a). Flood risk information and vulnerability assessments are considered equally as important as the methods by which the information is disseminated. This concern was mentioned by twelve government officials, CA staff members, NGOs directors and risk analysts (see Table 3-4).

The most commonly mentioned solution is the formation of a strong network of sensors and monitoring systems that facilitate early warning systems, real-time monitoring, and real-world modelling, which can assess flood hazards and vulnerabilities for riverine systems in urban and rural areas and account for coastal flooding using with real-world digital models presented as 3D reality mesh. By generating realistic visualization of a flood event, flood hazard and vulnerability communications can be simplified to pictures to understand the risk and the impacts of potential mitigation programs, which was highlighted by CA staff members and researchers (see Table 3-4) To harness opportunities and face challenges presented by drivers of change in technology

category a promoting a flexible process through institutional arrangement is presented as the most promising adaptive opportunity to face increasing flood damages (Hegger et al. 2016, Difrancesco and Tullos 2015).

Table 3-4: Technology drivers of change

Assessment steps		Drivers of change relative to the action situation: Technology category		
Identification		TEC1: The diversity in data collection options: for example, using drowns vs, google street view Different models to account for different types of flooding	TEC2: Establish the Canadian Centre for Climate Information and Analytics (C3IA) Privacy issues, data sharing challenges	TEC3 Estimating the direct impact of structural measures compared to non-structural measures is easier Combining structural measure with GI
Impact assessment	Scale	Global to local	Federal to local	Local
	Impact	Hazard & Vulnerability	Hazard & Vulnerability	Hazard & Vulnerability
	Challenges	The complexity of models is increasing as well as the need for required expertise. Issues around sharing data among neighbouring municipalities	Cybersecurity challenges Privacy and ownership Different rules in governing and accessing risk information	The ambiguity regarding operational and maintenance fee of GI, as well as the high construction cost of structural solution
	Opportunities	Improving the system performance by using high-resolution monitoring and close to real-time data	The opportunity to develop a platform for sharing information	Improving the flood mitigation efforts and flood structure performance
Adaptation opportunities		Monitoring and evaluation of the process Flexible process	Strengthening nested polycentric governance Flexible process	Flexible process Policy learning

3.5.4 Environment (ENV):

Identification: This category has two main drivers of change (see Table 3-5). *Changes in weather patterns and climate variability* (ENV1) is a driver of change that alter flood regimes and types of flooding. This driver is connected to different types of flooding in the City of Toronto.

The connection was mentioned by eight participants, including CA staff members, NGO directors, and urban planners, and was confirmed by document analysis (e.g., Feltmate and Moudrak 2021, TRCA 2019a, Blakelock 2017). Concerns raised by this driver of change include: first, a record-breaking (2019) and long-lasting high lake level along the Great Lake Basins is of great challenge to the have concerned IJC and the City of Toronto due to the increasing risk of shoreline erosion, lakeshore flooding and coastal damages (PA# 2, 11, 24). Second, an increase in the risk of fluvial (riverine) flooding and financial damages in different communities has challenged FRM in the City of Toronto (TRCA 2019b). The final concern was raised around an increase in pluvial (urban) flooding and issues around its management system compared to fluvial flooding (see Table 3-5).

Recognition of Green Infrastructure (GI) as FM tools and municipal assets (ENV2) is identified as drivers of change (see Table 3-5). A CAs staff member (PA# 11) argued that "translating the new and emerging knowledge and techniques to practice and tailor them for implementation in each project is a complex issue in the City of Toronto" where multiple departments and institutions are involved (e.g., parks, transportation, heritage, and TRCA). By recognizing GI as an asset, the local government can track the investment return, asset condition and performance, lifecycle costs, as well as current and projected risks to assets (Alaerts 2019, Ministry of Infrastructure 2018, Hino and Hall 2017).

Assessment: The degree of effectiveness of climate change adaptation actions compares the ecological changes that are occurring with a negative impact on FRM, putting pressure on the governing system (see Table 3-5). Eight interview subjects engaged in FRM pointed out many efforts to improve ecological systems in urban forests or biodiversity within waterways, support the use of GI, improve stormwater infrastructure, and control lakeside erosion. Nonetheless, a city staff member (PA #3) argued that "despite great efforts and lots of work that have been done in various areas, we do not see much of an improvement in some of the existing conditions". For example, in 2018, the TRCA watersheds received a 'D' grade in surface water quality despite many attempts to improve stormwater infrastructure or promote GI, as confirmed by document analysis (TRCA 2018b, 1). These concerns highlight the fact that local climate change impacts are highly uncertain and the cost of adaptations is high while the effectiveness of actions is limited, at least in the short term (Berndtsson et al. 2019, Alaerts 2019).

One of the most noted opportunities identified were the numerous coordinated efforts among local actors, TRCA, municipal partners, and other neighbouring CAs to rethink the green spaces and promote GI as non-structural flood management noted by various CAs staff members and urban planners (see Table 3-5). The institutional arrangement and the collaboration among various actors (see Figure 3-4) on a local scale enable TRCA "to implement flood remediation, erosion monitoring, maintenance work, stormwater retrofits, low impact developments, green infrastructure, and water quality and habitat restoration projects" as envisioned in the TRCA's Strategic Plan (TRCA 2018c).

Drivers of change in the environment category impact increasing uncertainty and the success of adaptation efforts that create challenges for current institutional arrangement and adaptation efforts. Policy learning, strengthening nested polycentric governance, equal and fair (re) distribution of risks, benefits and costs, and flexible processes are selected as opportunities that can guide adaptation efforts to transform increasing uncertainty into new opportunities and create space for innovation (Guerriero and Penning-Rowsell 2021)

Table 3-5: Environmental drivers of change

Assessment steps		Drivers of change relative to the action situation: Environment category	
Identification		ENV1: Change in flood regimes Erosion and lake level rise	ENV2: Recognition of GI in assent management planning changes the way these infrastructures are valued
Impact assessment	Scale	Regional and global	local
	Impact	Hazard	Hazard
	Challenges	Poor coordination and regulatory uncertainty among institutional policy and priorities at hierarchically state from the federal and provincial level,	Competition for funding Limited adaptation incentive Disagreement in use
	Opportunities	A strong local level institutional organization working with different local actor	More information is emerging about the use and operation of different types of GI
Adaptation opportunities		Strengthening nested polycentric governance Equal and fair (re) distribution of risks, benefits and costs	Policy learning Flexible process

3.5.5 Social (SOC):

Identification: This category has three drivers of change, including emerging risk communication outlets (SOC1); the evolution of public expectation and flood experiences are evolving after each flood event (SOC2); and change in socio-demographic and population growth (SCO3); are three main drivers of change in the final category (see Table 3-6).

Emerging Risk communication outlets (SOC1) and flood events recurrence have altered risk communication and public expectations (see Table 3-6). Five interview subjects engaged in FRM emphasized that sharing clear, consistent, and up-to-date information in a publicly accessible manner, before a flood event, during the event, and after the event is a critical part of flood communication. Document analysis indicated that challenges arise because mitigation strategies, response strategies, and processes to submit financial claims vary based on the type of flooding and the municipality where the event occurs (MNRF 2020, McNeil 2020).

The evolution of public expectation and flood experiences after each flood event (SOC2) is an important driver of change. Climate variability and the recurrence of flood events have increased the number of households who experience disaster and bear flood losses. These individuals become aware of their vulnerability; as a result, they are more likely to implement mitigation measures (see Table 3-6). Nonetheless, the willingness to act does not guarantee the implementation of adaptation and mitigation efforts (Government of Canada 2015, Oulahen 2021, University of Waterloo 2015).

Change in socio-demographic and population growth (SCO3) is presented as the final driver of change identified by the analysis. The demographic profile of Toronto has and continues to be rooted in young professionals (City of Toronto 2021) and senior citizens (citizens over 65 years of old). The senior citizens' population forms 16% of the total population (2016 Census) and is expected to grow to 19% by 2030 (City of Toronto 2016, Ministry of Long Term Care 2020), impacting vulnerability assessments in FM. In addition to demographic status, the number of basement rental units and the emergence of multigenerational or intergenerational housing has also affected vulnerability and values at risk in the city, a concern pointed out by the city and CA staff members (PA# 3, 18, 28).

Assessment: The impacts of norms and behaviour on forming maladaptive/adaptive decisions were independently identified as both a challenge and opportunity in FRM by 24 participants in this research. An increase in the number of basement rentals or increasing popularity of fully furnished basements and constructed swimming pools within the properties are examples flagged as norm or behaviour that increase vulnerabilities and has led to maladaptive decision-making despite several efforts to reduce the risk of flooding, as pointed out by CA staff members, NGO directors, urban planners, and the city staff members (see Table 3-6). Nonetheless, increasing interest among households to purchase recently launched flood insurance products or to implement the Home Flood Protection program reveals that norms or behaviours can imply in adaptive decisions making (Evans and Feltmate 2019, Government of Canada 2015). Changes in social or individual behaviour and risk perception impact the success and failure of FRM strategies(Seebauer and Babcicky 2018, O'Donnell, Lamond and Thorne 2018, Mann and Wolfe 2016). Promoting equal and fair (re) distribution of risks, benefits and costs, conflict prevention and resolution mechanisms, and collective choice arrangements are common opportunities that are suggested by scholars and used by practitioners to adapt to the risk of flooding and reduce flood damages (O'Donnell et al. 2018, Filatova 2014).

Table 3-6: Social drivers of change

Assessment steps		Drivers of change relative to the action situation: social category		
Identification		SOC1: Dissemination of information using social media outlets The issues regarding accuracy, misinformation, and reaching relevant audience arise	SOC2: Increasing the number of households who experienced disaster and bear flood losses Change in the ability of a homeowner to adapt and implement mitigation strategies	SOC3 Change in socio-demography changes vulnerabilities
Impact assessment	Scale	Local	Local	Local
	Impact	Vulnerability	Vulnerability	Vulnerability
	Challenges	Dissemination of simple but accurate information regarding different types of flooding	Stimulating public interested in mitigation efforts before a flood event occurs	Norm and belief imply a maladaptive decision
	Opportunities	Diverse tools and platforms for risk communication	Introduction of various mitigation tools and products by private actors	Norms and beliefs facilitate adaptive action
Adaptation opportunities		Collective choice arrangements Conflict prevention and resolution mechanisms Equal and fair (re) distribution of risks, benefits and costs	Collective choice arrangements Conflict prevention and resolution mechanisms Equal and fair (re) distribution of risks, benefits and costs	Collective choice arrangements Conflict prevention and resolution mechanisms

3.6 Discussion: identifying adaptation opportunities

This section explores how insights on current drivers of change and their impacts can be incorporated in FRM and governance to address the increasing risk of flooding effectively and to create effective adaptation strategies. The previous section identified and discussed potential adaptation opportunities for each broad category of drivers in Tables 2 to 6. In this section, the three most commonly noted opportunities for adaptation are discussed: (1) strengthening nested /polycentric governance; (2) equal and fair (re) distribution of risks, benefits and costs; and (3) flexible processes

3.6.1 Nested polycentric governance

Traditional actors in flood management, including municipalities and river basin organizations (e.g., CAs), have created the foundation for the nested polycentric governance (see Section 1.4 spiralling-inward and definition of nested polycentric governance) with the division of roles and responsibilities (Baggio et al. 2016, Huntjens et al. 2012, MNRF 2020). Despite having a shared framework to address flood management at various levels of governments, the implementation efforts depend on municipalities' and river basin organizations' capacity to address FRM. To address the risk of flooding, and to move towards understanding vulnerabilities to build resilience communities, river basin organizations (e.g., CAs) and municipalities need to create a long-term approach to strengthen nested polycentric governance by reaching out to various actors (Alaerts 2019, City of Toronto 2019b).

To strengthen nested polycentric governance, there is room for different levels of governments to reassess current governance settings and take a stand in filling in long-term FRM gaps that exist at each level by providing funding that matches the temporal scale of flood management and mitigation efforts, as noted by seven FRM representatives. This includes building a shared data governance system, as well as developing a flexible governance structure that has the capacity to account for appearing or reappearing private actors with their unique capacities and abilities (CWN 2020a). By keeping each level of governance accountable over broader political, economic, and temporal changes to bear costs and benefits, to undertake their financial and institutional role and responsibilities, there is potential to encourage the equal and fair (re)distribution of risks, benefits and costs at the multilevel context (Huq 2016, Huntjens et al. 2012, Henstra and Thistlethwaite 2016a).

3.6.2 Equal and fair (re-)distribution of risks, benefits and costs

Flood management is portrayed as a shared responsibility among actors and levels of government (MNRF 2020, Kuser Olsen et al. 2018). FRM literature encouraged local actors, including private property owners, businesses, and municipalities, to take responsibility for the delivery of prevention and mitigation actions (updating maps, asset management, developing non-structural measures). Nonetheless, in the selected action situation, the City of Toronto FRM system, the limitation of local actors' financial resources, as well as the lack of consistent baselines to guide prevention and mitigation actions, has resulted in an as-needed priority basis approach by local actors to address the risk of flooding (McNeil 2020). These circumstances might result in the (re-)distribution of risk away from main business and valuable properties, rather than reducing the risks of people in need or vulnerable groups. It should be noted that developing adaptation strategies that result in equal outcomes is extremely challenging when addressing drivers of change and their impacts on FRM.

To encourage equal and fair (re)distribution of risks, benefits and costs, there is a need to create a consistent baseline to guide prevention and mitigation efforts to guide local actors' actions (Public Safety Canada 2017, Ministry of Infrastructure 2018). This can be accomplished by developing diverse funding opportunities by public or private sectors, including grants, loans or green bonds through which local actors can finance their prevention and mitigation action. Other solutions include revisiting some percentage of disaster financial assistance funds to be partially used for prevention and mitigation efforts provided by various levels of government and creating a mechanism to reinvest the financial returns of resulted from the prevention and

mitigation efforts back to the disaster financial assistance (Public Safety Canada 2020). Creating venues for local actors to participate and engage with the decision-making process involving risk, especially providing opportunities for groups that are likely to be higher at risk or negatively affected by proposed adaptation strategies, can facilitate equal and fair (re)distribution of risks, benefits and costs (City of Toronto 2019a, TRCA 2020b, Kuser Olsen et al. 2018).

3.6.3 Flexible process

Changes in weather patterns, the intensity of precipitation, and types of flooding are altering the nature of the risk and impacting trends in policy, economic and household behaviour around the world and in Ontario (Muir 2018, Thistlethwaite 2017, Rollason et al. 2018, Aerts et al. 2018). These observations emphasized the need to develop flexible processes in engineering design and the current institutions and policy processes. Flexible processes enable the system to "continue to work satisfactorily when confronted with social and physical challenges and at the same time are capable of changing" to benefit from impacts of drivers of change (Huntjens et al. 2012, 70). In the selected action situation, considerable efforts have enhanced the capacity of the current systems (riverine and stormwater infrastructure) to absorb disturbances while remaining functional under various ranges of storm surge or precipitation using a combination of GI and structural measures on a local scale. Despite considerable efforts, the lack of coordinated efforts among neighbouring municipalities and CAs on a broader scale to consider drivers of change, including climate change and change household behaviour, can jeopardize FRM efforts as discussed by urban planners, CA staff members and NGO directors.

To create a flexible process, it is better to revisit and reevaluate institutional arrangements and decision-making processes to adapt to and benefit from changes in the broader context of social-ecological systems (Egan and de Loë 2020, de Loë and Patterson 2017b, Difrancesco and Tullos 2015). Increasing redundancy in flood-related infrastructure and governance systems facilitates the flexible process (Asokan, Yarime and Esteban 2017, Anvarifar et al. 2016, DiFrancesco and Tullos 2014). For example, by increasing the infrastructure capacity to hold excess water and by duplicating some roles and responsibilities in polycentric governance, which will, in turn, enable actors to change roles and responsibilities in reaction to the changes in boundary conditions to allow for risk mitigation in case of emergencies (Difrancesco and Tullos 2015, Tempels and Hartmann 2014). Another example of flexible processes in water resource engineering regarding flood management is designing. The participation of local actors in the development of regional and national advisory committees is one example that will increase redundancy in polycentric governance. Updating policy and technical guidelines in current systems, addressing the long term FRM gap that exists at different levels of governments, and creating room for private actors to participate in FRM are opportunities that can enhance the robustness and flexibility of the FRM process (McNeil 2020, Bergsma 2018, Cutter et al. 2018).

3.7 Conclusion

Drivers of change are altering the baselines, conditions, and outcomes in FRM while adding to complexity and uncertainty in FRM (TRCA 2019b, Feltmate and Moudrak 2021, Berndtsson et al. 2019). Developing a framework that identifies these drivers of change and accounts for their impacts on the FRM system is critical for FRM adaptation and mitigation (Winsemius et al. 2016, Berndtsson et al. 2019). Our conceptual framework was built on CIS (Cole et al. 2019), a recent diagnostic approach that also builds on SES scholarship (de Loë and Patterson 2017), and

modified institutional design principles (Huntjens et al. 2012). The conceptual framework allowed us to identify thirteen drivers of change and to conduct both a high-level and in-depth analysis of the case study action situation, the City of Toronto FRM system to identify current actors. We identified 13 drivers of change and organized these drivers into five broad categories: Policy (POL), Economic (ECO), Technology (TEC), Environment (ENV), and Social (SOC). Through assessing the impact of drivers of change on the action situation, our research proposed opportunities through which the FRM system can be strengthened to adapt to and cope with drivers of change and their impacts in addition to current efforts by the City of Toronto and TRCA to address the increasing risk of flooding and vulnerabilities. It is essential to strengthening nested polycentric governance, and flexible processes, and equal and fair (re) distribution of risks, benefits and costs among all actors who share the responsibility to manage and mitigate the risk of flooding if we are to successfully guide adaptation and mitigation to face drivers of change and their impacts.

Chapter 4

Rethinking governance of flood risk: lessons learned from the Port Lands Flood Protection Project

4.1 Introduction

The risk of flooding is rising globally. According to the World Resources Institute (Ward et al. 2020), floods are predicted to impact 230 million people annually by 2030. The total damages due to flooding in urban areas are estimated to exceed over US$ 700 billion annually by 2030 ((Ward et al. 2020). In Canada, the projected annual cost of disaster financial assistance (DFA) is estimated at over 673 million just for flood events (Canadian Parliamentary Budget Officer 2016), which accounted for 75 percent of DFA weather expenditures during 2016-2021. This increasing damage has drawn government attention to these escalating threats and to direct economic losses that can be exacerbated by drivers of change not normally considered or addressed by people working within the flood risk management (FRM) field. For the purpose of this study, we define drivers of change as natural or human-induced factors that directly or indirectly cause a change in the risk of flooding or the ways in which flooding is managed or governed.

In urban areas, growth and development pressures, housing needs and demands, the push for sustainable development and provision of green space are some examples of key drivers of change that impact the increasing risk of flooding (Teicher 2018, Bixler et al. 2020). Despite increasing awareness regarding the impact of drivers of change, the need to assess the flexibility of FRM systems to account for the impacts of drivers of change has not been addressed sufficiently to create solutions and opportunities for adaptation and risk mitigation (Baird and Plummer 2020, Difrancesco and Tullos 2015). Drivers of change are altering the pre-existing conditions under which baselines, models, and measurements are set, including guidelines, policies, and strategies through which success and failure of the projects are assets and determined (Winsemius et al. 2016, Hartmann and Driessen 2017). Therefore, it is critical to examine current FRM efforts, including flood protection projects, to study the impacts of drivers of change and the flexibility of current projects in managing drivers of change and their impacts.

The Don Mouth Naturalization and Flood Protection Project (DMNP) is one of the many flood risk management efforts conducted by the City of Toronto, Canada, along with other partners, to reduce the risk of flooding and to revitalize urban areas in the city (City of Toronto 2019a, TRCA 2021b). The DMNP provides an excellent opportunity to examine the institutional arrangements which guide the diversification of FRM approaches to reduce the risk and probability of future flood events. Importantly, the DMNP also focuses on spatial planning, land use development and demand management regarding future development. Thus, to ensure the success of flood protection projects such as DMNP, it is critical to account for social-ecological systems that impact the project and can be impacted by the project (Waterfront Toronto 2016b, TRCA 2021b, TRCA 2014a). Examining this project using a Combined Institutional Analysis Development and Social-ecological Systems (CIS) framework that draws on Ostrom's view of social-ecological systems assessment approach enables a deep understanding of the contextual factors, linkages and outcomes in such projects (Cole et al. 2019). This study is part three of our

research project focusing on identifying drivers of change in FRM systems. In the first part, we identify categories of drivers of change using a systematic review of FRM literature (Chapter Two). The second part of the research is built on the result of the systematic review, which is an empirical analysis was conducted to examine drivers of change in City of Toronto (Chapter Three). These two parts set foundations for this study in which we briefly identified drivers of change and then used CIS to guide a flexibility assessment of the DMNP to address three research questions: (1) What are the most noted drivers of change that influence the flexibility of flood management to reduce and manage risk? (2) How are institutional actors in flood management organized to adapt to and cope with drivers of changes and their impact? (3) In which ways can the flexibility of FRM and water governance be enhanced so that they can better accommodate drivers of change? In addition to exploring these research questions, our analysis sheds light on potential implications for water governance while presenting lessons learned from assessment of the Port Lands Flood Protection Project.

4.2 Identify flexibility metrics within the governance system

The impacts of drivers of change (e.g., change in weather patterns) on flood regimes and types of flooding have been evident for a long time (Winsemius et al. 2016, Cole et al. 2019), although recently scholars and practitioners have discussed drivers of change and their impact on FRM manageability and governability (Berndtsson et al. 2019, Muir 2018). Drivers of change alter social, economic, and environmental conditions incrementally or disruptively to undermine the FRM efforts to reduce the risk of flooding and improve flood protection (O'Connell 2017, Francesch-Huidobro et al. 2017). For instance, increasing housing prices can influence social and economic conditions and hinder the effectiveness of institutional and policy interventions.

The systematic review of FRM systems reveals that there is a lack of integration among drivers of change and FRM research and suggests developing a method or framework to better understand drivers of change (Chapter Two). In the second part of the analysis, we developed a framework that can assess FRM policy, intervention and projects while accounting for drivers of change and their impact by mapping the interlinkages between factors and conditions, processes, and rules and norms that affect actions and interactions among actors that form outcomes. We tested the framework in the empirical setting focusing on the City of Toronto. This resulted in identifying 13 drivers of change and organized these drivers into five broad categories: Policy (POL), Economic (ECO), Technology (TEC), Environment (ENV), and Social (SOC) in the context of the City of Toronto (Chapter Three). The developed framework is used in conducting this study to identify drivers of change in DMNP.

The conceptual framework includes the modified CIS (Combined Institutional Analysis Development and Social-ecological Systems) integrated with de Loë and Patterson (2017b)

diagnostic approach to analyze complex social-ecological interactions of the selected action situation with a broader context (see Figure 4-1).

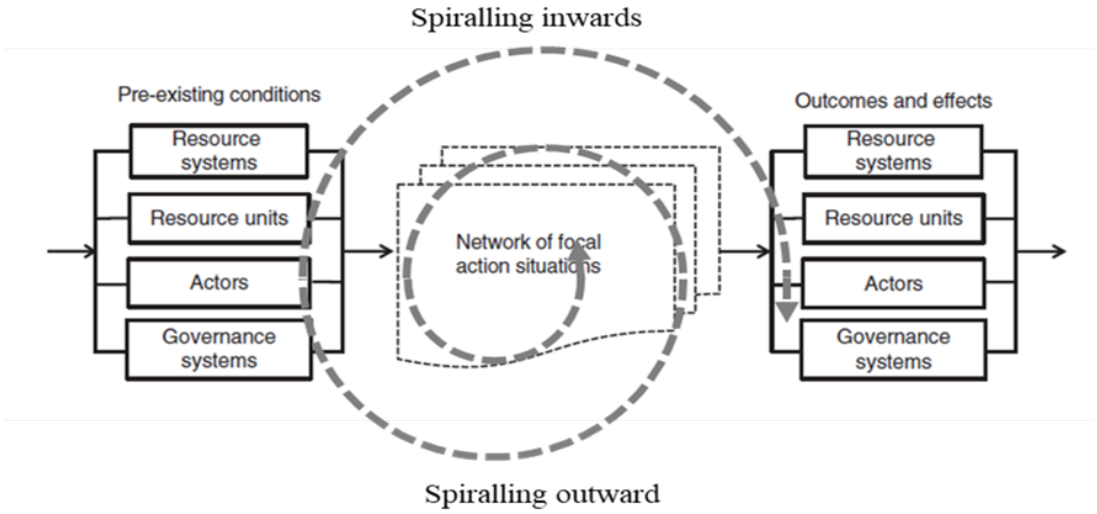

Figure 4-1: The conceptual framework

The adopted modified CIS framework is well-suited to address issues involving drivers of change (see Figure 4-1). The framework is built on IAD's ability to provide "breadth, clarity and structure by drawing the analyst's attention to the range of variables and questions to be considered when [conducting the research]" (Whaley and Weatherhead 2014, 1). The diagnostic approach is built on four-step processes. The first step is to define the action situation as clearly as possible. The second step, "spiralling inwards," allows us to determine if a FRM perspective is appropriate. The final two steps promote inquiry into interactions "external" to the selected action situation, which involves "spiralling outwards" to explore broader interactions and their impact on current FRM contextual factors (Egan and de Loë 2020). A diagnostic approach facilitates performing both a cursory and in-depth analysis in a particular action situation (Egan and de Loë 2020, Partelow 2018), which is useful in identifying the drivers of change and their impact on the selected FRM system.

Flood protection projects are evolving by moving away from large-scale flood control infrastructure projects (1930-1960) towards nature conservation by the 1970s. Around the 1980s, flood protection projects were designed to coordinate the development and management of water by focusing on maximizing economic benefits and social welfare while promoting sustainability through the Integrated Water Resource Management (IWRM) concept (Serra-Llobet et al. 2016, Global Water Partnership 2004). These efforts to address the increase in flood damages, mounting financial damages and uncertainties led to the introduction of risk-based assessment methods in flood protection projects design around the 1990s (Sandink et al. 2016, Hegger et al. 2018). These methods are still evolving, with recent flood protection projects around the world. FRM is also grappling with issues around adaptability and resiliency due to climate variability

and uncertainty using green infrastructure, restoration, and naturalization of rivers (TRCA 2014b).

In urban areas, flood protection projects have addressed flood control objectives while accounting for sustainability and conflicting social, economic, political interests of actors impacting or impacted by the project (Vojinovic et al. 2016, Begg 2018, Hino and Hall 2017). The success of these projects requires the inherent ability to cope with or adapt to uncertain and changing conditions in a timely and cost-effective manner. This ability is defined as *flexibility* in water resources management (Difrancesco and Tullos 2015, Tempels and Hartmann 2014).

The flexibility metrics developed by DiFrancesco and Tullos (2014) are focused on characteristics of the water systems, especially flood management systems which highlight the ability to cope with and adapt to uncertain and changing conditions. This research adopts the main metrics (see Table 4-1) from DiFrancesco and Tullos (2014)'s research. However, we modified some of the variables to account for the flood protection mechanism and pre-existing conditions in a complex urban environment for the purpose of this study. This study focuses on an empirical setting to conduct in-depth investigations and scientific inquiries to identify the most noted drivers of change and assess its flexibility in facing the impacts of these drivers.

Table 4-1: Modified flexibility metrics based on DiFrancesco and Tullos (2014)

Metrics	ID	Description
Slack	S1	Excess stream capacity: calculated as the stream conveyance capacity over the expected discharge during an x-year flood event
	S2	Excess capacity to release and convey floodwaters: calculated as the stream conveyance
	S5	The diverse pool of organizational, operational, and managerial resources for maintenance and operation
Redundancy	R1	Surface storage options
	R2	Structural vs. nonstructural diversity
	R3	Delegation of management responsibility
Connectivity	C1	Groundwater and surface water connections
	C2	Potential for floodplain connection
	C3	Public engagement and management/ governance
	C4	Infrastructure and public needs
Compatibility/ coordination	CC1	Access to data
	CC2	Access to data analysis tools: water managers have tools and the ability to analyze and utilize
	CC3	coordination of operations and management across scales and among local level institutions
Adjustability	A1	Ability to revise operations plans: level of governmental approval needed to adjust current and future needs
	A2	Opportunities to adjust the need

	A3	Ability to expand storage and conveyance capacity with levee setbacks: calculated as the percent of levees with greater than an x m buffer to infrastructure

4.3 Data and Methods

To identify the most noted drivers of change and to assess the flexibility of the flood protection project, we followed a four-step analysis informed by the conceptual framework (see Section 4.2). The first step of this four-step analysis focuses on defining the action situation as clearly as possible. The second step, "spiralling inwards," allows us to determine if a FRM perspective is appropriate. The third step critically reflects on the boundaries of the current action situation to facilitate the final step of the analysis, which focuses on identifying opportunities to improve governance by assessing the flexibility of the FRM system to account for drivers of change in the selected action situation. The final two steps promote inquiry into interactions "external" to the selected action situation, which involves "spiralling outwards" to explore broader interactions and their impact on current FRM contextual factors.

The conceptual framework also guided data collection. It informed the selection of institutional arrangements and helped identify actors whose insights have proven useful for the purposes of this research (see Section 4.1). Four different sets of data were collected, including semi-structured interviews, document analysis, personal observation, and a broad scan of Twitter Posts. Data triangulation was used to ensure rigour, accuracy, and validity among all four data sets.

The semi-structured interviews were conducted by telephone and in-person between 45 minutes to two hours with 20 participants who are knowledgeable or working in the Don Mouth Naturalization Project (DMNP), the City of Toronto, TRCA and the other involved organizations from 2018 to 2020. The semi-structured interviews provided rich data on participants' perspectives on the selected set of variables impacting the selected action situation (Roller and Lavrakas 2015). Study participants were selected using a purposive sampling technique, which involved connecting with senior leaders who are knowledgeable about the technical and socio-economic side of the project and can speak about the policy and governance aspects (Roller and Lavrakas 2015, Zeegers and Barron 2015).

In addition to primary data collected through semi-structured interviews, three secondary data sources were used for the study: document review, personal observations, and Twitter posts. In total, 62 documents that guide the structuring of the projects were analyzed. These included the City of Toronto official plan, EAs, Community Based Risk Assessment reports, progress reports, design review documents, and the Port Lands Planning Framework. These documents provided insight on pre-existing conditions and exposed path dependencies that impact the current selected action situation and will impact future actions and outcomes (Cole et al. 2019, Hollstein 2011).

Personal observation and field notes were collected by the first author during participation in multiple public consultation meetings in person or online regarding the development of the project. These provided detailed information on hydraulics and hydrometric, land use planning, design, ecosystems services, and details of construction (e.g. Public meeting July 18^{th,} 2018, December 4^{th,} 2020). Field notes were gathered by the principal researcher on public reactions and comments in the meetings. Finally, a broad scan of Twitter posts was used to collect

supplementary data. The scan focused on the hashtags #PortLands2024 #TRCA # TOwaterfront (60 posts) between 2019 up to 2021. Personal observations and the Twitter posts were important because they provided extensive and less intrusive ways to gain perspectives on different dimensions of the project not captured by the other two data sources (Hollstein 2011).

Data analysis was guided using the framework presented in Figure 4-1. All data were organized and analyzed using QSRNvivo version 10. The data analysis was divided into two parts (see Table 4-2). First, to spiral outward, all three sets of data were coded separately using a simultaneous analysis, which showed the perspectives presented in each dataset. Then a convergence analysis was used to bring the deductive and inductive codes and themes together to identify the most noted drivers of change on the selected action situation (Brannen 2005). The content analysis approach was used to identify the most noted drivers of change in DMNP. In addition, a reflective process was conducted to identify and condense units codes and categories using a systematic classification with a continuous deductive, inductive process of coding and categorization (Walsh and Downe 2004, Liamputtong 2013). To build on the systematic review of literature (Chapter Two) and following the developed conceptual framework (Chapter Three), this stage of analysis produced categories of drivers of change in which drivers with a similar domain of influence or origin were clustered together. Categories created were *Environment* (ENV), *Policy* (POL), *Technology* (TEC), *Economic* (ECO), and *Social* (SOC). These categories are created to present the results in a way that is compatible with the FRM approach in addressing vulnerability and risk assessment (Sandink et al. 2016).

To spiral inward, a thematic analysis was conducted through the lens of the conceptual framework focusing on the flexibility metric and the impact of drivers of change on the selected action situation (see Figure 4-2). The thematic analysis identifies patterns for detailed coding and analysis from within the larger body of text that has "at minimum described and organized the possible observations and a maximum interpreted aspects" of the FRM institutional arrangement in which drivers of change can be acknowledged or addressed effectively (Boyatzis 1998, 161). A sample of the coding process that was conducted for the four-step analysis is presented below, which allows us to conceptualize a system of interactions between themes which forms our results and analysis section (see Table 4-2).

Table 4-2: Variables and codes in two-tier analyses

Purpose of the analysis	**Example of codes**	**Consideration**
Drivers of change	Change in weather patterns Forces, Known and unknown factors Pressure New mindsets Change in public demands and needs	The scale of influence Temporal impacts Degree of influence (incremental and disruptive)

Flexibility metrics	Capacity Water conveyance design and systems Organizational structure Operation Structural and non-structural measures	Enabling and constraining factors (policy, funding, vision, acceptance, technical constraints, natural constraints,

The first step of the analysis is presented in the next section, where the Port Lands Flood Protection Project is the selected action situation (see Figure 4-1). By spiralling inward, following the second step of the analysis, we identified actors and broad perspectives in the selected action situation. The outcomes of the third and fourth steps of analysis will be presented in the result section, in which we explore the most noted drivers of change and assess the flexibility of the FRM process in facing the identified drivers of change.

4.4 Action situation: The Port Lands Flood Protection Project:

The Government of Ontario has established a policy framework to manage natural hazards, including flooding, using two-tier zoning or Special Policy Area (SPA) approach (MNRF 2020, McNeil 2020, Conservation Authorities of Ontario 2010). In this approach, the flood plain is divided into two major zones: floodways where new development is prohibited and flood fringes where new development can be permitted under specific conditions to address the risk of flooding (Conservation Authorities of Ontario 2010). The SPA approach provides the planning policy with a tool to address a circumstance in which development has occurred in existing flood vulnerable areas (see Figure 2), considering social economic risk in the existing developments (City of Toronto 2015). SPAs mechanism activates a process through which various local levels (municipalities and Conservation Authorities) have to work with provincial partners, including the Ministry of Natural Resource and Forestry (MNRF) and the Ministry of Municipal Affairs and Housing (MMAF), to tailor a suitable approach for that area (City of Toronto 2015, TRCA 2008). The Lower Don: Don River in Toronto is one of the ten special policy areas (City of Toronto 2015, TRCA 2008), with the largest area stretched along the waterfront (see Figure 4-2).

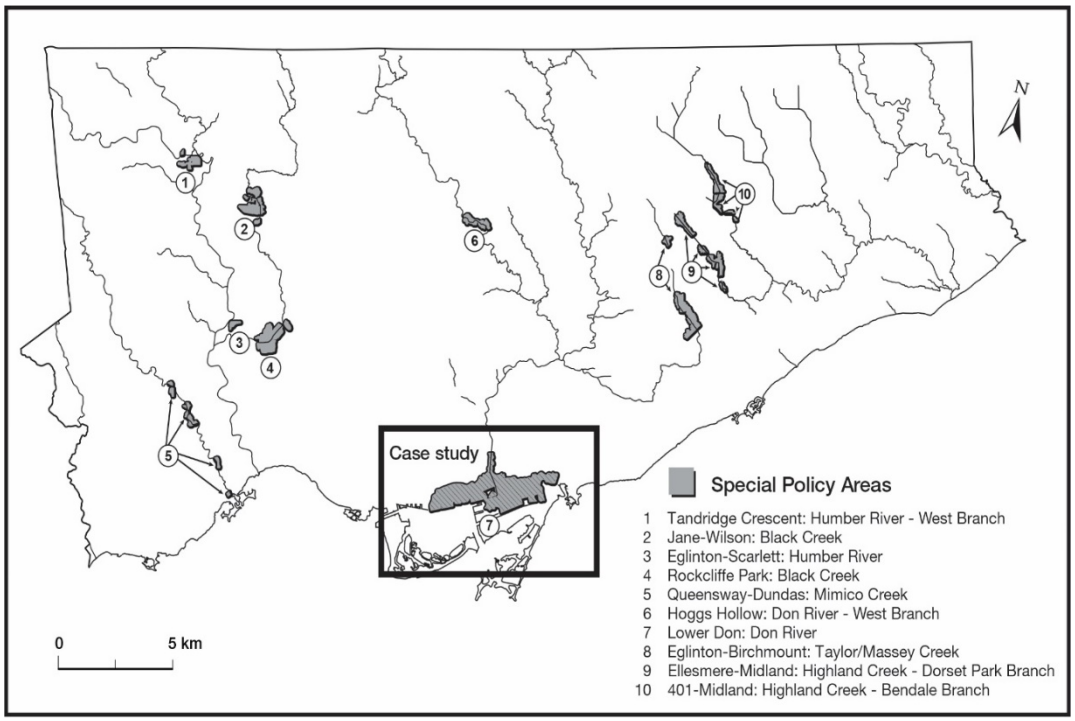

Figure 4-2: Special Policy Area modified from the city of Toronto Planning Division

The Don River spans approximately 360 km^2 in a heavily urbanized area (see Figure 4-2), including the City of Toronto. Prior to development, the long land lakefront was covered by forest and marsh habitats (TRCA 2008, TRCA 2018). The alteration of physical habitats and land uses over time has resulted in profound changes in the river mouth area (see Figure 4-2), which contains an "altered, hardened, artificial channel, sheltered from the lake, and continuously dredged" (TRCA 2014a, 5). The channelization and industrialization of the Don Mouth area have disconnected the area from the urban growth and development in the City of Toronto and have drastically degraded the ecological value in its terrestrial environment (TRCA 2014a). The impact of the built environment, including an outlet that is too narrow for flood conveyance under the Canadian National Railway and other utility bridges, combined with the nature of the river, which tends to fill with sediments, have exacerbated the risk of flooding in this area (TRCA 2014a). To reduce the risk of flooding, the TRCA removed an average of 30,600 cubic meters of dredged sediment each year, which impacts the quality of water and the aquatic habitat in the Inner Harbour (TRCA 2014a).

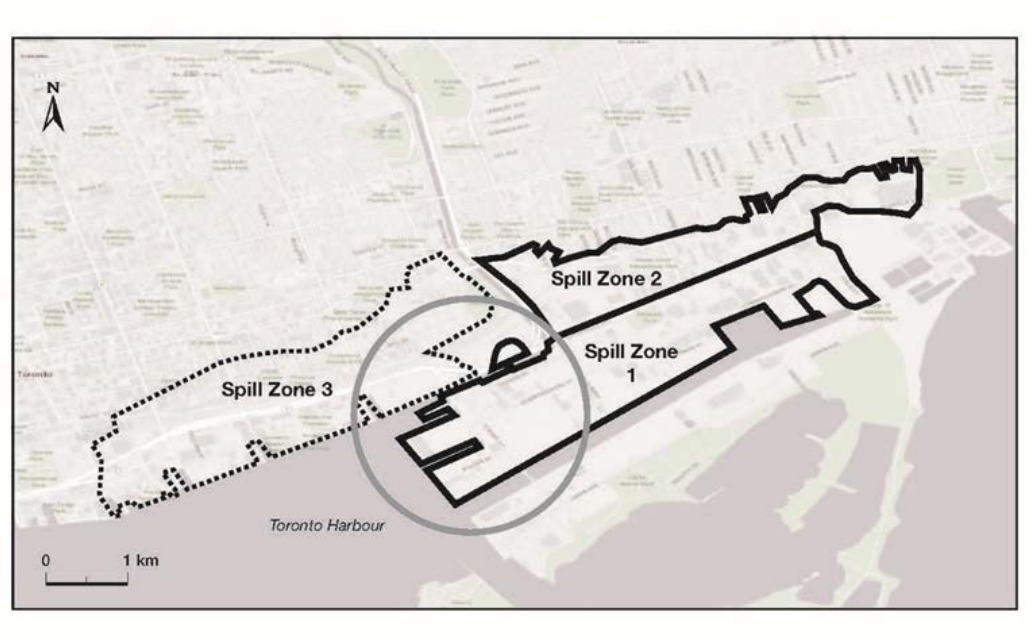

Figure 4-3: Regulatory flood modelling modified (TRCA 2014a)

The public attempt to restore the Don Mouth area, and to reconnect it with the 290 hectares southeast of downtown Toronto, started around 1989 and still is ongoing (Waterfront Toronto 2021a). The revitalization of the Don Mouth area (see Figure 4-3) as a SPA is conditional on a complete and functional flood protection infrastructure (City of Toronto and Waterfront Toronto 2017). The collaboration of three levels of governments to address Toronto's waterfront restoration started in the 1990s and resulted in the formation of Toronto Waterfront Revitalization Corporation, which advocates for the public interest toward revitalizing and boosting social, economic, and ecological conditions along the waterfront (Flynn and Valverde 2019, Eidelman 2013). The analysis shows DMNP culminated from a collaboration of different actors and the support of the public. Thus the FRM system fits the definition of polycentric governance systems as the organization of small-, medium-, and large-scale democratic units that each may exercise considerable independence to make and enforce rules within a circumscribed scope of authority for a specific geographical area''(Ostrom 2001, 2). Waterfront Toronto's collaboration with partners (see Figure 4-4) has created a foundation for strong polycentric governance.

The DMNP, as one of four main projects identified by Toronto Waterfront (previously known as Toronto Waterfront Revitalization Corporation), has been through numerous iterations for planning and reviews by diverse sets of actors (see Figure 4-4). Don Mouth Naturalization and Port Lands Flood Protection Project Environmental Assessment was initiated by TRCA in 2004 and was approved by the province in 2014. The project secured $1.25 billion in shared funding announced by the governments of Canada, Ontario, and Toronto to deliver the full Port Lands Flood Protection project in 2017. The project is going to be delivered in 2024 (Waterfront Toronto 2021a). To deliver the DMNP, actors at different levels (from international to local) have been working together (see Figure 4-4); this illustrates the increasing complexity of flood control projects, especially within urban areas

Figure 4-4: Actors in DMNP

4.5 Results:

The result section has two main parts. The first part summarizes the most noted drivers of change under five categories Policy (POL), Economic (ECO), Technology (TEC), Environment (ENV), and Social (SOC). We identified the five most noted drivers of change (see Table 4-3) in DMNP, which are nested in broader categories of drivers of change that impact the City of Toronto FRM systems (Chapter Three). Following the conceptional framework, the second part presents the flexibility assessment of the DMNP facing the identified drivers of change. The result of the flexibility assessment is also presented in five parts focusing on Slack, Redundancy, Connectivity, Compatibility-Coordination, and Adjustability. These findings emerged from conducting the third and fourth steps of the conceptual framework: an inquiry into interactions "external" to the selected action situation. Together these two parts shed light on lessons learned by exploring DMNP and ways in which the process is shaped to account for drivers of change. These lessons will be explored in detail in the discussion section.

4.5.1 Drivers of change

In this study, we identified five main drivers of change (see Table 4-3) that impact the FRM in the DMNP. These drivers of change are classified into five categories, including Technology (TEC), Policy (POL), Economic (ECO), Environment (ENV), and Social (SOC).

Technology (TEC): The most noted driver of change mentioned by 14 participants is *relying on structural measures to reduce the risk of flooding (TEC1).* The structural solution is considered the primary solution selected by flood policy and decision-making systems. These insights highlight the concerns around the uncertainty of using new methods and the unknown risk attached to their use. The DMNP follows this trend, despite a strong focus on the naturalization process, presence of natural-based solutions (e.g., designed wetland as runways, designed vegetation inbuilt flood plain), the foundation of the DMNP is a channel designed to mimic the natural flow of a river which was described by urban planners, and TRCAs staff members and emphasized by document analysis (TRCA 2014a, Waterfront Toronto 2016b).

Policy (POL): *Changes in the current institutional arrangement (POL1)* are highlighted as a driver of change by TRCA staff members and urban planners. Both planning and development of the DMNP are built on the collaboration of public and private actors to share risk and financial resources (see Figure 4-4). The example that shows the change in institutional arrangement include altering the Provincial Policy Statement (Conservation Authorities of Ontario 2020); reducing the role of the Conservation Authority to guide development and changing the building codes to facilitate the development in DMNP proposed by the provincial government

Economic (ECO): The projected economic impacts of the project (e.g., added value to the Canadian economy, full-time employment, and added tax revenue) provided incentives for funding DMNP (Waterfront Toronto 2016a). *Real estate and residential demands (ECO1)* are considered the main driver of change, which impacts the current and future planning and development of the DMNP as stated by urban planners and NGO directors as highlighted by documents (e.g., City of Toronto and Waterfront Toronto 2017, Waterfront Toronto 2016b).

Environment (ENV): *Change in the weather pattern and climate variability (ENV1)* is the most noted driver of change that impacts the DMNP. This driver of change was mentioned by 20 participants, including TRCA staff members, urban planners, NGO directors and Waterfront

Toronto staff members and confirmed by document analysis (e.g., TRCA 2021b, Waterfront Toronto 2021b, TRCA 2021a). Change in the weather pattern manifests itself as increasing precipitation, ice jams, or high lake levels (TRCA 2018, TRCA 2014b). The review of design documents shows detailed attention to precipitation and temperature variability in modelling, which guided the design of the flood protection structure (TRCA, City of Toronto and Toronto 2013, Lura Consulting 2009, TRCA 2021a). Nonetheless, in comparison, less attention is dedicated to the impact of high lake levels, which according to various sources (TRCA , IJC , USACE), have exceeded historical levels in recent years (2017, 2019).

Social (SOC): Public participation and public support have been the cornerstone of the development of the DMNP, and they have also driven the changes in the project as highlighted by all participants and confirmed by personal observation (e.g., open house February 2018 and July 2018) and document analysis (Comparey and Shenker 2020, Lura Consulting 2009). The change and trends in demands (SOC1) are highlighted as a driver of change with an impact on the project's development

Table 4-3: The most noted drivers of change

Driver of change	Impact	Scale	Identified by
TEC: Relying on structural measures to reduce the risk of flooding	Hazard and vulnerability	Local	Urban planners, and TRCAs staff members and document analysis (TRCA 2014a, Waterfront Toronto 2016b)
POL: Changes in the current institutional arrangement	Vulnerability	Provincial to Local	Waterfront Toronto staff members, TRCA staff members, and urban planners (Fox 2018, TRCA 2021b)
ECO: Real estate and residential demands	Vulnerability	Global to Local	Urban planners and NGO directors as highlighted by (City of Toronto and Waterfront Toronto 2017, Waterfront Toronto 2016b)
ENV: Change in the weather pattern and climate variability	Hazard	Regional to Local	TRCA staff members, urban planners, NGO directors and Waterfront Toronto staff members and confirmed by document analysis (TRCA 2021b, Waterfront Toronto 2021b, TRCA 2021a)
SOC: The change and trends in demands	Vulnerability	Local	Urban planners and confirmed by personal observation open house February 2018 and July 2018) and document analysis (Comparey and Shenker 2020, Lura Consulting 2009)

4.5.2 Flexibility assessment: accounting for drivers of change

We used the modified flexibility metrics (Baird and Plummer 2020, Difrancesco and Tullos 2015) to assess the project's ability to cope with and adapt to uncertainty and change. In the last two

steps of analysis guided by the conceptual framework (see Figure 4-1), we examined the DMNP and identified FRM efforts and actions that have improved the flexibility of the project facing the impacts of drivers of change. We also highlighted potential points which can result in inflexibility of the project when facing change and uncertainties. Due to the stage of the project and the possibility of change in the unfunded parts of the project, we were not able to calculate system flexibility. Nonetheless, we will highlight the actions that would increase or pose a challenge to the project's ability to cope with or adapt to uncertainty.

Slack is defined as the degree of excess capacity enhanced by a strong Public-Private Partnership (Waterfront Toronto 2013) and can address the driver of change in the policy category. The result of flexibility analysis (see Table 4-4) highlights slack in both flood protection and structural design (e.g., river system and its banks as well as Keating Channel and the designed spillway as a wetland) as well as flood management and governance system (strong public-private partnership formed and guided by Waterfront Toronto). Having waterfront Toronto as the public sector partner enhances the slack in FRM by representing all three levels of government and balancing private partnership and public interests. The role of Waterfront Toronto in DMNP was emphasized by an urban planner and NGO director (see Table 4-4). Despite limited financial power (e.g., they are not allowed to borrow money and cannot use assets as collateral), Waterfront Toronto has expanded its influence by harnessing local/public support by holding community meetings and utilizing a diverse set of media to inform the public on the project design, development and progress (Flynn and Valverde 2019, Bunce 2017)

Table 4-4: Flexibility of DMNP facing the most noted drivers of change- Slack

Metrics	ID/ Description	DMNP actions increasing flexibility	Potential challenges	Impact	Driver
Slack	S1: Excess stream capacity:	Convened through the naturalized river system, riverbed, slope armouring, and the park design around the river.	The hydraulics and hydrology modelling and calibration for the case study of the DMNP	Hazard	ENV, TEC
	S2: Excess capacity to release and convey floodwaters	The naturalized river system, the existing Keating Channel, and the designed spillway will function as a wetland	The issue of high lake level which was occurring after conducting the EA	Hazard	ENV TEC

	S3: Organizational pool of expert	Conducting two separate EAs: (1) focused on flood protection and naturalization, and (2) focused on roads, bridges, connectivity, and land use. Port Lands Flood Protection and Enabling Infrastructure Due Diligence amalgamate both naturalization and infrastructure	The complexity of the project and the number of actors involved	Vulnerability	POL

The City of Toronto and TRCA, and Waterfront Toronto create a dynamic governance system (see Figure 4-4) that can harness the innovation using privately ordered and publicly regulated arrangements to address flooding issues focused on Toronto's waterfront as highlighted by the City staff members, TRCA staff member and urban planners. In addition to TRCA's expertise on flood management and risk assessments, partnering with private companies facilitated by Waterfront Toronto enables public partners to share risk and other burdens (e.g., legal, financial, and professional) on the design, planning and implementation of the flood protection project (Waterfront Toronto 2016b, Margerum and Robinson 2015, Hegger et al. 2014). Current slack in the FRM and governance system also can address change in current institutional arrangements (Difrancesco and Tullos 2015, Baird and Plummer 2020), which was previously identified as a driver of change (POL1) with impacts on the DMNP. For example, changes in the Provincial Policy Statement that reduce the role of Conservation Authority as highlighted by NGO directors, urban planners and Conservation Authority staff members (PA# 11, 18, 17) to guide development might be offset due to the involvement of other public actors (Conservation Authorities of Ontario 2020). Nonetheless, the changes in institutional arrangements impact the project, and the degree of these impacts depends on how contracts and collaboration have been previously established (Havemann et al. 2016, Margerum and Robinson 2015, Erisman et al. 2015).

Redundancy facilitated by funding diversification has addressed the driver of change (ECO1) in the economic category (see Table 4-5). The diversity of financial resources has provided the DMNP with a degree of repetitiveness and diversity to meet the goals and objectives (Petridou and Olausson 2017, DiFrancesco and Tullos 2014). The secured funding of 1.25 billion provided by three levels of government has established the main critical infrastructure, including flood protection measures, transit, and utilities (Waterfront Toronto 2018). The due diligence reports break down the estimated cost for different parts of the project through the recommended scope of the cost (Waterfront Toronto 2016b). Revisiting the project components and their cost by putting more emphasis on the site condition and potential costs (Waterfront Toronto 2016b) resulted in the fact that some other components were deferred to find funding which can be sourced by municipal services, private sector funding (e.g., Hydro One, development charges, private investment), or other governmental funds that the project can be eligible for later on (e.g., infrastructure funds or climate change adaptation funds) noted by urban planners, Waterfront

Toronto staff and NGO directors and confirmed by document analysis (Waterfront Toronto 2016a, Waterfront Toronto 2021b, Flynn and Valverde 2019).

The flood protection project enables further development in the area, which can be labelled as growth-related projects that give the power to the City of Toronto to collect development charges to increase the municipal capital funding and cash flow that is needed for maintenance and operation of the flood protection measures in the long term highlighted by urban planners and the city staff member (see Table 4-5). The financial redundancy of the project balances some parts of the financial risk that the flood protection project is facing (Alaerts 2019, United Nations Environment Programme 2007) while enabling the project to cope with the changes that the economic driver of change imposes (e.g., changes in market demands for residential units in the City of Toronto). The redundancy in the project also empowers the decision makers to choose between scenario, design options, and implementation, which costs more but fits better considering the social-ecological characteristics of the project (Petridou and Olausson 2017, Difrancesco and Tullos 2015) and addressing the need of the residents as it happened by conducting the due diligence report in the DMNP highlighted by urban planners and NGO directors (PA# 22, 11).

Table 4-5: Flexibility of DMNP facing the most noted drivers of change- Redundancy

Metrics	ID/ Description	DMNP actions increasing flexibility	Potential challenges	Impacts	Driver
Redundancy	R1: Surface storage options	15 hectares of green space and wetland, which will transform to a spillway to existing ship channel in a Regional storm event	The issue of high lake level which was occurring after conducting the EA	Hazard	ENV TEC
	R2: Structural vs. non-structural diversity	Examples of structural measures: Change in landform, adjustable upstream weir, side-flow weir, Combination of structural and non-structural: Bioengineered bands, a soil conservation technique using plants Non-structural measure: designed vegetation and parks	Maintenance and operation issues Some of the non-structural factors are not currently funded in the project	Hazard and vulnerability	ENV TEC

	R3: Delegation of management responsibility	Using Construction Manager/General Contractor (CM/GC) while collaborating with various local-global partners	The collaboration is bounded by the contract, which might not consider the potential change in the process	Vulnerability	POL ECO

Connectivity of the project to broader social-ecological systems established on Watershed Management Approach (PA# 11, 19, 17, 5) has provided some solutions to drivers of change (ENV1) in the Environment category (see Table 4-6). Our analysis shows the DMNP flood protection project has been connected to components inside (e.g., utility project and transit project) and outside (e.g. addressing the Toronto Area of Concern) of the project (City of Toronto and Waterfront Toronto 2017, TRCA 2014a). The Watershed management approach guided by the Don River Watershed Plan prepared by TRCA provides direction for urban development in the watershed, which was mentioned by half of the participants, including urban planners, TRCA staff members, Waterfront Toronto staff members and NGO directors (see Table 4-6). The Watershed management approach facilitates best management practices and opportunities for environmental stewardship to reduce the risk of flooding and erosion damage as one of its mandates confirmed by document analysis (TRCA 2008, TRCA 2009). The watershed planning approach also provides support for various provincial plans (Consolidation 2020, Government of Ontario 2017b, Government of Ontario 2017a, Government of Canada and Government of the United States of America 2012), including the Growth Plan for the Greater Golden Horseshoe, 2017 (Growth Plan), the Greenbelt Plan, 2017 (Greenbelt Plan), as well as connection to Great Lakes Water Quality Agreement (2012).

Table 4-6: Flexibility of DMNP facing the most noted drivers of change- Connectivity

Metrics	**ID/ Description**	**DMNP actions increasing flexibility**	**Potential challenges**	**Impacts**	**Driver**
Connectivity	C1: Groundwater and surface water connections	Instrumentation of 98 of the boreholes with groundwater monitoring wells to depths of 3.05 to 32.93 m BGS.		Hazard	ENV TEC

	C2: Potential for floodplain connection	The watershed planning for Don rivers provides a holistic view of flood plain connection.	The change in budget and responsibilities of actors involved can have a negative impact	Hazard and vulnerability	TEC ENV
	C3: Public engagement and management/ governance	Long-term public engagement with the public since 1989 by using https://portlandsto.ca/ Regular update on the project via social media (e.g., Twitter #WaterfrontTO, #PortLands2024)	Public comments might change the focus of the project	Vulnerability	ECO SOC POL
	C4: Infrastructure and public needs	Providing residential and office spaces while providing critical infrastructure for transportation and recreation	Change in market and demand	Hazard and vulnerability	ECO SOC POL

The collaboration among TRCA, Waterfront Toronto, and the City of Toronto has improved the connectivity of the flood protection project to a broader social-ecological system highlighted by TRCA staff members, Waterfront Toronto staff members and urban planners (see Table 4-6). The examples of these efforts include addressing urban runoff impact on water quality, erosion control, aquatic systems health, and high lake levels, while also tackling demands on public transit and housing (City of Toronto and Waterfront Toronto 2017, Sutton 2014, Waterfront Toronto 2016b). Connectivity has enhanced the capacity of the project to deal with drivers of change (ENV1), including a high lake level. Nonetheless, more effective and coordinated planning at all levels and scales is needed to address climate adaptation failures which have a noticeable impact on flood risk at local levels (Dieperink et al. 2016, Berndtsson et al. 2019).

Compatibility and Coordination are facilitated by accessing a wide range of data (e.g., real-time gauging, soil composition, and stream flows) and using analysis performed by a collaboration of public and private actors (e.g., as presented in Don River Hydrology Update (TRCA 2018)). This ability to utilize and share information across social-ecological components has enabled the DMNP to be better situated and to coordinate the current (e.g., the Keating channel and the ship channel) and new the structural flood protection measures (the river system) with a designed natural and built environment system (e.g., the proposed parks, wetland, community centers) which was mentioned by TRCA staff members and NGO directors (see Table 4-7).

Table 4-7: Flexibility of DMNP facing drivers of change-Compatibility and Coordination

Metrics	ID/ Description	DMNP actions increasing flexibility	Potential challenges	Impacts	Driver
Compatibility/ coordination	CC1: Access to data	The partnership between the public sector and private sectors resulted in a diverse set of data (e.g., soil quality, marine ecology, flow, precipitation, financial, social, and economic forecasts)	Path-dependency And the need to update the guidelines to address climate change issues	Hazard and vulnerability	ECO SOC POL TEC ENV
	CC2: Access to data analysis tools: water managers have the tools and ability to analyze and utilize	TRCA and the City of Toronto have the tools and expertise to address flood management issues. Waterfront Toronto and its partnership unlock broad opportunities for data analysis	Path-dependency And the need to update the guidelines to address climate change issues Flood related funding	Hazard and vulnerability	ECO SOC POL TEC ENV
	CC3: coordination of operations and management across scales and among local level institutions	Waterfront Toronto, coordinate the management and planning efforts General contractors (e.g., EllisDon Civil Ltd also oversee the DMNP	The change in role and responsibilities can impact collaboration and partnership contract	Vulnerability	POL ECO

A dedicated website https://portlandsto.ca collected all related documents regarding the project (e.g., public participation, reports, plans and historical documents) while providing an update on construction and the advancement on the implementation of the project, as monitored by EllisDon Civil Ltd. and Waterfront Toronto (see Figure 4-4 and Table 4-7: Flexibility of DMNP facing drivers of change-Compatibility and Coordination). Collecting related documents and information that impact the project, including that which was collected and analyzed by the different actors, has positive impacts on the project's ability to address issues generated by drivers of change (TEC2) emerging in technology categories. This coordination can be further improved

by adding information about the entire watershed (TRCA 2018) and the impact of the project on Lake Ontario, for which new updates regarding EA assessment has strengthened this metric with respect to the flexibility assessment (TRCA 2021a)

In terms of **adjustability**, the flood protection project is connected with Port Lands, Toronto's current social-ecological systems (see Table 4-8: Flexibility of DMNP facing the most noted drivers of change-Adjustability) and through the amalgamation of the Port Lands Flood Protection and Enabling Infrastructure project (Waterfront Toronto 2016b). Adjusting these connections with respect to social-ecological changes, future growth, and development has been considered through the Port Lands Planning Framework (City of Toronto and Waterfront Toronto 2017). The framework is the product of four years of collaboration between public and private agencies, including but not limited to the City of Toronto, TRCA, and Waterfront Toronto, the Toronto Transit Commission, Hydro One Network Inc., Public Work, Dillon Consulting Ltd., Archaeological Services Inc., and CH2M. The framework moves beyond the DMNP and plans for the wider area in which the flood protection project is situated which was discussed by urban planners and NGO directors.

The planning process allows the public to share their inputs on broader social-ecological issues (land use directions, green infrastructure, biodiversity, parks, open spaces). The Port Lands Planning Framework has enhanced the ability of the flood protection project (see Table 4-8) to add, modify, and remove components in a broader system where the flood protection project is located to adjust for needs and drivers of change (SOC1) originated in the social category. Nonetheless, the adjustability of the structural components of the project becomes limited due to the path dependency of the previous structure (e.g., channelization) and design of the project, including the excavation of the river system (TRCA 2014b, TRCA 2021a).

Table 4-8: Flexibility of DMNP facing the most noted drivers of change-Adjustability

Metrics	ID/ Description	DMNP actions increasing flexibility	Potential challenges	Impacts	Driver
Adjustability	A1: Ability to revise operations plans level of governmental approval needed to adjust current and future needs	The iterative process has provided the ability to revise the project focus on the urban and land use planning part. A regulatory approach is taken to meet the governmental guidelines	Time-consuming Change in interests Change in guidelines	Hazard and vulnerability	POL

	A2: Opportunities to adjust the need	Port Lands Planning Framework provides opportunities to adjust the need for future land use planning.		Vulnerability	POL ECO
	A3: Ability to expand storage and conveyance capacity	The design of the structural and non-structural part of the project provides the ability to expand the flow and capacity of the river in large storm events	Path dependency	Hazard and vulnerability	TEC POL

4.6 Lessons learned and governance implications

Our analysis provides insight into drivers of change impacting the flood protection project and the flexibility to account for drivers of change. We identified five main drivers of change and categorized them into five categories: Technology, Policy, Economic, Environment, and Social. From a management perspective, the identified drivers of change exceed the temporal scale of the flood protection project (2017-2024); yet the current FRM and governance systems have provided pathways to cope with and adapt to these drivers of change. By conducting the flexibility assessment, we identified two main lessons from DMNP which can enhance the flexibility of the FRM systems in facing drivers of change. First, the diversity of institutional arrangements formed by several collaborative partners (public, private, non-profit) let by public sector advocates can enhance the flexibility of the project. Second, temporal continuity in planning is secured by presenting a business case (e.g., generating funds for reinvestment and linking costs to revenues) combined with long-term public engagement and public support.

4.6.1 Diversity of institutional arrangements

Our analysis highlights the diversity of actors and how contracts and collaboration processes have achieved outcomes that impact all flexibility metrics, including slack, redundancy, connectivity, coordination and adjustability of flood protection projects and, in general, the water management system (Rouillard and Spray 2017, van der Pol et al. 2017, Difrancesco and Tullos 2015). A nested polycentric governance approach “emphasizes the importance of institutional diversity to solve collective action problems”(Baird et al. 2019, 201), which fits the institutional needs to adapt to and cope with drivers of change and their impacts (Newig and Koontz 2014, Gruby and Basurto 2014).

The requirement of polycentric governance is described by McGinnis and Ostrom (2011, 15), as “a complex combination of multiple levels and diverse types of organizations” including the public, private, non-profit, with “overlapping responsibility and functional capacities”. In practice, implementing a polycentric approach is challenged with respect to coordinating large sets of actors and the costs associated with it (Dennis and Brondizio 2020, Heikkila, Villamayor-Tomas and Garrick 2018, McCord et al. 2017). Issues involving accountabilities and the distribution of roles and responsibilities are other pitfalls that can emerge when implementing the polycentric approach in water resource management systems (Thiel 2017). Our analysis shows that DMNP institutional arrangements are aligned with the polycentric governance theory by enabling public actors (different levels of governments, City of Toronto, TRCA, Waterfront

Toronto) to collaborate with private actors (e.g., consulting companies, construction companies, financial sectors), and non-profit sector (e.g., Friends of the Don East) (see Figure 4-4). The DMNP's institutional arrangements show attributes including independent institutions representing three governments and government levels, and an approach which facilitates collaboration that has implications for FRM and water governance (Bunce 2017, Flynn and Valverde 2019).

Our analysis illustrates that Waterfront Toronto, as an intergovernmental institution representing three levels of government, is a unique governance experiment that can support needed redundancy in the DMNP, reduce the transition costs associated with coordination of three levels of governance, and increase compatibility among policies and strategies of three levels of government (Eidelman 2013). This innovative approach has proven moderately successful in addressing complex social-ecological issues at Toronto's waterfront. It also provides solutions for addressing power imbalances and political disagreement among three levels of governments while creating stability at the planning or project level to address the impacts of drivers of change (POL1) emerging in the policy category.

The institutional design of Waterfront Toronto facilitates the collaborative process and government-led approach by "balancing private sector efficiency, public accountability, and tri-governmental cooperation"(Waterfront Toronto 2021b, Flynn and Valverde 2019). The design of intergovernmental institutions can be modified to address needs and pre-existing conditions on a SES by accruing different sets of financial, political, and intellectual roles and powers. For example, the Port Authority of New York and New Jersey, as an intergovernmental institution with a different set of powers (e.g., issuing bonds and implementing innovative financial strategies), has created a road map for the use and development of port property by introducing a short-term to long term strategy (Rosenzweig et al. 2011, Galvao, Wang and Mileski 2016). Having strong strategic business plans and corporate perspective while advocating for the public are other characteristics of the intergovernmental institutions (e.g., Waterfront Toronto), which enable long-term infrastructural and land use planning, that is more aligned with FRM temporal scales (Alaerts 2019, Alexander et al. 2016).

4.6.2 Pathways to enable long term planning and policy continuity

The continuity in long-term planning is a critical factor in flood risk management, including implementing and maintaining flood protection projects and conducting mitigation strategies (Alexander et al. 2016, Berndtsson et al. 2019). Our analysis reveals that in the case of the DMNP, the continuity of long-term planning has become viable by presenting a strong business case (e.g., long-term employment and residential growth, a mechanism to generate funds for reinvestment and linking costs to revenues) combined with continuous public support and engagement, which was started in 1989 (Waterfront Toronto 2021a). Presenting a business case for a complex SES (e.g., a flood risk adaptation project, flood protection project) is presumed to be difficult because of uncertainties, complexities, and institutional fragmentation (Dentoni, Pinkse and Lubberink 2021, Whelan and Fink 2016). Our analysis shows pathways through which developing a business case for an SES becomes viable by learning from the DMNP management and governance system and the role of intergovernmental institutions to harness private actors' efficiency (see Table 4-6)

The design of intergovernmental institutions (e.g., Waterfront Toronto) has enabled collaboration with private actors who are specialized in crafting business cases for future urban development, revenue-generating, risk aversions, and operations management, while the process is guided by the public advocate when can balance the public and private interest in the process (Waterfront Toronto 2021b, Flynn and Valverde 2019, Waterfront Toronto 2016b, Eidelman 2013). Despite the fact that building a strong business case enhances the flexibility of the system to face drivers of change (POL1 and ECO1) in policy and economic categories (e.g., change in funding, fiscal policies, market volatility, and market demands), it is not sufficient to enable the long-term planning and policy continuity that is required for FRM or other long-term infrastructural projects (e.g., an example of Sidewalk Lab collaboration with Waterfront Toronto)(Green et al. 2016, Newig et al. 2014, Flynn and Valverde 2019).

Our analysis highlights the importance of public support and public engagement (Berndtsson et al. 2019, Petridou and Olausson 2017) as an indivisible factor to accompany strong business cases to enable long-term planning and policy continuity in a complex SES (e.g., flood risk mitigation projects). Public engagement and public support are considered a cornerstone towards reaching resiliency to adapt to and cope with the change (Alexander et al. 2016, Hegger et al. 2014). Public engagement and public support can enable or constrain the planning, implementation, and continuity of FRM related policies and projects (e.g., Making Room for the river's approach in the Netherlands or Making Space for Water project England) (Van der Most et al. 2018, Van Buuren et al. 2015). An institutional design that engages with the public and can harness the power of public support is more flexible since it can adjust to drivers of change (SOC1) emerging in social categories. Overall harnessing the power of public support while presenting strong business cases related to plans, projects, and strategies will strengthen the flexibility management and governance system, which in turn can enhance the continuity of planning and policy in a longer temporal scale.

4.7 Conclusion

Drivers of change impact FRM at different stages in the flood protection projects by altering pre-existing conditions under which baselines, models and assessment criteria are designed and established to guide management and governance efforts (UNWWAP 2009, Hartmann and Driessen 2017, Serra-Llobet et al. 2016). Reviewing current flood protection projects and their approaches in addressing emerging drivers of change can help FRM and governance identify pathways through which FRM can cope with and adapt to drivers of change and their impact emerging from technology, policy, economic, environmental, and social categories. Our analysis of the DMNP using modified CIS and flexibility metrics shows that drivers of change have posed challenges in various stages of the process, including feasibility assessment (e.g., changes in role and responsibility of CAs or change in EA policy), design (accommodating trends and changes in public needs), planning (e.g., changes in the housing market), implementation (e.g., facing new high lake level), and operations and maintenance (de Voogt and Patterson 2019, de Loë and Patterson 2017b, Difrancesco and Tullos 2015). Our analysis reveals that an increased degree of flexibility in the project aid in dealing with these challenges properly with the support of innovative institutional design to enhance collaboration among public and private actors while presenting a strong business agenda to ensure continuity of the projects and plans.

An innovative institutional design (e.g. Waterfront Toronto) enhances slack, redundancy, connectivity, coordination and adjustability in the flood protection project (see Table 4 to 8) by working with all levels of government to align priorities and strategies within each level of government with respect to the project vision and local needs(Bunce 2017, Waterfront Toronto 2016b, Eidelman 2013). The institutional design will mobilize diverse sets of actors (public, private, non-profit) and their capacities by advocating for the public while focusing on increasing efficiency and innovation by working with private partners (Havemann et al. 2016, Erisman et al. 2015). In order for the collaboration and partnerships established within the innovative institutional design to have the potential to address the increasing risk of flooding and to account for the impact drivers of change, FRM must bridge social, economic, environmental, technological, and political (policy) dimensions to reduce tangible and intangible damages of flooding by risk-sharing among actors and building flexibility in the process of planning and implementation.

Chapter 5

Conclusion

This chapter provides a synthesis of findings and contributions in the previous chapters by highlighting the original and significant scholarly and practical findings and contributions. I begin with a restatement of the purpose and objectives that guided the study (Section 5.1). Section 5.2 synthesizes the major findings of the research, both within each individual chapter and across the chapters. Specific contributions to scholarly knowledge, and recommendations for policy practice, are discussed in Section 5.3. The chapter concludes with a discussion of study limitations and future research opportunities (Section 5.4).

5.1 Purpose and objectives

The purpose of this research is to identify and assess drivers of change in flood management in Canada and to determine their influence by examining broader social-ecological systems. Four objectives guided this research toward achieving its purpose.

1. Build a conceptual framework that recognizes and accounts for impacts of drivers of change on flood management using insights from the Social-Ecological Systems (SES) Framework, institutional design and analysis, flood management, and broader water governance literature.
2. Apply the conceptual framework to detect drivers of change and to understand the ways in which flood management and water governance literature have identified and addressed the influence of drivers of change on flood management.
3. Use this framework empirically to examine flood management approaches concerning the influence of drivers of change in Ontario and the City of Toronto.
4. Identify ways in which institutional arrangements for flood management can be changed to reduce and manage the risk of flooding by accounting for drivers of change.

All chapters in the dissertation contributed to Objective 1. Chapter Two focused on achieving Objective 2. Chapters Three and Four contributed to Objectives 3 and 4.

5.2 Major Findings

Major findings of the research were presented in three stand-alone manuscripts in the form of interconnected chapters that addressed an overarching research problem. The research problem focused on identifying drivers of change and finding pathways to determine and account for these drivers' impacts on the risk of flooding.

- Chapter Two presented findings from a systematic review of 170 studies from the EU, the US, and Canada, using Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) to provide a broad view on defining and identifying drivers of change and their impacts on FRM.

- Chapter Three was grounded in an empirical case study to dive deeper into the current FRM system in the City of Toronto with a focus on drivers of change. The analysis in Chapter Three is built on a conceptual framework based on Ostrom's IAD-Institutional Analysis, SES-Social-Ecological Systems Cole et al. (2019), the diagnostic approach developed by de Loë and Patterson (2017b) and institutional design principle (Huntjens et al. 2012). The conceptual framework used facilitated identifying drivers of change and creating adaptation and mitigation pathways to account for the impacts of drivers of change.
- Chapter Four was also grounded in the City of Toronto but focused on a specific project: the Don Mouth Naturalization and Flood Protection Project (DMNP). This is one of the many flood risk management efforts conducted by the City of Toronto and other partners to reduce the risk of flooding and revitalize urban areas in the city (City of Toronto 2019a, TRCA 2021b). The conceptual framework used in Chapter Three provided the foundation for the analysis, which took the form of a flexibility assessment. DiFrancesco and Tullos's (2014) research on flexibility analysis guided this chapter to identify drivers of change and highlight the lessons that can be learned from DMNP regarding flexibility and ability to cope with and adapt to drivers of change.

5.2.1 Chapter specific findings

Chapter Two, the systematic review, identified that drivers of change (see Table 5-1) are emerging in five key categories: Environment (ENV), Policy (POL), Technology (TEC), Economy (ECO), and Social (SOC). The analysis also highlighted three main points regarding FRM literature and drivers of change. First, there is an awareness in FRM around the most noted drivers of change, which included population growth, urbanization, climate change, change in land cover. These drivers are usually portrayed as factors that negatively impact flood risk and increase vulnerability. Providing solutions or addressing the impacts of these drivers usually stays outside the scope of the FRM approach in the literature. Second, our analysis highlighted that there is a gap in defining and categorizing drivers of change or weighing their impact on flood risk and vulnerability. I found that examining drivers of change, assessing their influence, and exploring their evolution helps to identify pathways through which FRM can tackle these drivers. Constructing a definition, baselines, and evaluation criteria will assist FRM to translate drivers of change into more defined issues that specify the source of the problems, as well as to develop strategies or courses of action to reduce risk and vulnerabilities. Third, a full examination of drivers of change is a lengthy process. The complexity of FRM, interactions between drivers of change, and the degree of influence of drivers of change on levels and scales where FRM efforts are shaped, processed, and implemented are examples of factors that add to the complexity of assessing drivers of change and their impacts.

Table 5-1: Drivers of change: a systematic review of literature, regional perspective

Categories	Drivers
Environment	Changes in weather and the impacts of climate change (ENV1)
	Recognition of natural assets and implementing ecological measures (ENV2)

Policy	The shift in role and responsibilities (POL1)
	Emerging new discourses and knowledge (POL2)
	Change in risk communication approach (POL3)
Technology	The rapid change in modelling, data gathering, and representation (TEC1)
	Accessibility of data and data sharing (TEC2)
	Structural measures remain the most preferred option for flood defence (TEC3)
Economics	Increase in financial pressure (ECO1)
	Change in funding distribution (ECO2)
	The emergence of market-based solutions and market-based actors (ECO3)
Social	Changing household behaviour (SOC1)
	Increasing flood risk experience a two-edged sword in FRM (SOC2)
	Change in socio-demographic patterns (SCO3)

The landscape of FRM and the nature of flood risk are rapidly changing, and pressures from drivers of change add to the complexity and uncertainty. New research is needed to address the lack of integration among drivers of change and FRM research. This research should be grounded in an interdisciplinary, measurable, and consistent framework that takes local context and other pre-existing conditions into consideration. Chapter Three was designed to examine drivers of change and their impact. It was grounded in interdisciplinary research that explored and contextualized drivers of change of FRM systems and expanded the evidence base for explanations of their impacts. In Chapter Three, insight from the systematic review and the concepts from social-ecological systems analysis (Cole et al. 2019, Partelow 2018), water governance (Egan and de Loë 2020, Bixler et al. 2020, de Loë and Patterson 2017b, Baird and Plummer 2020), and institutional design (Huntjens et al. 2012) were used to identify drivers of change and their impact on FRM of the City of Toronto, Ontario, Canada. Chapter Three built new theoretical insights from changes in the pre-existing conditions and emerging challenges that are shaping the ability of FRM systems to cope with and adapt to the increasing risk of flooding and uncertainty in the governance of FRM and land use planning.

Chapter Three resulted in two major findings. First, thirteen drivers of change relevant to FRM in the City of Toronto were identified and categorized into five major categories (see Table 5-2). Second, the result sheds light on the most noted challenges and opportunities posed by drivers of change that impact the FRM system's ability to recognize and adapt using the conceptual framework. I argued that to enhance the ability of the current FRM system; there is a need to strengthen nested polycentric governance by engaging all three levels of government. A strong nested polycentric governance system can help to fill short-term and long-term FRM gaps that exist by providing funding and technical and political support. A strong governance system has the ability to bear costs and benefits from change by balancing financial and institutional roles and responsibilities can encourage the equal and fair (re)distribution of risks, benefits and costs at the multi-level context. Flexible processes in FRM and governance systems can facilitate the development of policy, strategies, programs, and products throughout the collaboration of

public or private actors that can encourage an equal and fair (re)distribution of risks, benefits, and costs.

Table 5-2:Drivers of change affecting FRM in The City of Toronto

Categories	Drivers
Policy	Clarifying role and responsibilities (POL1)
Economics	Increasing damages, negative impact on the economy, and increasing value at risk (ECO1)
	Market-based solutions (ECO2)
	Diversification of funds (ECO3)
	Return on investments of projects searching for financial sustainability (ECO4)
Technology	Data collection, modelling, and data gaps (TEC1)
	Data sharing and issues around privacy (TEC2)
	Preferred structural solutions combined with Green Infrastructure (TEC3)
Environment	Changes in weather patterns and climate variability (ENV1)
	Recognition of Green Infrastructure (GI) as FM tools and municipal assets (ENV2)
Social	Emerging Risk communication outlets (SOC1)
	Public expectation and flood experiences are evolving after each flood event (SOC2)
	Socio-demographic and population growth impact vulnerabilities (SCO3)

The major finding of this research presented a new approach to identify the impacts of drivers of change on flood risk management by accounting for broader social-ecological, political, temporal changes as well as considering pre-existing conditions using the conceptual framework. A key outcome from Chapter Three is considering nested polycentric governance as a foundation to establish collaboration strategies and new institutional design. This foundation can also support flexible processes and establish equal and fair (re)distribution of risks, benefits and costs among all actors who share the responsibility to manage and mitigate the risk of flooding.

Chapter Four built on the finding of Chapter Three and recommendations in the literature (see section 4.5) for identifying flexible processes to create solutions and opportunities for adaptation and risk mitigation. The Don Mouth Naturalization and Flood Protection Project (DMNP), one of the many flood risk management efforts in the City of Toronto, provided a research opportunity to study drivers of change and their impact on the flood protection project. I used the conceptual framework to identify drivers of change by accounting for broader social-ecological systems and pre-existing conditions. This was followed by an assessment of the flexibility of the project-facing drivers of change, drawing on an approach adapted from the one

used by DiFrancesco and Tullos (2014). This analysis revealed lessons and implications for FRM and water governance that could increase flexibility, a key concern for FRM systems.

Chapter Four used the same five broad categories of drivers of change that were used in chapters Two and Three but focused on specific drivers relevant to the DMNP (see Table 5-3). The chapter also identified actions and efforts that impacted the flexibility of the project facing change and uncertainties. A strong Public-Private Partnership, funding diversification, following a Watershed Management Approach, accessing a wide range of data, and strong connections between flood protection projects and spatial planning are highlighted as actions and initiatives that enhance flexibility in the flood protection project. In addition to these efforts, our analysis reveals that the degree of flexibility can help the project to deal with drivers of change impacts properly with the support of an innovative institutional design. This innovative institutional design has enhanced collaboration among public and private actors while presenting strong business agenda to ensure continuity of the projects and the plans.

Table 5-3: Drivers of change relevant to the DMNP project

Categories	Drivers
Technology	Relying on structural measures to reduce the risk of flooding (TEC1)
Policy	Change in current institutional arrangement (POL1)
Economics	Real state and residential demands (ECO1)
Environment	Changes in weather patterns and climate variability (ENV1)
Social	Changes in trends of public demands (SOC1)

5.2.2 Global findings

Three important global findings span the individual findings from each chapter. These relate to (1) the most common drivers of change of FRM across the various levels and scales examined; (2) the importance and value of a framework that allows for situating a specific problem such as FRM into a larger social-ecological context; and (3) the importance of strong governance systems that are equipped with tools and means to address the impacts of drivers of change in a flexible manner to co-create solutions for adaptation, mitigation, and increasing resiliency. These global findings and the chapter-specific finding explained earlier establish the foundation for our significant and original contribution to the knowledge presented in this study.

The first global finding is that people working within FRM, at all levels and scales examined, clearly are aware of drivers of change; nonetheless, drivers of change are usually portrayed as global challenges outside the scope of FRM or governance, despite having a noticeable impact on the risk of flooding and vulnerability at a local level. Changes in FRM approaches shed light on the fact that FRM communities are connecting and engaging with diverse sets of actors and tools to reduce risk and vulnerability. For example, FRM systems under study were using various approaches to engage with actors (e.g., insurance companies, households, and different levels of governments) to share risk and reduce the increasing financial pressure. This research attempts to define and categorize drivers of change to provide insight on

the ways to examine drivers of change, their impacts, and the scale of influence in FRM to develop solutions for risk mitigation and adaptation. The evidence shows that there are broad similarities among identified drivers of change resulting from a systematic review of literature and the FRM system under study. These include changes in weather patterns (ENV); and rapid changes in modelling, data gathering, and representation (TEC), which can present different challenges to the FRM system or the subsystems (e.g., specific flood protection project). Developing a better understanding of drivers of change can guide current FRM efforts to better pursue adaptation strategies, funding priorities, and collaborative actions that are more impactful in addressing drivers of change. It also facilitates reducing the negative impacts of the risk of flooding and vulnerabilities depending on the FRM systems characteristics and broader social-ecological systems in which this system is situated.

The second global finding relates to the benefits of using an integrative, interdisciplinary conceptual framework for studying FRM. This research used a conceptual framework that built on Ostrom (2011a)'s Institutional Analysis and Development (IAD) framework, the Social-ecological Systems (SES) framework (Cole, Epstein and McGinnis 2019), and a diagnostic approach developed by de Loë and Patterson (2017b). All three building blocks are situated within the same large pool of literature that recognizes and attempts to account for interconnections among social-ecological systems. The conceptual framework used in this study supported assessment and understating of FRM action situations and their connection and linkages with broader social-ecological systems and pre-existing conditions. Conceptual frameworks such as the one used in this research enable researchers and practitioners to map linkages, interactions and feedback loops among systems, actors, components and variables to account for the complexity, diversity, and uncertainty in social and natural systems (Cole et al. 2019).

An important benefit of the conceptual framework used in this study is that it helped to avoid adopting a water-centric orientation that ignores related systems, such as land-use planning. Using a four-step analysis, the framework helped connect FRM at various scales and levels to the broader social-ecological systems within which it is situated. The first step of analysis focused on the delineation of the action situation using practitioner and user perspectives. In the second step, the framework guides spiralling inward to define the question and problem from a practical point of view. The final two steps involved spiralling outward to collect and map relevant contextual factors from different manifestations of actors or governance and resource systems and units into comprehensive lists. The four-step analysis enables both a cursory and in-depth analysis of a particular action situation, which facilitates understanding of drivers of change and their impacts on the action situation, institutional arrangements, policy interactions, and outcomes. It also proved to be useful to insight to governance and management of the system (water systems, flood risk management systems) for creating adaptive, resilient, and flexible approaches to advance sustainability and face uncertainty and change.

Across all the chapters, I highlighted the importance of strong, nested polycentric governance (e.g., water governance or broader environmental governance) that is equipped with tools that can facilitate collaboration, participation, deliberation, inclusiveness, and transparency, all of which contribute to resiliency and flexibility. The analysis highlighted the need to create a short-term to long-term approach through strengthening polycentric governance by reaching out to various actors to address the risk of flooding, moving toward understanding vulnerabilities, mitigating risk, and building flexible FRM systems. I proposed an institutional design in Chapter

Four that facilitates the interactions among levels of government while benefits and harvests the efficacy and innovation of private actors to enhance flexibility in facing the risk of flooding. The proposed institutional design with the support of a strong nested polycentric governance can support accountable institutional arrangements. Accountable institutional arrangements can face broader political, economic, and temporal changes to bear costs and benefits, to share financial and institutional roles and responsibilities and encourage the equal and fair (re)distribution of risks, benefits and costs at the multi-level context.

5.3 Scholarly and Practical Contributions

This research makes scholarly and practical contributions. These address research gaps, propose solutions and identify opportunities for adaptation and mitigation. Scholarly contributions complement literatures on governance (e.g., water governance and environmental governance), flood risk management, institutional analysis, and flexibility literature. Practical and policy contributions address the impacts of drivers of change on FRM in Ontario in general, and Toronto in particular highlights potential pathways to advocate for flexible institutional arrangements.

5.3.1 Scholarly contributions

Scholarly contributions relate to three gaps identified in the current FRM literature: (1) the need to understand and acknowledge the impact of drivers of change through having clear definitions and categories of drivers of change in a way in which can be used in current risk assessment and vulnerability analysis; (2) the need to better understand, assess, or calculate the connections and interactions among drivers of change, their scale of influence, their impact on hazard or/and vulnerability; and (3) the need for tools and approaches that can facilitate co-development of solutions, enable a detailed analysis of challenges and opportunities imposed by drivers of change on FRM systems, and translate the results to risk or vulnerability factors. Scholarly contributions relating to these three areas are relevant to the water governance literature, the FRM literature, and the emerging flexibility assessment literature. Contributions related to the three gaps identified here are discussed in turn, followed by a discussion of insights for water governance and FRM.

Clarification of drivers of change in FRM is the first major contribution of this research. A key concern in this research was identifying a role played by drivers of change: natural or human-induced factors that directly or indirectly cause a change in the risk of flooding or the ways in which flooding is managed or governed. Chapter Two contributed a novel typology organized by practical and strategic categories that were further contextualized in Chapters Three and Four. Chapter Three expanded on the impacts of drivers of change in FRM in the City of Toronto with evidence for how to enhance adaptation and mitigation measures while facing drivers of change. Chapter Four also shed light on using the categories in a flood protection project which also provided case-specific evidence on how drivers of change impact the process and implementation of a flood protection project. The clarity brought by Chapters Two, Three, and Four on drivers of change contributed to significant new evidence and opportunities to address the limited research on categorizing and assessing drivers of change impacts as expressed by researchers and practitioners.

Tracking interactions among drivers of change is the second major contribution. This contribution shows that there is a need to bridge different kinds of research that seek to

understand multiple dimensions of FRM. The finding in Chapter Two highlights a significant research gap related to disconnections among approaches and studies on FRM. The empirical identification of this gap was significant and original because the gap applied to the entire FRM research, including drivers of change and their impacts on hazard, vulnerability, and exposure. This research provides broader insights on drivers of change since empirical research sometimes focuses on one or two drivers of change (e.g., change in weather pattern and economic damage) and often does not consider other drivers of change interaction or impacts on the FRM system (Winsemius et al. 2016). At the same time, the research reveals that the empirical research tends to focus on one or two case studies in a particular geographical setting while ignoring the global perspectives on drivers of change (Francesch-Huidobro et al. 2017). Chapter Two addressed these gaps by providing insights on ways to measure these interactions, building on the argument that drivers of change do not exist independently of each other (Berndtsson et al. 2019); they coexist and interact across levels and scales (e.g., temporal, or spatial).

Framing drivers of change in a broader social-ecological system is the third major contribution of this research. This contribution is grounded in the development and use of a novel interdisciplinary framework built on previous work within the broad field of social-ecological systems thinking. Specifically, the conceptual framework in Figure 5-1. As noted previously, draws on Ostrom's IAD framework (McGinnis 2016), contemporary SES thinking (Cole et al. 2019), and the diagnostic approach developed by de Loë and Patterson (2017b). The conceptual framework enabled assessing impacts of drivers of change in defined action situations, processes, and outcomes, to guide adaptation and mitigation strategies. In that respect, the framework and its use is another significant, original contribution to knowledge.

The framework enables framing the actions situation in a broader context and shedding light on the connection and feedback loops among the broader contexts and the defined action situation. In addition, the framework enables the analyst to critically review the action situation using four-step analyses. The first step of the analysis address challenges around problem definitions. To assess water challenges, the analyst needs to look beyond currently defined boundaries, including watershed, municipal districts, or basin level, to provide a holistic understanding of the risk and vulnerabilities. The framework also guides the researcher to assess appropriate problem definition in the second step of the analysis to identify influential actors and governance systems to engage within addressing the problem (see Section 3.4 and 4.4).

Framing action situations using the guidance of the framework enables water governance and water resource management to move beyond the traditional case study approach that was used in water resource engineering and management. Traditionally, case studies were bound to geographical boundaries that were delineated by water engineers, including watersheds, basins, and water service areas. The framework allows researchers and practitioners to move beyond the traditional case study approach while focusing on the issue at hand. Researchers and practitioners can define and delineate appropriate social-ecological boundaries regarding the issue using their best knowledge. In the step-by-step processes, when researchers and practitioners develop a better understanding of the issue in the broader social-ecological context, they can revisit the initial delineated boundaries and adjust them accordingly through a network of focal action situations (see Figure 5-1). For example, in this research, International Joint Commission (IJC) was considered an influential actor in the City of Toronto. Despite this assumption, using the framework, it became evident that the IJC has a strong role in addressing coastal flooding, which

was outside the scope of this research. Using the framework enables me to account for this fact and adjust the social-ecological boundaries accordingly.

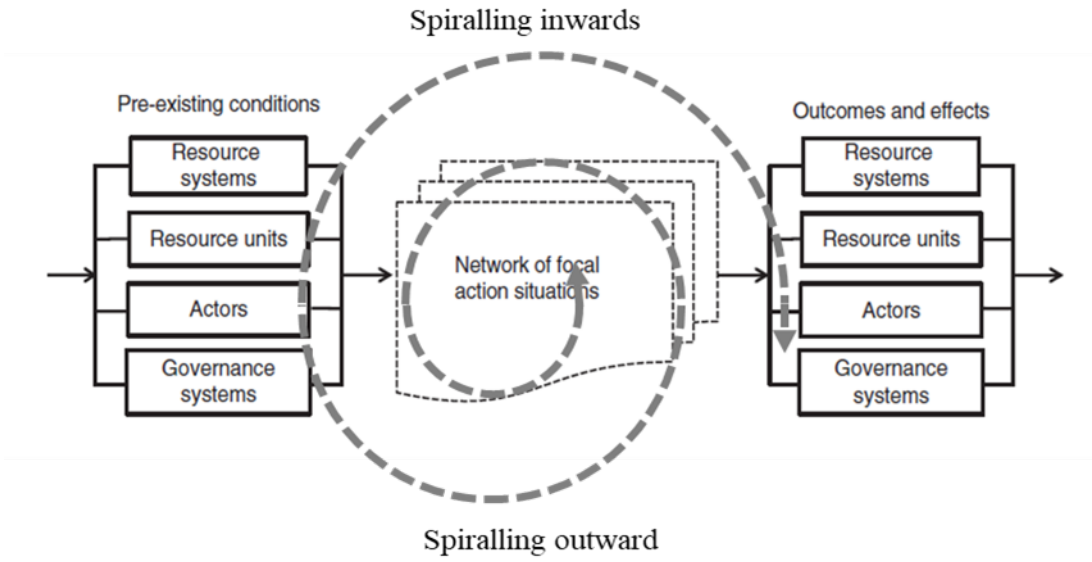

Figure 5-1: The conceptual framework

Applying the conceptual framework in Chapter Three and Chapter Four facilitated the identification of drivers of change that originate in broader social-ecological systems within which FRM is situated. Evidence about the challenges and opportunities these drivers present to reduce the risk of flooding and vulnerability sheds new light on proposing adaptation opportunities and mitigation strategies to address the impacts of drivers of change. In Chapter Four, the application of the conceptual framework to the DMNP project highlights the capacity of the conceptual framework to connect with theoretical concepts (e.g., flexibility or adaptability) and provide a foundation for analysis of the problem context through the lens of these concepts (e.g., flexibility). Chapters Three and Four also pointed to the fact that the conceptual framework can be used as a foundation for conducting other assessments or analyses. The conceptual framework provided the opportunity to map "institutional, financial and organizational governance arrangements and processes" (Zwarteveen et al. 2017, 8), track interactions, connections and feedback loops in social-ecological systems, and present opportunities and challenges that have the potential to impact the selected action situation.

Contributing new insights regarding water governance and the role of external drivers is another significant contribution of this research. Increasing complexity and the scale of many environmental problems have challenged current water governance approaches. Development of new technologies, the growing importance of trends such as urbanization, changes in consumption, and concerns about interconnected global risk, and a trend to decentralization, have also put pressure on current governance systems to provide flexible and sustainable solutions for environmental problems (Heikkila 2016, Skinner 2016, Baird and Plummer 2020). At the same time, trends in environmental governance that advocate for the realignment of institutions

towards market-based modes of governance have increased the involvement of non-state actors and created ongoing discussions for less regulatory and state-centric governance (Ciplet and Roberts 2017).

Moving beyond "water box" or "water-centric approaches" is also a contribution of this research. This dissertation provides a comprehensive perspective on potential ways to account for external factors and drivers that are impacting water governance, in general, and FRM efforts. Chapter Two highlights ways to reconsider drivers of change by breaking the challenge into criteria and metrics that are commonly used by current governance and management approaches. Chapters Three and Four demonstrate how common drivers manifest themselves in the FRM and governance systems. Chapter Three explores developing opportunities for adaptation by reassessing the impacts of driver change on water governance systems. Chapter Four highlights how strong nested polycentric governance has created opportunities to recognize drivers of change and respond to their impacts and harness the opportunities presented by these drivers of change using diverse sets of actors and collaboration arrangements. Chapter Three and Four provides a novel perspective on moving beyond the recognition of the driver of change toward co-developing solutions and identifying strategies to cope with and adapt to the impact of external factors that influence the defined "water box."

Building on institutional design literature and its implications for adaptation and mitigation is facilitated by applying the conceptual framework to the empirical setting. This research provides guidance on identifying adaptation opportunities through rethinking institutional design in Chapters Three and Four. The application of the conceptual framework in Chapters Three and Four enables this research to provide a broad scan of governance systems (GS) and actors (A) in the FRM systems that guide flood risk mitigation and adaptation strategies. It also facilitated the identification of drivers of change and assessment of adaptation challenges and opportunities presented by these drivers of change. Chapter Three presents categories of drivers of change and their impacts on specific sets of actors and governance systems involved in FRM. I used a modified version of the institutional design principle by borrowing insights from Huntjens et al. (2012). Using the conceptual framework, I explored opportunities to rethink current FRM systems by putting emphasis on strengthening nested polycentric governance, flexible processes, and equal and fair (re) distribution of risks, benefits and costs among all actors who share the responsibility to manage and mitigate the risk of flooding if I am to successfully guide adaptation and mitigation to face drivers of change and their impacts.

Lastly, this research contributes to flexibility assessment literature with a focus on water management and governance in flood protection projects in urban areas in Chapter Four. The flexibility assessment was built on DiFrancesco and Tullos (2014) flexibility metrics and was modified to explore the flood protection mechanism and pre-existing conditions in a complex urban environment. I revisited the metrics and adjusted them based on the infrastructure in place., In addition, I added metrics that assess the linkages among urban planning policies and flood protection projects and water management in general. Some examples of these metrics include the diverse pool of organizational, operational, and managerial resources for maintenance and operation (S3), public engagement and management/ governance (C3), infrastructure and public needs (C4) and opportunities to adjust the need (A2). By conducting the flexibility assessment, I identified two main lessons from DMNP which can enhance the flexibility of the FRM systems in facing drivers of change. First, the diversity of institutional arrangements formed by several collaborative partners (public, private, non-profit) let by public sector advocates can enhance the

flexibility of the project. Second, temporal continuity in planning is secured by presenting a business case combined with long-term public engagement and public support. These findings contribute to flexibility assessment literature and water resource management and governance by emphasizing the importance of a nested polycentric governance approach that can support diversity and the needs of complex social-ecological systems (Baird et al. 2019).

5.3.2 Recommendation for policy practice

The need to rethink water governance and management approaches is becoming more evident as water challenges are persisting and damages due to flooding are increasing and are projected to rise globally (Winsemius et al. 2016, Ward et al. 2020). Traditionally, flood management and flood protection were water-centric and seen as engineering design challenges (e.g., dams, flood levies) to make land in floodplains usable (Hartmann and Driessen 2017). In recent years, FRM has moved away from the traditional engineering approach to an integrated risk management approach to address ongoing FRM challenges. Globally accepted concepts such as integrated water resources management (IWRM) emerged to account for broader issues such as spatial planning, economics, and sustainability. These concepts guide policy practices around the world, including the Water Framework Directive and the Floods Directive in EU countries.

Changes in the nature of the risk (e.g., change in precipitation pattern) have introduced new sets of governance and FRM challenges (Oulahen 2021, Alaerts 2019). FRM, water resource management, and water governance are exploring new concepts and perspectives to account for increasing uncertainty and change in nature of the risk in theory and practice. Situating the water challenges in broader social-ecological systems has proven to be stepping in the right direction in policy and practice to reduce risk and build capacity for adaptation. Among these, analytical frameworks that are built on Ostrom's IAD (Institutional Analysis and Development) and SES (Social-Ecological Systems) frameworks have been used in various water resource management situations to understand the dynamics in complex social-ecological systems, including water resource management, natural flood risk management, and fisheries management (Wells et al. 2020, Cole et al. 2019). By building on Ostrom's approaches, this research offers two main policy and practice contributions. The first contribution focuses on creating pathways to transform awareness into action addressing drivers of change with impact on broader social-ecological systems. The second contribution explores a successful institutional arrangement that enabled DMNP to deal with and adapt to identified drivers of change.

This study's first practical contribution involves highlighting that *awareness* of drivers of change is important but not sufficient; flood risk must be viewed from a perspective that considers drivers of change in the context of complex social-ecological systems. This study explores pathways to develop a holistic approach that absorbs undesirable changes in the complex social-ecological systems, acknowledging drivers of change as an essential first step. All three stand-alone chapters build on the arguments that researchers and decision makers should have a nuanced understanding of how drivers of change can shape and alter social-ecological systems incrementally or disruptively as discussed by (e.g., Berndtsson et al. 2019, Tortajada and Biswas 2018, Breen et al. 2018, Francesch-Huidobro et al. 2017, Räsänen et al. 2017, Winsemius et al. 2016, Egan and de Loë 2020).

Chapter Two also introduces a pathway that can facilitate an action-oriented effort by following a three-step process. Identifying, describing, and categorizing drivers of change is the first step to conducting an in-depth analysis. The next step is then to develop qualitative or quantitative indicators that can be measured and compared in temporal and spatial scales. After developing these indicators, a third step is the evaluation of the interaction among drivers of change and social-ecological systems, which has direct implications for governance, including identifying and supporting approaches to share information and compare successful and replicable cases to support cost-effectiveness, resilient, and adaptive solutions to flood damage mitigation.

The second policy practice contribution has emerged from the analysis of the DMNP (Chapter Four). This contribution presents two components for an innovative institutional design. A diverse institutional arrangement aligned with the polycentric governance theory that enables public actors (different levels of governments, City of Toronto, TRCA, Waterfront Toronto) to collaborate with private actors (e.g., consulting companies, construction companies, financial sectors), and the non-profit sector (e.g., Friends of the Don East). This is followed by institutional design that presents a strong business case combined with continuous public support and engagement. I highlighted these components in an innovative institutional design that enhances flexibility metrics, including slack, redundancy, connectivity, coordination, and adjustability in the flood protection project (see Chapter Four). These innovative institutional design components have mobilized diverse sets of actors (public, private, non-profit) and their capacities by advocating for the public while focusing on increasing efficiency and innovation by working with private partners (Havemann et al. 2016, Erisman et al. 2015).

5.4 Study limitation and future research

This section reviews the study's limitations and highlights potential future research opportunities that emerged from the analysis. Chapters Two, Three and Four, with specific objectives, conceptual framework, method, and results, have their limitations (see **Error! Reference source not found.**). These chapters also shared overall limitations that resulted from the dissertation's research design which are further discussed below.

This study research design has three major limitations. First, this dissertation highlights the importance of drivers of change interactions with each other and broader social-ecological systems. I examined interactions among these drivers of change and their categories in Chapter Two. In this chapter, interactions between pairs of drivers of change were explored by examining the number of shared articles in the analysis. Nonetheless, an in-depth analysis of drivers of change interactions is needed to better understand the dynamics, connection pattern, coherence, and commonality of the drivers of change in a social-ecological system (Berndtsson et al. 2019, Winsemius et al. 2016).

Second, this research identifies key drivers of change and their impacts but is limited to the selected action situation or the selected geographical boundaries. This research does not explore deeper to recognize the origins of drivers of change, their impacts across scales or levels, or drivers of change relation as internal or external to different levels in the system. The third limitation emerged in relation to data collection, collecting primary data by conducting in-depth interviews. First, fieldwork coincided with a change in government in Ontario that led to

significant organizational changes in the public service (Ontario 2018) and funding cuts (Meckbach 2019). Additionally, fieldwork took place during multiple flood events in the province (McNeil 2020). Together, these circumstances made it challenging to recruit key informants. Despite these challenges, it was possible to recruit a satisfactory number of senior participants. Additionally, a research design that also prioritized other data sources ensured that the necessary data were secured. Second, limited representation of specific actors and groups (e.g., home builders, private businesses, indigenous communities). Nonetheless, by targeting knowledgeable participants who provide insights regarding the interests of these actors, I addressed this limitation in our research design and data collection. It should be added that part of fieldwork was also coincided with the global Covid-19 pandemic that impacted participation and recruitment process; I used available virtual tools (e.g., participating in virtual open houses and events held by TRCA, Waterfront Toronto, and other actors) to address the emerging challenges.

This chapter recommends three major research opportunities for future research. The first opportunity is presented in Chapter Two as a process to transform the existing awareness of drivers of change in FRM into action in institutional and policy settings and to understand their potential implications. New research can be conducted to develop metrics and assess these metrics to track the impact of drivers of change in flood risk and vulnerability over time. I proposed a three-step analysis including identifying, describing, and categorizing drivers of change, developing qualitative or quantitative indicators that can be measured and compared in temporal and spatial scales, and evaluating the interaction among drivers of change and social-ecological systems, which has direct implications for governance. New research can better understand the drivers of change and their impact in a measurable and comparable to action-oriented approach.

The second research opportunity evolves around drivers of change multi-levels, cross-scale and rescales interactions among themselves and their connection to water governance and FRM. A more detailed understanding of the driver of change dynamics and interlinkages can highlight ways in which change in one driver enables or constrain the emergence of other drivers. For example, Chapter Three shows "*clarifying roles and responsibilities*" (POL1) as drivers of change in policy has an impact on the available funding and *diversification of funds* (ECO3) as the third driver of change in the economics category. Changing the role of the federal government in the FRM system has impacted the available funding streams and enabled or strengthened another driver of change that impacts the selected FRM systems. In this study, I solely focused on identifying drivers of change and their impact on the success or failure of the selected action situations in Chapters Three and Four. Thus, future work can devise a way to account for drivers of change interactions among themselves and the degree of their impacts on FRM systems.

Last, critical research is needed to review the impact of strong nested polycentric governance on reducing the risk of flooding in both short-term and long-term FRM efforts in Canada. Chapter Two, Three and Four, highlight that there is a shift in role and responsibilities (POL1). This study shows that the pressure on harnessing the abilities of river basin organizations, local level governments, and private property owners is increasing to address the risk of flooding (Penning-Rowsell and Priest 2015, Plummer et al. 2018, Serra-Llobet et al. 2016). Importantly this research highlights the role of an innovative institutional arrangement with the capacity to create flexible processes to account for drivers of change and their impacts on the selected action situations. The need to review polycentric governance approaches has been emphasized by scholars (Dennis and Brondizio 2020, Heikkila et al. 2018, Thiel 2017). In the

future research opportunity, this research adds to these scholars. It also highlights the need for the review of polycentric governance focusing on FRM systems and specific action situations shaped around flood mitigation and risk reduction.

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Appendix A:

7.1 Semi-structured interview guided

Basic information

1. What is your occupation?
2. Do you live or work in the region? If so, how long?
3. In which ways are you connected to flood risk management (FRM) in the region? What is your role in FRM?

Analyzing drivers of change have influenced FRM

4. How has FRM changed in the region since 2000?
5. Which institutions, groups of people, organisations have managed/ impacted/ or influenced FRM in this region,?
6. What drivers/ actions/ approaches have led to change in FRM? Which drivers/ actions/ approaches are likely considered the most influential? Which drivers are likely to be most important in the future? (e.g. population growth, climate change, land use change, economic shifts)
7. Are there any connection/ interrelation among these drivers? If yes what are these connection?
8. To what extent do these drivers impact the risk of flooding?
9. Have these drivers been addressed in FRM in the region? If yes which ones? what kinds of rules, formal and informal, are used to address the impact of these drivers of change? If No why not?

Analyzing drivers of change have the potential to influence FRM

10. Are there new drivers/ actions/approaches that are emerging and impacting current or future FRM? If yes what are these drivers?
11. To what extent FRM can adapt to and cope with current and emerging drivers of change?
12. What should be changed in approaches to FRM to reduce the risk of flooding?
13. Are there groups of people or institutions (formal and informal) outside current FRM that can manage the risk of flooding and enhance FRM ability to cope with or adapt to current and emerging driver of changes?
14. To what extent these external groups of people and institutions should work with current flood management to reduce flood damages and reduce the risk of flooding?
15. Are there any other aspects of FRM and the impact of drivers of change on FRM that you would like to comment on or add to this discussion?

Appendix B

8.1 Interview consent form

By signing this consent form, you are not waiving your legal rights or releasing the investigator(s) or involved institution(s) from their legal and professional responsibilities.

I have read the information presented in the information letter about a study being conducted by Parastoo Emami of the School of Environment, Resources & Sustainability at the University of Waterloo in Ontario, Canada. I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions, and any additional details I wanted.

I am aware that I have the option of allowing my interview to be audio recorded to ensure an accurate recording of my responses. I am aware that I will have the opportunity to review and approve the quotations as they are written in the paper prior to finalizing the paper. I was informed that I may withdraw my consent at any time without penalty by advising the researcher.

Below I have indicated my preference regarding attribution. If I indicate that I can be quoted, I understand that excerpts from the interview may be included in the thesis and/or publications to come from this research.

This project has been reviewed by and received ethics clearance through the Office of Research Ethics at the University of Waterloo. I was informed that if I have any comments or concerns resulting from my participation in this study, I may contact Dr. Maureen Nummelin, Director, Office of Research Ethics at (519-888-4567 ext. 36005) or by email (maureen.nummelin@uwaterloo.ca).

With full knowledge of all foregoing, I agree, of my own free will, to participate in this study.

___ YES ___ NO

I agree to have my interview audio recorded.

___ YES ___ NO

Regarding quotation and attribution of things that I say during the interview in the thesis and or publications to come from this research, the following is my position:

___ My comments can be quoted with attribution (including my job title and the name of the organization I represent)

___ My comments can be quoted with attribution (including the sector and country I represent)

___ My comments can be quoted without attribution (stripped of identifying information, which will be kept confidential by the researchers)

___ I do not wish to be quoted or attributed

_____ _____

Participant Name (Please Print) **Witness Name (Please Print)**

_____ _____

Signature of Participant **Witness Signature**

_____

Date