A COLLABORATIVE APPROACH FOR DISASTER RISK REDUCTION: MAPPING SOCIAL LEARNING WITH MISTAWASIS NÊHIYAWAK

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ABSTRACT

Social learning and its relation to disaster risk reduction (DRR) have been increasingly highlighted in the literature. Yet, limited empirical research has hampered practical DRR applications. This thesis demonstrated social learning loops and their outcomes by reflecting on the case of 2011 flooding in Mistawasis Nêhiyawak. Using a mixed-methods research design, I explored the role of participatory processes, including communication of scientific knowledge to lay-experts, in social learning.

First, I created flood extent maps for the community using spatial data and modeling techniques. In the second phase, I presented the maps in a workshop held at the community center to understand their value in regard to what people learn from them. This included deliberating not only about physical parameters of the flood but also exploring the social (and human) parameters. Hence, I used fuzzy cognitive mapping (FCM) as a novel method to represent the human perception of flood risk and to measure social learning. In the workshop, FCM was complemented by focus group discussions and participatory mapping. From the results, it was found that i) social learning can be measured using social sciences tools, ii) sharing experiences and stories from past events augmented learning, and iii) awareness on the role of emergency planning in DRR was found to be a significant outcome of social learning.

In the growing urgency of climate uncertainties, social learning theory will be critical in helping design practical and ethical research approaches to DRR that emphasize knowledge sharing, two-way communication, and reflexivity. These will ultimately have enhanced emphasis on behavioral responses to disasters that are complementary to the investments in structural responses.

KEYWORDS

Disaster risk reduction, social learning, participatory research, community-engaged research, Fuzzy cognitive mapping (FCM)

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Figure 1.3 (participatory modeling typologies), Figure 3.2 (FCM graphical and mathematical structure) and Table 1.2 (description of social learning components) are reproduced, in this thesis, with the permission of respective authors.

DEDICATION

This thesis is dedicated to my beautiful mother, who continues to inspire me to become a strong, kind, and independent woman.

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ABBREVIATIONS

DRR	Disaster Risk Reduction
EM-DAT	Emergency Events Database
WCED	World Commission on Environment and Development
UN/ISDR	United Nations International Strategy for Disaster Reduction
INDR	International Decade for Natural Disaster Reduction
PA	Participatory Appraisal
PRA	Participatory Rural Appraisal
PAR	Participatory Action Research
CBPR	Community-based Participatory Research
CBDRR	Community-based Disaster Risk Reduction
PM	Participatory Modeling
NGO	Non-Governmental Organizations
IWRM	Integrated Water Resources Management
PPR	Prairie Pothole Region
GIS	Geographic Information System
GPS	Global Positioning System
UTM	Universal Transverse Mercator
LiDAR	Light Detection and Ranging
SRTM	Shuttle Radar Topography Mission
ALOS	Advanced Land Observation Satellite
RS	Remote Sensing
DEM	Digital Elevation Model
WDPM	Wetland DEM Ponding Model
CRHM	Cold Regions Hydrological Model
MNDWI	Modified Normalised Difference Water Index
FCM	Fuzzy Cognitive Mapping
TSGFCM	Total Social Group Fuzzy Cognitive Map

CHAPTER ONE: INTRODUCTION

1.0 Background

The relationship between humans and nature has always been rather a precarious one. Historically, we have depended on nature, first, for sustenance and shelter, transforming it in ways that facilitated our lives, and later, for wealth (e.g., agricultural operations, industries, energy). On the other hand, nature has retaliated at times to flood our lands or even wipe out civilizations (e.g., drought as a catalyst for the fall of Maya civilization) (Costanza et al., 2007). Through this adversity, human beings have developed an innate ability to respond and adapt to crises. Can we, however, take the lessons from the past onboard fast enough to face the realities of the 21st century in which disasters are becoming more uncertain, more frequent and connected to changes in social and cultural systems, and more difficult to make choices to offset the increasingly complex disaster risks?

In the past few decades, the number of disasters has increased worldwide (Figure 1.1). Disasters can be natural (e.g., earthquake, flood), human-made (e.g., social and political conflicts), and technological events (e.g., industrial and transport accidents) (Smith, 2003; EM-DAT, 2019). In this thesis, disasters refer to natural events unless otherwise stated. The number of natural disasters in general and flood, in particular, has increased during the last 30 years (Figure 1.1; EM-DAT 2019)[1].

[1] The numbers shown in the graph represent only the reported events therefore may not reflect the actual number. Lack of historical data account for the limitation in the reporting of actual disaster events in the past

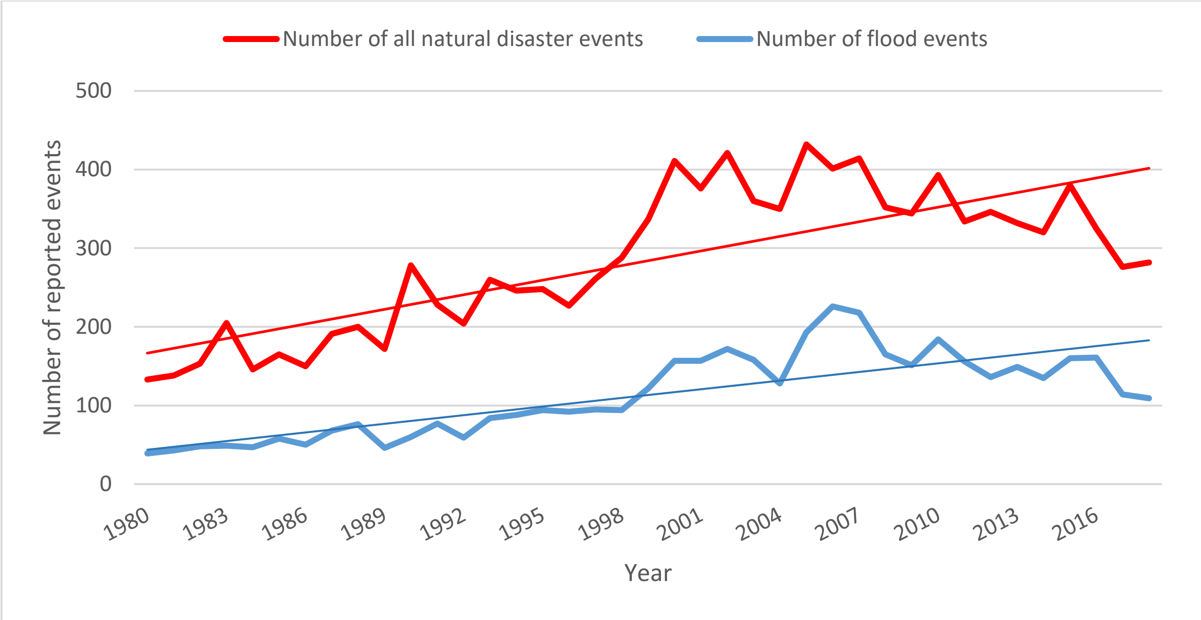

Figure 1.1 Number of reported all natural disasters in general and flood in particular from 1990-2018 globally. All natural disasters include floods, droughts, earthquakes, extreme weather, wildfires, landslides and volcanic activity. (Source: The Emergency Events Database, EM-DAT, 2019)

Moreover, 91% of the disasters that occurred in the last two decades were climate-related (Figure 1.2), culminating in an estimated US $3 trillion worth of economic damages across the world (UN/ISDR, 2019). Furthermore, reports show that more people have been affected by floods than any other climate-related disasters in these twenty years (UN/ISDR, 2019). In Canada, there is a growing body of evidence showing the increasing severity and frequency of flooding and flood damages (Brooks et al., 2001; Dumanski et al., 2015; Burn & Whitfield, 2016). For example, the 2013 flood in southern Alberta is reported as one of the worst disasters in Canada, with damages estimated at $6 billion (CAD) (Burn & Whitfield, 2016). Similarly, the 2011 ‘superflood’ in Manitoba left many First Nations communities uninhabitable, resulting in the permanent displacement of thousands of peoples (Ballard & Thompson, 2013). A majority of flood events (almost 40%) occurs in April and May which overlaps with the spring snow-melt in many parts of Canada including the southern Provinces (Shrubsole et al., 2003); over the years increased rainstorms (e.g., Vanguard flood in 2000) (Shrubosle et al., 2003) and rain-on-snow events (Dumanski et al., 2015) have played a significant role in large-scale flood damages.

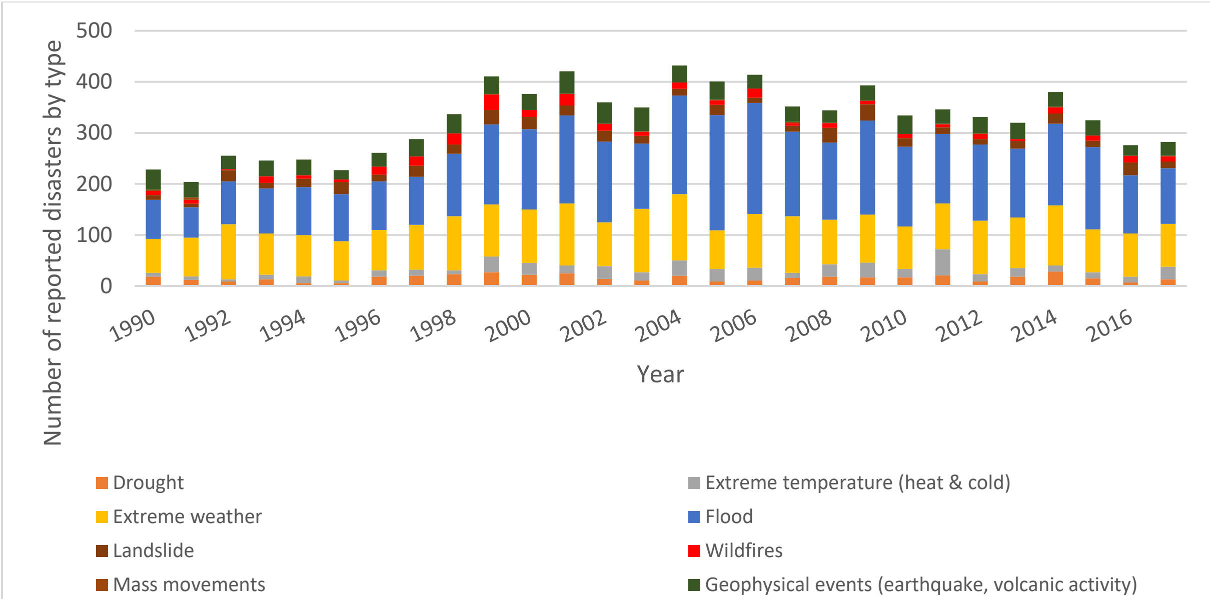

Figure 1.2 Global reported natural disasters by type including both weather and non-weather related disasters (Source: EM-DAT, 2019)

Disaster-related fatalities, however, have decreased significantly over the years as a result of the advancement of science and technology and changing social values, attitudes, and perceptions (McPhillips et al., 2018; EM-DAT, 2019). Nevertheless, the impacts of climate change continue to threaten the lives of millions of peoples across the world (i.e., through diseases, anxiety, and population displacement) (McPhillips et al., 2018). This growing concern and urgency in dealing with disasters have generated much interest in disaster risk conceptualization in multiple disciplines.

For example, in the natural sciences (e.g., geology and earth sciences), a disaster is considered a natural phenomenon, one that more or less can be predicted (Perry, 2007). This perspective of disaster as a natural event, however, tends to disregard the related risk or vulnerability (Cardona, 2013). The approach used in the engineering field comes from the structural design perspectives and studying disaster risks primarily comprises estimating the probability of event occurrence (i.e., 50-, 100-, 200-year return periods) (McPhillips et al., 2018). The notion of nonstationary (i.e., accounting for a change in the frequency of events over time) in the reoccurrence of these events is still emerging (Read & Vogel, 2013). Given the growing evidence of climate change (Gaur et al., 2018; Judi et al., 2018) using *return period* based approaches increases the risk of viewing disasters as *'static and mitigation as an upward, positive, linear trend'* (Mileti & Peek-Gottschlich, 2001 p.61). Disaster studies in social sciences (e.g., human geography, sociology, anthropology) involve assessing individual and collective values, attitudes, and perceptions on risks (McEntire, 2007; McPhillips et al., 2018). Disasters are not just natural phenomena but also ones that are influenced by the social, cultural, and political context (Cardona, 2013). Even within the social sciences, approaches to risk conceptualization and evaluation are diverse (Cardona, 2013). For example, economists tend to use risk assessment models to quantify risks (*ibid*, 2013), whereas sociologists and psychologists argue that risks are socially constructed, subjective, and based on perceptions that cannot be easily quantified (Renn, 2004).

Two things are undeniable; first, disasters are uncertain and complex (Cardona, 2013), and second, scientific knowledge is incomplete and insufficient for dealing with disasters (Walker et al., 2002; Özesmi & Özesmi, 2004; Cardona, 2013). Isolating disaster risk studies from their social contexts can result in the inability to consider the reality of unstable and disoriented times we are living in (Wilson, 1999; Walker et al., 2002; Akamani, 2016). The idea, however, is not to disregard any disciplinary contribution to the field but to shift the emphasis on the fact that disaster-related challenges, *"are interrelated and complex, and solutions are multifaceted with both advantages and disadvantages…collaboration among all participants are vital for success [to addressing the challenges]"* (McEntire, 2007 p.5). A holistic approach, one that has its foundation on inter- and trans-disciplinary, learning-focused, and community-based approaches, will be vital for dealing with extreme and frequent disasters such as a flood. To do this, it is important to revisit some of the critical debates that have shifted and shaped the current approaches to disaster risk studies.

1.1 Unpacking perspectives on disasters

"Controlling all floods is impossible, but working with them is not" (Williams, 1994 p. 51)

Seven decades ago, the cascading effect of an increased number of extreme events (e.g., floods and droughts) and changing sociopolitical context in the U.S. (e.g., the Great Depression) marked the beginning of a paradigm shift in disaster management (MacDonald et al., 2012). In western worlds, particularly in the U.S., the civil defense approach was a standalone strategy used to control flooding in the early 1940s (Alexander, 2015). This defense approach comprised of building control structures (e.g., dams, levees) to protect civilians from extreme events (Smith, 2003; Hilhorst et al., 2013; Alexander, 2015). It was indeed the time when engineering was considered *"panacea for solving all flood management problems"* (Macdonald et al., 2012 p.

128) despite the failures of structures that inflicted major human and economic losses (White, 1945). The catastrophic effect of structural failure is particularly evident in the Mississippi flooding case in 1927 that displaced more than 700,000 people (Williams, 1994) and the rock-fall case in the Vajont Dam that swept many villages in the area away within minutes, and cost 1909 lives (Kilburn & Petley, 2003).

In the 1950s, the control and defense approach shifted to the notion of response and adjustment to floods marking a new geographical perspective (White, 1945; Smith, 2003; Macdonald et al., 2012). Gilbert White, a geographer by profession, redefined the concept of disasters which before the 1950s was considered as 'acts of gods' to more of a social concept: *"floods are acts of God, but flood losses are largely acts of man"* (White, 1945 p. 2). This presented disasters through the lens of 'hazards' rather than 'natural' events[2]; that later came to be known as the 'behavioral (dominant) paradigm' (White, 1945; Smith 2003). Although White's earlier work was focused in the U.S., it resonated with other disaster challenges across the world, including in Europe (Macdonald et al., 2012).

White's 'Human adjustment to floods' (1945) shed light on hazard-prone areas (e.g., floodplains). This tome acknowledged and reinforced the work that was being done by geographers at that time, i.e., spatial planning (Smith, 2003). Moreover, he emphasized the integration of different 'adjustment' strategies, including structural and non-structural (e.g., land-use planning and management, insurance policies) for improved flood management. At the same time, his recommendations on a range of options also highlighted the decision-making abilities of individuals in response to the crisis (Wescoat, 2006). This invited social scientists into the DRR realm to explore the role of human behavior for disaster response and has greatly influenced current disaster preparedness (Hillhorst, 2013) and emergency management (McEntire, 2007).

White's pragmatic approach to disaster management was revolutionary at the time when the responsibilities of scientists and engineers were to study the geophysical processes but had no influence in policymaking (Wescoat, 2006; Macdonald et al., 2012). White's pragmatic approach

[2] There are some mentions of Rousseau (1756) as being pioneer in hazards because he had long established that disaster related fatalities were consequences of people's behavior (Kelman et al., 2011).

was influenced by John Dewey's American pragmatism philosophy that coincided in four major areas (Wescoat, 1992):

- First, the idea of adaptation or adjustment of humans to the environmental crisis,
- Second, investigating a problem to develop appropriate solutions rather than the other way around or in other words 'command and control' solution is not favorable for dealing with complexities,
- Third, learning from concrete human experiences to shape future actions, and
- Fourth democratic principles for individual and collective decision-making processes (for detailed comparison see Wescoat, 1992 and Macdonald et al., 2012).

These four themes form the basis of current environmental and sustainability discourses (Garmendia & Stagl, 2010).

In the late 1970s, however, a group of scholars (known as the 'radical critics'), criticized White's adjustment approach to natural hazards for being Eurocentric, i.e., the proposed adjustment responses focused on improving the technological or 'command and control' approaches rather than addressing human vulnerability (Torry 1978; Hewitt, 1983; O'Brien et al., 2010; Macdonald et al., 2012; Hewitt, 2019). Moreover, behavioral paradigms tended to focus on technical expertise and resources in developed nations, disregarding the role of sociocultural and economic impact such as poverty and marginalization on hazards, particularly in poor and developing countries (Smith, 2003; Macdonald et al., 2012; Hilhorst, 2013). Hewitt (1998) pointed out that the dominant behavioral paradigm was *"an authoritarian outcome…addressing social problems without social content" (p.77).*

The criticism led to a new school of thought called 'radical (structuralist)' paradigm (or vulnerability paradigm). The structural paradigm did not necessarily replace White's approach to defining disasters as hazards but instead helped in the reconceptualization of disaster risk (i.e., risk = hazard x vulnerability) (Macdonald et al., 2012). Vulnerability-focused approaches emphasized placed-based understandings of disaster risk (Smith, 2003; Dintwa et al., 2019), and the participation of those affected by disasters in planning (Hilhorst et al., 2013). Alongside the vulnerability-based approach, emergency planning was also emerging as a new field in disaster studies, particularly in response to increasing technological hazards such as nuclear explosions, but quickly became accepted widely in the natural disaster domain (Alexander, 2015).

In the same era, anthropologists also increasingly highlighted the impact of cultural factors such as knowledge, narratives, values, norms, and beliefs in DRR (Kulatunga, 2010; Mercer et al., 2012; Benadusi, 2014). They argued that the culture played a critical role in influencing the behavior of individuals and communities in shaping their risk perception and response, *"…culture is important to the individuals as well as to the society. As individuals, people rely on culture because; it provides information for them to survive in the world"* (Kulatunga, 2010 p.310). Kulatunga (2010), in her review of the impact of culture in DRR, demonstrated how cultural factors could strengthen or impede the interventions in many cases. For example, the Javanese community who have long lived in the slopes of Merapi Volcano in Indonesia refused to be evacuated upon the government orders during the 2006 eruption. They evacuated the area only after they got instructions from their 'religious leader'. In another case, traditional knowledge transferred through generations helped many individuals and communities to survive the Indian Ocean Tsunami in 2004. However, for many tourists and locals, it was not the case (*ibid, 2010)*. The two cases highlight the significance of engaging communities and integrating cultural factors in planning and implementing DRR.

The International Decade for Natural Disaster Reduction (INDR) in the 1990s embraced and adopted this concept of hazard and vulnerability with the focus on disaster reduction at all scales (i.e., local to global):

> *"Since the 1990s, the understanding of disasters again shifted to emphasize the mutuality of hazard and vulnerability to disaster due to complex interactions between nature and society. In this view, hazards are increasingly the result of human activity. This has the important implication that vulnerability might not just be understood as how people are susceptible to hazards, but can also be considered as a measure of the impact of society on the environment (Oliver-Smith and Hofmann, 1999; Hilhorst, 2004)" (Hilhorst et al., 2013 p. 174-175)*

Disaster risk reduction (DRR) in the 1990s was strengthened by the growing significance of 'sustainable development' (WCED, 1987). The sustainability paradigm provided a holistic framework to DRR called 'sustainable hazard mitigation' (Mileti & Myers, 1997; Smith, 2003) and emphasized enhancing practices that are locally-relevant, and included the involvement of Indigenous and marginalized communities in the planning (Smith, 2003), and multi-stakeholder development of long-term, flexible and sustainable DRR policies (Berke, 1995; Hilhorst et al., 2013).

Coming to the current context, DRR studies continue to evolve. Despite the criticism, White's 'adjustment and adaptation' concept is apparent in many of the works that have happened in the last decade including European Union's water directive framework (Mostert et al., 2007; Carmona et al., 2013) and Dutch flood adaptation projects (Roth & Winnubst., 2014). Through past debates and current studies, disasters are now termed as complex phenomena that involve environmental and societal interactions. This is captured in the definition of disasters from UN/ISDR:

> *"serious disruption of the functioning of a community or a society causing widespread human, material, economic or environmental losses which exceed the ability of the affected community or society to cope using its own resources." (UN/ISDR, 2019)*

Although conceptualization of disaster risks remains contested across disciplines (Mayner & Arbon, 2015), the UN/ISDR definition captures two important perspectives. First, disasters are not 'natural' events; instead are 'social' phenomena caused through interactions between society and environment (Kulatunga, 2010; Hilhorst et al., 2013; Mayner & Arbon, 2015). To ensure the wellbeing of people, understanding the risks will require not only different disciplinary perspectives but also the input from individuals and communities affected by disasters (Cardona, 2013; Dintwa et al., 2019). Second, the definition also highlights the role of community-based strategies to develop both short-term coping abilities as well as long-term adaptation. In regard to both, participatory approaches to DRR is recommended and have led to improvements and emergence of novel participatory techniques to engage social actors.

1.2 Participatory Approaches to Disaster Risk Reduction (DRR)

While the DRR paradigm was undergoing a transition in the latter half of the 1960s, the notion of public participation was becoming prominent in environmental planning and assessment (Arnstein, 1969). The recognition of the need for public participation grew out of the realization that traditional approaches to problem-solving were inadequate, coupled with increased environmental awareness among the public (Pahl-Wostl, 2002; Keen et al., 2012b). Arnstein (1969) was one of the first to provide a systematic framework for participation levels (in his ladder of citizen participation) in the context of urban planning. The eight typologies of participation determined the outcomes of participatory processes. For example, according to Arnstein (1969), citizen control or delegated power will yield more ‘community-controlled’ decisions than passive forms of participation, such as informing or consulting. Others also agreed that active forms of participation yielded self-sufficiency in the sense that citizens would take on responsibilities and initiatives to reduce the risks with limited external assistance (Smith, 2003; Sinthumule & Mudau, 2019).

Disasters, particularly in disadvantaged groups and marginalized communities, continue to affect people geographically (because more than often they are forced to live in hazard-prone areas), socially (because the affected are often from the low-income groups), and politically (because the voices of affected groups seldom are heard in decision-making) (Gaillard et al., 2007; Mercer et al., 2008; Dodman & Mitlin, 2013). With this realization and significant momentum gained by public participation, participatory approaches became critical for interacting with local people for not only understanding the socio-cultural and situational factors of disasters but also to involve them in the decision-making process (Mercer et al., 2008; Kelman et al., 2011).

An array of participatory approaches (see Box 1.1) that are now applied as research methodology initially started as ‘alternative development initiatives’, in the 1980s, for encouraging local participation in community development projects by funding agencies and NGOs (Cornwall & Jewkes, 1995; Pain & Francis, 2003; Pelling, 2007; McCall & Peters-Guarin, 2012; Sinthumule & Mudau, 2019). The purpose of participatory approaches is to serve as a ‘template’ that is flexible enough for researchers to adapt to the research context (Pain & Francis, 2003; Mercer et al., 2008). Regardless of the approach what is important is to; *enhance* the level of participation from the public (Chambers, 1994), *empower* local people (Kelman et al., 2011), *enhance* social learning for researchers and participants (Webler et al., 1995), and *implement* collective action (Pain & Francis, 2003).

The support or ‘intervention’ from external agencies helped bring local voices into DRR; however, others argued that such interventions tend to be short-lived and do not necessarily enhance the community’s capacity for long-term adaptation (Maskrey, 1989; Wisner et al., 2004; Heijmans, 2009). As a result, community-based approaches that focused on grassroots efforts became widely acknowledged primarily in developing countries (Heijmans, 2009). Some examples of its application include strengthening disaster resilience in Papua New Guinea through Indigenous and western knowledge integration (Mercer et al., 2008), enhancing community disaster communication, preparedness and response to flooding in Manitoba, Canada (Buckland & Rahman, 1999; Stewart & Rashid, 2011; Thompson et al., 2014), and climate change adaptation to reduce disaster risks in Australia (Forino et al., 2019).

The significance of community-based approaches to disaster risk reduction (CBDDR) became prominent with the growing awareness of; *failed* dominant approaches from the past (e.g., structural and technological response), *demonstrated* evidence that showed bottom-up initiatives are more significant in bringing behavioral and transformative changes and *exerted* social injustice as a result of top-down approaches (Petal et al., 2008). In regard to social justice concerning DRR, Petal et al. (2008) write:

> *"Knowledge denial is a phenomenon rooted in the hierarchical organization of knowledge in society. Social injustice is perpetuated in part because of the weight and credibility we give to the voices of scientific and technical 'experts', to the exclusion and denigration of knowledge acquired through experience. Written, logically-presented material is too-often valued above knowledge transferred orally and the unwritten experiences of community elders or the visual evidence left by vernacular construction" (p 196)*.

Despite, the significant progress in participatory CBDRR in the last 40 years (Maskrey, 2011), there is still a gap when it comes to bringing the knowledge of local and Indigenous peoples into 'mainstream knowledge environments' (Kelman et al., 2012; Balay-As et al., 2018). Some have pointed out that the inclusion of Indigenous knowledge has been especially 'downplayed' in DRR (Kelman et al., 2012). This idea of the validity of one knowledge over the other goes against the democratic and pragmatic rationales for participatory processes and creates the risk of placing Indigenous peoples as 'clients' in DRR rather than actors or agents for risk reduction and social change (Petal et al., 2008).

Box 1.1: Participatory research approaches relevant to DRR

- **Participatory appraisal (PA)** comprises of interactive research approaches to enhance public participation in all stages of the research. The idea is to allow all groups of society (i.e., scientists, decision-makers, citizens) to take ownership of developing solutions to real-world problems (Chambers, 1994). PA has been used to integrate science and public deliberation for policy development in many European countries (Chilvers, 2008).

- **Participatory rural appraisal (PRA)**, similar to PA, involves approaches and methods that allow local people (particularly from rural settings) to share and analyze their knowledge to develop community-based solutions (Chambers, 1994). PRA is prevalent in developing countries and, like PA, uses interactive methods (e.g., mapping, semi-structured interviews) as opposed to extractive practices (Pain & Francis, 2003).

- **Participatory action research (PAR)** is embedded in the philosophical underpinnings of translating research into action and generating practical knowledge, particularly in disadvantaged and marginalized groups (MacDonald, 2012). It is a systematic research process by, with and for local people from identifying, analyzing and solving locally relevant problems (Ozanne & Saatcioglu., 2008). However, critiques have also pointed out the hierarchical and top-down nature of PAR in a sense that the research itself is guided by researcher's hypothesis (Pain & Francis, 2003; Ozanne & Saatcioglu., 2008)

- **Community-based participatory research (CBPR)**, an alternative to the hierarchical and top-down approach, CBPR uses an array of research approaches and methods to enhance grassroots people's participation in decision-making for long-term capacity building, empowerment and social change (Heijmans, 2009). The rationale of CBPR is to advocate human rights issues and improve the lives of vulnerable and disadvantaged groups (Shaw, 2016).

- **Participatory modeling (PM)** is an emergent approach that uses different levels of engagement from a broad range of stakeholders to create a formalized and shared understanding of the system or problem. The purpose of PM is to enhance collaborative learning for researchers and participants (Voinov et al., 2018). As such, the process of participation (i.e., deliberation and learning) is more important than the outcome (Webler et al., 1995; Voinov et al., 2018).

1.2.1 Indigenous knowledge in DRR

Indigenous peoples[3] in Canada and around the world face greater exposure to hazards and risks (including environmental, health, and socioeconomic) compared to non-Indigenous groups (Howitt et al., 2012; Thompson, 2015; Shaikh et al., 2017). Colonialism has played a significant

[3] Indigenous people, in Canada, include First Nations (FN), Métis, and Inuit groups (Statistics Canada, nd). FN is a specific legal identity given to recognize the Indian status (people engaged in livelihoods and cultural activities on ancestral territories) of Indigenous person by the Indian Act in 1876 (Statistics Canada, nd).

role in displacing Indigenous groups to hazard-prone areas (e.g., swampy lands) to make room for settlers (Thompson, 2015). This has resulted in long-term geographical isolation, increased vulnerability, and inequity (Thompson, 2015; Shaikh et al., 2017). In addition, disregard of Indigenous ways of knowing and knowledge over scientific and institutional expertise (Howitt et al., 2012), failure to acknowledge Indigenous sovereignty (ownership rights for traditional territories including land and resources), and reduced infrastructural (e.g., cheap and unsafe housing) and human capital has resulted in such disproportionate exposure to hazards (Thompson, 2015). Similar observations have been made in other studies where disadvantaged groups, including Indigenous peoples, are found living in disaster-prone areas despite increased vulnerability exacerbated by climate change (Walker & Burningham, 2011; Fielding, 2012; Shaikh et al., 2017).

The concept of environmental justice[4], combined with the growing significance of CBDRR in the 1990s, helped bring Indigenous peoples concerns, voice, and preferences into DRR. The importance of Indigenous knowledge and participation in understanding disaster risks has been highlighted in numerous studies (Turner & Clifton, 2009; Kelman et al., 2012; Thompson et al., 2014; Chandra & Gaganis, 2015; Sinthumule & Mudau, 2019). For example, Turner and Clifton (2009) discuss the value of Indigenous knowledge in understanding the changing environmental conditions in British Columbia, Canada. They highlighted three specific areas where Indigenous knowledge should be used, for i) providing insights to environmental changes, ii) co-developing long-term and sustainable practices for risk mitigation, and iii) co-developing models for understanding climate change effects and adapting to the change. The survival and adaptation strategies are particularly relevant to today's context of accelerated climate change.

Indigenous knowledge is developed through complex understandings of the ecological system accumulated over historical time, generally through lived experiences and/or handed down through generations (Gadgil et al., 1993). Indigenous peoples and communities are among the most resilient groups in the world, referring to the persistence of Indigenous ways of knowing over centuries despite transformative forces such as colonization, globalization, and

[4] Environmental justice involves fair treatment to and inclusion of all despite their ethnicity, religion, race, socioeconomic background in regards to environmental benefits, development, policies and regulations (Thompson, 2015).

environmental hazards (Agrawal, 1995; Barnhardt & Kawagley, 2005; Kelman et al., 2012). This experiential knowledge has been key to developing a deep understanding of their environment. McCall & Peters-Guarin (2012, p. 731) even argue that experiential knowledge of hazards *'is always richer and probably more convincing than is statistical data'*. Similarly, Agrawal (1995) and Mercer et al. (2010) contend that acknowledging this depth of knowledge is essential for western scientists, First Nation knowledge keepers, and others to work together to move beyond the dichotomy of knowledge systems.

Despite the depth of Indigenous knowledge and experience, the inclusion of it in DRR often remain just as a theoretical notion (Turner & Clifton, 2009; Thompson, 2015). This again comes back to the point that Indigenous knowledge *"…does not conform to the standard or format expected, making it hard for scientists to know how to deal with it"* (Mercer et al., 2007 p. 246). The idea of generalization and transferability also hinders the uptake of Indigenous knowledge in DRR. Indigenous knowledge is contextual, and the idea is not to generalize (although lessons of doing research itself may be transferable) but to enrich the understanding of 'conflicting observations' in the system (Mercer et al., 2007; Shaikh et al., 2017). Moreover, Etkin (1999) emphasizes that excluding Indigenous peoples from disaster-related decisions increases the risk of reliance on external assistance and structural measures to DRR rather than developing complementary initiatives that are sustainable and relevant to the community. Hence, Indigenous participation (equal and active) in DRR research is critical from both practical and ethical perspectives (Turner & Clifton, 2009).

Due to the growing urgency of climate change-related shifts in global water cycles, DRR can no longer be approached through a single knowledge framework. There is a need to seek and apply approaches that pursue a balanced knowledge sharing so that they do not dominate one another but provide complementary support to deliver a holistic perspective on disasters (Mercer et al., 2010; Castleden et al., 2017). New forms of participatory approaches provide different ways to blend or integrate knowledge forms (Box 1.1). Of relevance to this thesis is participatory modeling (PM). PM is an emerging participatory approach that provides a promising avenue for a structured way of sharing and integrating local, Indigenous and scientific knowledge (D'Aquino & Bah, 2013; Gray et al., 2012; Voinov & Bousquet, 2010; Voinov et al., 2018). The next section reviews the participatory modeling concept, existing framework, challenges, and outcomes.

1.3 Participatory Modeling

"Nowhere else can science and practice come as close together as in the process of participatory modeling" (Voinov & Gaddis, 2017 p. 62)

Models represent a simplified version of complex environmental systems. Scientific modeling in environmental studies has evolved from an individual representation of physical processes (e.g., precipitation and runoff) to integrated tools for managing dynamic environmental, social, and economic processes (Singh & Frevert, 2002c). For example, physically-based hydrological models dominated water resources planning through the 1980s and 1990s in the U.S. (Singh & Frevert, 2002c). Similarly, economic models were used to predict the behavior of human-environment interactions based on parameters such as behavior alternatives, pay-offs, rational choice, and information gathering (Simon, 1955; Prell et al., 2007). Such traditional approaches, however, are often constrained by objectively definable parameters, generalization, and do not represent the place-based values of people (Fraser et al., 2006).

In the U.S., the role of stakeholders in implementing modeling results was recognized in the 1970s as models began to enter the policy field (Voinov & Bousquet, 2010). Eventually, Integrated water resources management (IWRM) emerged alongside the sustainable development movement in North America in the 1990s. This approach integrated multiple disciplines, stakeholders, and governance structures in water resources management (Cervoni et al., 2008; Akamani, 2016).

Scientific research with public participation has evolved through the concept of post-normal science[5] (Funtowicz & Ravetz, 1993) to interdisciplinary, transdisciplinary, or participatory research (Reed, 2008; Diduck, 2010a; Cubelos et al., 2019). These have gained significant attention for facilitating modeling with non-scientists and improving effective information flow within science-society interfaces.

[5] Following an era of top-down or western science-dominated approaches in natural resources management, the paradigm gradually shifted to post-normal science (PNS) (Funtowicz & Ravetz, 1993). Ravetz (1999) defines the approach as practicing science in a social context. The PNS perspective acknowledges the inherent human-environment interactions, embedded societal values, and institutional complexities that exist on top of the uncertainties in the changing environmental conditions. The philosophical underpinnings of PNS involve improving the legitimacy and quality of scientific research by promoting inclusivity and participation (Ravetz, 1999).

Participation in modeling can be used to enhance improved engagement in decision-making or to facilitate, develop, and improve models. In many cases, there can be an overlap between the two. Participation can additionally help to create a platform for science-society boundary studies (Webler et al., 1995; Larson et al., 2013) to ensure that the scientific information is relevant to users' needs (salient), scientifically rigorous (credible), and reflects the divergent viewpoints of stakeholders and rightsholders (legitimate) (Cash et al., 2003; Offermans & Kemp, 2016). Participation in modeling studies has been cited as an approach built on the foundation of adaptive management that promises the integration of diverse knowledge systems and learning (Prell et al., 2007; Henly-Shepard et al., 2015; Villamor & Badmos, 2016).

Three rationales (normative, substantive, and pragmatic) for participation in modeling studies are frequently cited. Normative justification supports democratic principles of participation for equity, social justice, and the empowerment of those who are affected by outcomes (Jones et al., 2009; Pahl-Wostl et al., 2007; Reed, 2008). Jones et al. (2009) elaborated on the normative rationale, in the context of models, for the legitimacy of modeling outputs through the inclusion of diverse viewpoints. Substantive explanation supports the rationale for the integration of local and Indigenous knowledge lead to an improved understanding of a problem (Korfmacher, 2001; Van Vliet et al., 2017). The pragmatic rationale for participation is to achieve an enhanced quality of outcomes, self-sufficiency, and people's commitment to the process (Webler et al., 1995; Reed, 2008). Jones et al. (2009) further explained the pragmatic benefit of a participatory process in modeling studies to reduce conflicts and implement collective actions.

Although the rationales have been confirmed by several participatory modeling studies (Jones et al., 2009; Johnson, 2009; Van Vliet et al., 2010), factors such as time, resources, transparency, and quality issues in modeling can limit public participation (Korfmacher, 2001). Participation also depends on social relations between groups, knowledge and skills, interaction, and exchanging information as well as clarity and availability of modeling tools (Voinov & Bousquet, 2010). The complexity of conventional modeling tools can also hinder knowledge sharing and information flow between the groups compromising the trust in these tools and limit participation (Cockerill et al., 2004).

Depending on the purpose and nature of modeling efforts, the level of participation can vary, which means that social actors (i.e., stakeholders and rightsholders) can be engaged in different phases or ways in the modeling process (Table 1.1). For example, participation can be in the form of sharing information or management practices making it a passive form of involvement or participants can guide the entire modeling process and hence have a more active role in model development. Similarly, models can range from rich pictures representing participants' values (Voinov et al., 2018) to system dynamic models capturing complexities in the system (Hassanzadeh et al., 2019).

Table 1.1 Degrees of public participation in modeling projects (adapted from Arnstein, 1969 & Seidl, 2015)

Level of participation	**Description**
One-way communication (Passive involvement)	
Information	Modeling work driven by scientists and the public (or participants) is informed about the process, results, and conclusions
Consultation	Participants are asked to provide information relevant to their needs, which are then tested or analyzed scientifically for feasibility.
Two-way communication (Active involvement)	
Cooperation	Participants are actively involved in the research/modeling process, but scientists/researchers define the project structure and process.
Collaboration	Project structure and process is co-developed with equal inputs from participants and scientists
Empowerment	Participants get full power over the project conceptualization, development, content, and process.

The flexibility in tools and levels of engagement can make it challenging to distinguish what accounts for participation or how PM is defined (Basco-Carrera et al., 2017). Van Den Belt (2004) describes that any level of engagement in modeling activities qualifies for participation or, in other words, if the modeling studies include participatory or engagement component, it qualifies for participatory modeling (Seidl, 2015). What becomes important is the tools used in PM studies should be able to promote social learning (Voinov et al., 2018) and provide support in decision-making (Carmona et al., 2013). The next section gives an overview of the PM methods, process, and issues with knowledge integration.

1.3.1 Overview of PM methods: issues with knowledge making

Participatory Modeling (PM) studies are growing in natural resources management and DRR (Gaillard & Pangilinan, 2010; Strickert et al., 2010; Gray et al., 2014; Henly-Shepard et al., 2015; Singh & Chudasama, 2017; Voinov et al., 2018; Hassanzadeh et al., 2019). This has led to the proliferation of PM approaches, typologies, and tools. For example, PM approaches may be distinguished based on the level of engagement (Arnstein, 1969; Robles-Morua et al., 2014) or the choice of modeling tools (Voinov & Bousquet, 2010). A more recent overview of PM methods and tools is captured in Figure 1.3 (Voinov et al., 2018).

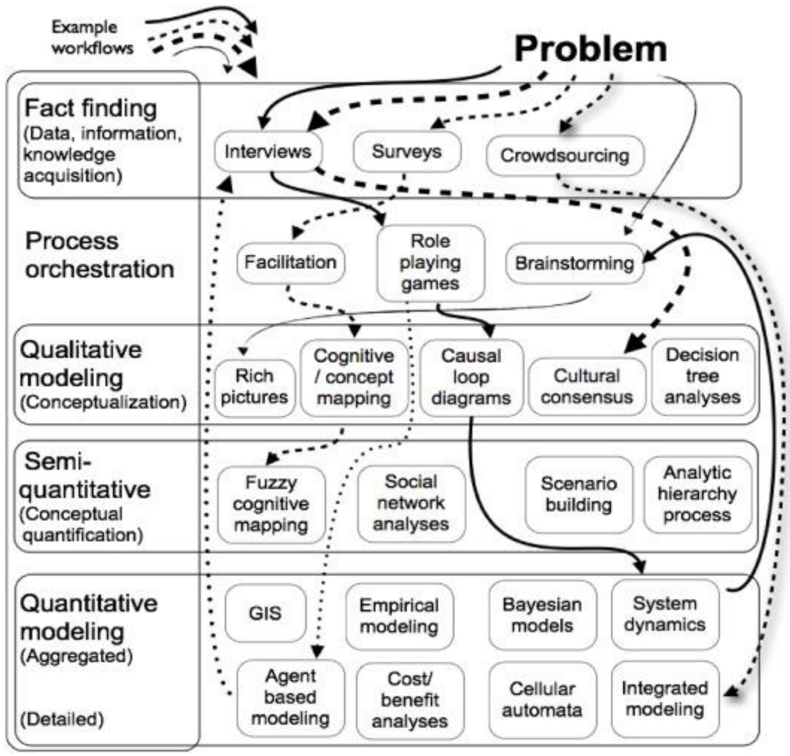

Figure 1.3 Participatory modeling broad typology based on the methods and tools. The different arrows show examples of possible combinations of mixed methods in PM studies. Process orchestration represents the facilitation process in the PM, including organizing, managing, and follow-up. It can happen at all stages of the PM process, from knowledge sharing to quantitative modeling (used with permission from Voinov et al., 2018).

Each approach (e.g., fact-finding, quantitative modeling) can consist of a wide range of tools (e.g., interviews, system dynamics) that determine different levels of engagement at different stages (Figure 1.3). These tools can be used individually or sequentially, depending on the purpose of the study. The arrows in the figure show some possible combinations. For example, interviews (fact-finding) can be used to get insights into a problem, which can then be used to develop a conceptual model (e.g., cognitive maps). Conversely, participants can develop conceptual models themselves, for example, using concept mapping. Participation in modeling can end there with a qualitative understanding of the problem, or additionally, the conceptual models can be further developed into a semi-quantitative (e.g., fuzzy cognitive mapping) or quantitative one (e.g., system dynamics model). Most PM studies, however, rarely use a combination of methods (e.g., cognitive mapping and interviews) with the exception of few (see Strickert et al., 2010; Hassanzadeh et al., 2019). In addition to providing an enriched understanding of the problem, combining participatory methods and tools can provide clarification and validation of the results (Greene et al., 1989; Strickert et al., 2010; Brown et al., 2017).

The individual or combined methods and tools used in PM can serve different purposes. For example, decision-making (Carmona et al., 2013), social learning (Johnson et al., 2012; Henly-Shepard et al., 2015), conflict resolution (Gurung et al., 2006), model validation and improvement (Johnson, 2009; Thapa et al., 2019) or all of them (Bradford et al., 2019). Although much effort is put into developing participatory modeling tools, Seidl (2015) argues that the systematic evaluation of the participatory process and the purpose served by PM is not well studied.

More recently, scholars agree that the focus of PM should shift from the outcome to process (e.g., reflection, deliberation, and learning) (Robles-Morua et al., 2014; Seidl, 2015; Voinov et al., 2018). In a comprehensive review done by Seidl (2015), only 34% of the participatory modeling studies discussed and reflected on the process while the remaining discussed more on the outcomes (e.g., the model itself). Emphasizing only the outcomes can be detrimental to retaining the interest of participants in the project, the quality of information they provide, and the trust and value of the results (Johnson, 2009). Hence, it is becoming increasingly important that the purpose of participation in modeling studies should be to promote a collaborative learning space for participants and researchers that will enhance system understanding and knowledge co-creation (Seidl, 2015; Voinov et al., 2018). Others also agree that the participation process should be emphasized to enhance the iterative and reflexive learning that leads to a common understanding of the problem (Voinov & Gaddis, 2008; Smajgl, 2010). Hence, formal model co-development will first require participants and researchers to identify their preferences and challenge their existing knowledge as new information or evidence emerge. In doing so, it is critical to acknowledge different worldviews and unite different knowledge systems.

1.3.1.1 Issues with knowledge integration

Integrating knowledge is not always straightforward. It can become even more complicated when researchers are attempting to formalize and incorporate Indigenous knowledge into models. Issues such as ethical context, characteristics of scientific models, epistemologies, and local capacity often hinder modeling with Indigenous peoples (Barber & Jackson, 2015). D'Aquino & Bah (2013) identified two major challenges in Indigenous people's participation in modeling studies. First, they argued that modeling tools are influenced by the decisions and worldviews of scientists and modelers, which may not necessarily align with Indigenous peoples' worldviews. Second, they claim that selecting appropriate modeling tools is difficult because not only must they elicit Indigenous knowledge and explore scenarios but also develop shared acknowledgment of different ways of knowing. Agrawal (1995) had also previously pointed out that the methodological and epistemological differences between Indigenous and western knowledge can hinder effective knowledge sharing and mobilization. In this context, there is general agreement that modeling with Indigenous peoples and communities will require epistemological (control over guiding modeling practices) as well as methodological improvements (D'Aquino & Bah, 2013; Butler & Adamowski, 2015).

Conceptual modeling tools such as mind mapping and sketch maps allow participants to choose their priorities and preferences to represent their knowledge (bottom-up process) as opposed to using scientifically driven information. This gives the participants control over the knowledge-making process as well as provides visualizations that allow the participants to explore and evaluate their conceptual framework (Cornwall & Jewkes, 1995; Voinov et al., 2018). Evidence has shown that mapping exercises are particularly beneficial in sharing ideas and knowledge in local and Indigenous communities in the context of DRR (Cadag & Gaillard, 2012; Haase, 2013; Gray et al., 2014; Klonner et al., 2018). With regards to the significance of tools that provide visualizations, Cornwall & Jewkes (1995) write:

> *"Visualizations provide opportunities for local people to explore, analyze and represent their perspectives in their own terms. People choose their own symbols from local materials to represent aspects of their lives in a shared medium which can be amended, discussed and analyzed…The process of constructing a visual representation is in itself an analytic act; revealing issues and connection that local people themselves may not have previously thought about." (p 1671).*

Hence, in the process of representing knowledge in the form of cognitive or spatial maps, the processes of reflection and learning become key to understanding disaster risks. In addition to tools, it is equally important to explore modeling with Indigenous communities built on the foundation of communication and learning that acknowledges multiple ways of knowing. Approaching modeling studies through the lens of social learning will enrich the participation process because it acknowledges (Cornwall & Jewkes, 1995):

i) Individual and collective knowledge is valuable,

ii) People are capable of analyzing and reflecting on their situations

iii) New knowledge created through communication fosters ownership and empowerment to take action.

iv) Learning processes themselves are flexible and reflexive, which can lead to transformative (or behavioral) changes

On the one hand, social learning can address the knowledge-making issues in PM, and on the other hand, learning can have a long-term transformative impact in reducing disaster risks and adaptation.

1.4 Social Learning for Disaster Risk Reduction

The uncertainties associated with managing disasters are large (Walker et al., 2002; Pahl-Wostl et al., 2007; Akamani, 2016). The effects of climate change are not linear, or in other words, climate change is highly unpredictable, and the use of predictive models may be limited by the turbulent nature of hazards (i.e., their frequency of occurrence may be higher or less than the predictions) (Walker et al., 2002). Additionally, human behavior and action is reflexive and proves difficult to be predicted (*ibid*, 2002). These limitations of predictive discourses have led to the recognition of learning to live with the changes (Walker et al., 2002; Akamani, 2016). While learning generally means an *"act or process by which knowledge, skills, and attitudes are acquired"* (Boyd et al. in Knowles et al., 2005 p. 10), the term social learning encompasses wider behavioral, cognitive and relational processes (Reed et al., 2010; Muro & Jeffrey, 2012). Given the ineffectiveness of 'command and control' approaches to managing complex systems, the notion of learning-based adaptation practices became popular by the late 1970s (Cundil & Rodela, 2012). As a result of these conceptual changes, adaptive management started gaining momentum, emphasizing flexibility and resiliency of ecological systems (Holling, 1978; Folke et al., 2005).

Adaptive management accounted for the non-linearity of the system, adaptation, human-environment interactions, and iterative learning (Cundil & Rodela, 2012). This iterative learning was later referred to as 'social learning' by Lee (1993). The difference in learning in adaptive management and social learning was that the former involved learning about the interventions by reflecting on the intervention outcomes and one that occurred between the scientists and managers (Cundil & Rodela, 2012). Social learning, on the other hand, involved not just scientists and managers but other stakeholders and occurred even outside the project boundary at all scales from individuals to organizations (Lee, 1993).

The role of social learning in building resilience and adaptation became even more prominent in adaptive co-management (Folke et al., 2005). Adaptive co-management combined the iterative learning component of adaptive management, and inclusion of diverse stakeholders' component of participatory or collaborative approaches (Armitage et al., 2008). Social learning, then, became a key governance process and not just the outcome of participatory approaches. In the context of responding to environmental crisis and shocks, Garmendia & Stagl (2010) have highlighted social learning as a pragmatic approach that has its roots in Dewey's philosophy:

> *"Dewey's view of nature as a constructed cultural artifact have influenced current discussions in environmental ethics, and in the field of environmental pragmatisms, in which science is perceived as a creative activity that is going beyond the search for an objective truth, learning is seen as a central process to overcome the current environmental crisis, reconstruct the problems at hand and shape new values in society."* (p. 1714)

This highlights the significance of learning not only in responding to a crisis but also for innovation and creativity (both important for dealing with the unknown). O'Brien et al. (2010) elaborate that learning in DRR should not be about how to respond to crisis better but about rethinking the concept of disaster risks or, in other words learning should be about 'doing it differently' rather than 'doing it better'. Moreover, they argue that the current model to disaster risk management (e.g., building institutional capacity, prevention, and response, risk assessment) may be ineffective unless the focus is on preparedness, and individuals are recognized as first responders.

This shift in the approach will require social learning methods that are based on human-environment interactions for preparedness planning. Such a learning-based approach enables that (O'Brien et al., 2010):

- Significance is given to all knowledge forms,

- Recognition can be found that the future may be different (no-steady state system),
- Thinking differently permits innovation to emerge, for example, proactive action (preventing floods) is taken as opposed to reactive (controlling floods) approaches

Furthermore, social learning increases the success of development and implementation of disaster planning, as shown in numerous studies (Henly-Shepard et al., 2015; Samaddar et al., 2015; Benson et al., 2016; Murti & Mathez-Stiefel, 2019). Differences in learning conceptualization (reviewed in chapter 3), and limited empirical evidence that explicitly demonstrate the social learning process (Muro & Jeffrey, 2008,2012; Reed et al., 2010; Benson et al., 2016) has limited its uptake and application in DRR. The constant challenge of evaluating the social learning process and outcomes have impeded the design of practical learning-focused participatory approaches.

Box 1.2: Social learning and Community development in Participatory Research Context

Community development and social learning, in the context of community-based action research, both call for inclusive and equitable participation of local people with diverse perspectives to collaborate in taking joint action (Chambers, 1994; Grassini, 2019). Unlike conventional interventions to community development (e.g., consultation, informing), social learning provides new ways to bringing multiple cognitions with interest to developing collective or shared meanings through dialogue, expression of interests, reflection on others viewpoints and reflexivity which ultimately enhances the community development outcomes including solidarity, accountability and self-sufficiency (Percy-Smith, 2006; Bonatti, 2018).

While participation and diverse knowledge integration are vital for both social learning and community development, participation alone may not yield sustainable and equitable outcomes because of emphasis (often) placed on the desired goals rather than creating conditions for learning and reflection (Reed et al., 2010; Grassini, 2019). This point is demonstrated in the community-based water supply project implemented in Ahmedabad, India (Grassini, 2019). The community-based project was commended for producing best water governance practices for its participatory and collaborative learning elements; however, close examination done by Grassini (2019) revealed that the project did not create opportunities for social learning and as a result, the decisions made did not reflect on the shared perspectives, created distrust among partners and ultimately limited its uptake at the community level. Grassini's (2019) evaluation showed that the social learning is a critical process in participatory approaches that may or may not directly contribute to research goals or meet project objectives but creates space for dialogue across groups to collectively restructure problems and guide the quality of outcomes produced. Social learning, therefore, can be interpreted as a necessary mechanism of participatory action research to create effective and sustainable community development outcomes. In that sense, social learning and community development are not independent approaches instead complementary processes within the context of action research (Percy-Smith, 2006). Identifying elements of learning (Table 1.2) can be beneficial for developing effective community-based participatory action research (Muro & Jeffrey, 2012; Bonatti, 2018).

1.4.1 Social Learning Evaluation

In the context of participatory approaches to DRR, social learning here is defined as a change in understanding in individuals that become situated within broader social units (e.g., group, community) facilitated by social interactions (Reed et al., 2010). Many social learning components (process and outcomes) are relevant to the participatory context (Table 1.2).

Table 1.2 Description of social learning components (process and outcomes) (Used with permission from Muro & Jeffrey, 2012)

Social learning conditions and processes			(adapted from Webler et al. 1995, Schusler et al. 2003, Mostert et al. 2007)
Inclusiveness			All relevant views are represented in the process.
Extended engagement			The process provides opportunities for prolonged and frequent interaction.
Opportunities for information exchange			The process allows participants to exchange knowledge and information.
Opportunities for dialog and interaction			Participants should be able to engage in in-depth discussions and dialog.
Process control			The process allows participants to define the collaboration agenda and procedures.
Open communication			Participants openly share information and articulate and expose their views and interests.
Equal participation			Communication and interaction are characterized by equal participation by all parties involved.
Social learning outcomes			(adapted from Webler et al. 1995, Schusler et al. 2003, Röling. 2002, Mostert et al. 2007)
	Relational change	{ Relationship building	Participants establish new relationships and develop a sense of community.
		Trust building	Participants believe in the honesty and commitment of other group members.
	Cognitive change	{ Knowledge and reflection	Participants learn about and reflect on RBM, their understanding of the management problem at hand and that of other group members.
Agreement†		Developing common views	Participants develop a shared understanding of the environmental situation.

† The extent to which stakeholder groups developed a common view of the environmental situation at hand is used as an intermediate indicator for process outcomes.

Several studies have used social learning to develop and assess participatory processes (Godschalk & Stiftel, 1981; Webler et al., 1995; Schusler et al., 2003). For example, social learning was found to be a critical process in designing community-based natural resources co-management in the Lake Ontario Basin in North America (Schusler et al., 2003). Learning frameworks have been used in evaluating public involvement in sustainability programs since the 1980s. Godschalk and Stiftel (1981) evaluated public participation in over 200 water planning programs in North Carolina, U.S. They used seven criteria for measuring engagement, which included a learning criterion named public awareness, i.e., *"How knowledgeable did public participants become about [the] planning program?"* (Godschalk & Stiftel, 1981 p. 601). Later, Webler et al. (1995) used social learning as a normative criterion for evaluating public participation in impact assessment (IA) processes in Switzerland. They used cognitive enhancement (acquiring knowledge) and moral development (transforming an individual to collective interest) as their criteria to assess the participatory process in IA. The comprehensive review of social learning in environmental governance by Muro and Jeffrey (2008, 2012) summarized learning indicators frequently used in participatory programs such as acquisition of factual knowledge, technical and social skills, changes in cognition and attitudes, and building trust and relationships (Table 1.2).

Tàbara and Pahl-Wostl (2007) maintain that participatory approaches such as PM can help elicit mental models of individuals and groups for understanding system complexities at multiple scales. The measurement of *understanding* therein did not refer to consensus-building or finding a system steady-state. It meant learning to see things from multiple frames of references (underlying values and assumptions) (Pahl-Wostl, 2007; Garmendia & Stagl, 2010). Thus, the researchers have demonstrated that focusing only on consensus building can result in power imbalances in the group and does not reflect the learning process of those with less power (Muro & Jeffrey, 2008; Diduck, 2010b).

Mental models represent cognitive frameworks used by individuals to make sense of their external world, including filtering and selecting information to be stored and used for reasoning (Pahl-Wostl & Hare, 2004; Gray et al., 2012). Changes in mental models can indicate group dynamics, acquisition of evidence or knowledge, and reflection on experiences. For example, refining existing mental models (i.e., changing actions and practices), can indicate single-loop learning whereas, questioning, and potentially modifying existing mental models (i.e., underlying values and beliefs) indicate double-loop learning. Voinov et al. (2018) suggested that 'before and after' diagrams of how individuals and/or groups perceive a problem, or their ecological systems can reflect a shift in the mental models and indicate the occurrence of learning in participatory studies. Others have proposed and used a similar framework for evaluating social learning before and after participatory programs (Pahl-Wostl, 2002; Scholz et al., 2014; Henly-Shepard et al., 2015). Selecting appropriate methods and tools to capture learning can, however, be challenging.

The conceptual modeling approach is often used for eliciting mental models (Pahl-Wostl & Hare, 2004; Henly-Shepard et al., 2015). For example, Henly-Shepard et al. (2015) used fuzzy cognitive mapping (FCM) to develop a conceptual model of community disaster planning in Hawai'i, U.S. The four-phase modeling process was used to demonstrate single-, double-, and triple-loop learning among participants. Henly-Shepard et al. (2015) were one of the first groups to provide a systematic evaluation of social learning loops using the PM approach. Before their work, Garmendia & Stagl (2010) used a Likert scale to evaluate learning loops in three participatory case studies in Europe. While the quantitative and semi-quantitative methods can be informative for assessing social learning before and after participatory workshops, these methods do not tell much about how the participatory processes support or hinder social learning (Muro & Jeffrey, 2012).

Understanding the source of learning and process is particularly important in participatory approaches (Tuler et al., 2017). For example, evaluating the learning process was challenging for researchers in Vulnerability, Consequences, and Adaptation Planning Scenarios (VCAPS) program that was intended to integrate scientific and local knowledge through creating learning platforms using models (Tuler et al., 2017). Although the participants indicated the acquisition of new information that was considered as a criterion for social learning, there was no clarity of the source of awareness, development of shared understanding, and the role of modeling as a learning tool. Therefore, evaluating social learning would require not only assessing how knowledgeable participants were before and after participatory activities but also the evidence of the transition between the different learning (single-, double-, and triple- learning) loops. Additionally, qualitative analytical methods (e.g., group discussions, workshop dialogue as data) can enrich the understanding of what deliberative processes enhance social learning and, thereby, complement the quantitative assessment of learning (Benson et al., 2016; Bentley Brymer et al., 2018).

1.5 Summary

Participatory approaches involve applying methods and techniques that allow participants to describe a context (i.e., in this thesis context, flooding) in a detailed manner using their knowledge, understanding, experiences, and beliefs. Therefore, participation allows those affected by disasters to voice their concerns and contribute to creating innovative, relevant, and sustainable solutions. In addition, the active involvement of Indigenous peoples in disaster risk reduction will increase the success of the implementation of necessary mitigation procedures and emergency management.

Participatory approaches encompass diverse methods and tools to facilitate engagement. Participatory Modeling (PM) is one such approach that is emerging in the environmental and disaster risk management field. The process in PM enhances the participation of non-scientists, lay-experts, and other social actors in the scientific modeling practice. The level of involvement in the modeling itself varies, ranging from participants providing information and data inputs for modeling to commenting and giving feedback on model outputs, and/or co-developing a systems model. The methodological and epistemological challenges embedded in PM often limits the participation of Indigenous peoples in modeling studies. Additionally, most PM studies tend to focus on the outcomes (e.g., models, reports) but rarely discuss the process (e.g., engagement, learning). The process of PM is equally significant (if not more) because the process itself involves iterative and reflexive learning among participants leading to an improved and shared understanding of the system or problem.

Participatory modeling methods and tools that allow the inclusion of diverse knowledge, perspectives, and reflection can facilitate social learning. However, multiple conceptualizations and limited empirical studies have limited the uptake of social learning in DRR. Therefore, this thesis proposed and applied a participatory modeling framework that:

i. enhanced participation of Indigenous peoples in DRR, supported by modeling,
ii. demonstrated the use of mixed-methods approach to capture spatial and human perceptions of disaster risks for providing a holistic understanding of disaster complexity and,
iii. investigated and measured the social learning process using mixed methods to demonstrate its relevance to DRR studies.

1.6 Research Purpose and objectives

The overall purpose of the thesis was to explore the application of a participatory modeling approach for enhancing and evaluating social learning in the context of disaster risk reduction (DRR). The project itself involved responding to the community's request[6] for up-to-date flood information. The specific objectives further included exploring some critical questions within those objectives:

1) Integrate community inputs into spatial data and modeling process to create locally relevant flood extent maps

[6] This research emerged back in 2018 in the first Prairie Water multi-stakeholder meeting. One of the significant outcomes of the meeting was to access and utilize LiDAR for decision making. Mistawasis Nêhiyawak, one of the community partners of Prairie Water project, were keen to utilize their LiDAR that could potentially support their ongoing flood risk reduction initiatives. This interest of the community (aligned with the wider Prairie Water stakeholders' interest), therefore, led to our collaborative work.

i) *Are the modeling tools (and outputs) beneficial to help address community flood concerns?*
ii) *Are the modeling tools flexible enough to engage the community in creating locally relevant flood information?*

2) Explore to what extent social learning is enhanced or impeded by participatory processes including communicating scientific knowledge
    a) *Was social learning observed as an outcome of the participatory process?*
    b) *What processes foster or inhibit learning?*
    c) *What are the outcomes of learning?*

1.7 Methodological Overview

For the 'integrative' nature of the research project, it was necessary to develop a sequential mixed-methods (Creswell, 2014) framework that helped collect and integrate different forms of knowledge such that they complemented one another. The methods and tools used in the study are described in detail in the manuscripts or chapters in which they appear. In this section, I provide a brief overview of mixed-methods research design, personal standpoint, and ethical considerations.

1.7.1 Mixed-methods research design

Mixed-methods research involves combining qualitative and quantitative research approaches (e.g., viewpoints, data collection, and analysis tools) for exploring complex research question or phenomenon (Aramo-Immonen, 2011; Schoonenboom & Johnson, 2017). The concept of using multiple methods to inquire about a complex problem is well-acknowledged and advocated in social and behavioral sciences (Jick, 1979; Greene et al., 1989; Creswell, 2014), and has been demonstrated empirically in numerous studies (Wheeldon, 2010; Samarasinghe & Strickert, 2013; Brown et al., 2017; Bradford et al., 2018; Elder & Odoyo, 2018). Several authors have discussed different purposes for mixing methods from triangulation to ensure the credibility of findings (Greene et al., 1989) to using one method to explain unexpected results from the other (Bryman, 2006) to creating community-based actions (Elder & Odoyo, 2018). The methods used in this study are summarized in Table 1.3.

Table 1.3 Summary of methods used in the thesis

Method	Purpose	Strengths	Limitations	References
Wetland DEM Ponding Model (WDPM)	-To create a flood extent map for the community using community-held LiDAR data	-Simple diagnostic tool for creating an overview of the flood extent -Can be used to explore and examine ‘what-if’ scenarios (i.e., extreme flooding, sandbagging)	-To derive accurate runoff, hydrological models are needed -Can be time-intensive and expensive	Shook et al., 2013; Armstrong et al., 2013;
Evaluation survey	-To evaluate the relevance of modeling outputs to the community	-Takes relatively less development time (depending on the context and research purpose) -Provides quick and easy data collection method	-Does not tell much about the thought process or reasoning of a person (lacks details and depth) -Can be rigid in structure, hence, ‘top-down’ in nature	Queirós et al., 2017
Focus group discussions	-To facilitate interaction and information sharing among participants and researchers -To corroborate the quantitative results from other methods	-Gives insights into group processes such as interaction and deliberation -Opportunity to explore unexpected ‘avenues’ that may be relevant to the research question so further clarification can be possible -Considered relatively a culturally sensitive method for data collection	-It can be hard to control the course of the discussion -Difficulty in getting equal participation from all -Small and purposeful sampling does not allow generalization (although this may not be considered a limitation)	Morgan & Spanish, 1984; Khan et al., 1991; Halcomb et al., 2007; Queirós et al., 2017
Participatory mapping (GPS collection, problem description)	-To use an aerial image as visualization and mediating medium for recollecting experiences and memory	-Plot and describe locally relevant information for understanding social and environmental context -Allows representation and respect for local and Indigenous spatial values.	-Quality of map can be an issue; for example, image distortion can lead to incorrect identification of risk areas -Require other methods for further interpretation of the maps	Smith et al., 2000; McCall & Minang, 2005; Cubelos et al., 2019;
Fuzzy cognitive mapping (FCM)	-To collect flood risk perceptions of community members -To measure social learning	-Provides means to externally represent an individual or collective perception of a given problem (mental model) -Can be useful to evaluate and compare different policy options or ‘what-if’ scenarios	- lack of concept of time delays; describes only the linear relationship between variables -does not tell much about the reasoning for the causal relationships (why’s)	Kosko, 1989; Özesmi & Özesmi, 2004; Papageorgiou & Salmeron, 2012

The main goals of using mixed methods research design in this thesis were to expand the breadth of knowledge in participatory DRR studies, pilot a novel approach, and meaningfully contribute to the advancement of this growing field. Additional purposes for mixing methods include:

i. 'Expansion' for using different (but complementary) methods to explore various aspects of research purpose and hence, enrich the depth and breadth of inquiry (Greene et al., 1989)
ii. 'Triangulation' to complement the strengths and offset the weaknesses of distinct methods used in the study (Greene et al., 1989; Brown et al., 2017). Doing so would also allow convergence and corroboration of the results (Greene et al., 1989).
iii. 'Diversification of views' for enhancing inclusivity and equity (Bryman, 2006). This purpose extends to breaking down the dichotomy of knowledge systems by using methods and approaches that explore human-environment relationships and contributes to inter- and trans-disciplinarily works relevant to DRR studies (Schoonenboom & Johnson, 2017).

The study also incorporated aspects of Indigenous methodologies, including visiting the community regularly to build relationships, participating in cultural activities (Ballard & Thompson, 2013), promoting participatory and meaningful dialogue (Kovach, 2010), navigating conversations about access to, and ownership of research findings (Kurtz, 2013). Wilson (2001) explains that often 'dominant paradigms[7]' methods can be essential and relevant from Indigenous perspectives. To this, Kovach (2010) elaborates:

> *"it is not the method, per se, that is determining characteristics of* Indigenous *methodologies, but rather the interplay (the relationship) between the method and paradigm and the extent to which the method itself is congruent with Indigenous worldview….a focal discussion of* Indigenous methodologies *ought to be a deep concentration of worldview or paradigm" (p. 124)*

The use of a mixed-methods approach enhanced the collaborative, flexible, and reflexive nature of the project (Kovach, 2010). Furthermore, the approach fits into the transformative worldview (Creswell, 2014). The theoretical foundations of the transformative worldview are based on the ethical stances of greater social inclusion, community-engaged

[7] In research context, dominant paradigm means the western scientific worldviews or using methods and approaches based on western science

research designed towards building trust and transparency, and empowerment (Creswell, 2014). This worldview relates to the ideologies of blending multiple knowledge systems in the study. Making sure that the methods and approaches used in the study were ethically appropriate and respectful was also something I was well aware of (Smith, 1999). Throughout the research process, on-going communication was ensured to maintain transparency. I also participated in cultural activities, including a water ceremony, fire knowledge-sharing activity, and community gatherings (e.g., photovoice exhibit) to acknowledge the social and cultural context of the community. Finally, being responsive to the realities and needs of the community was a priority for the project at all times.

1.7.2 Researchers Positionality

Reflecting on one's positionality as a researcher is a critical element in doing good and ethical research with local and Indigenous peoples (Smith 1999; Kovach, 2010; Kurtz, 2013; Elder & Odoyo, 2018). The process of reflecting on one's positionality addresses the issues of biases and subjectivity that are often inherent in any research process, be it quantitative, qualitative or mixed-methods (Balay-As et al., 2018).

My position in the research is that of an outsider (i.e., non-Indigenous, non-Canadian), something that is inevitable having been born and raised in Nepal. Yet, I have epistemological foundations that come from western scientific paradigms (Elder & Odoyo, 2018). Hence, I am aware that this positionality can bring some inherent biases and objectivity by interpreting the knowledge through a western framework (Cochran et al., 2008). I attempted to use multiple sources of information (both literature and data) to make sure that my interpretations did not mask the historical context of researching with Indigenous peoples, the community's realities, and community member's experiences. I also want to acknowledge that the study design does not directly conform to decolonizing methodologies. Nevertheless, I gathered a lot more awareness and knowledge of decolonized research through this thesis, something I will take into account in my future works.

Finally, as a researcher, I position myself in the constructivist or interpretive paradigm (Guba & Lincoln, 1994). According to Creswell & Miller (2000), the constructivist position is guided by "*pluralistic, interpretive, open-ended, and contextualized (e.g., sensitive to place and situation) perspectives towards reality "(*p. 125—126). These are reflected through my choice of using multiple methods to create rich information rather than generalizations and working with community members to bring in lived experiences into the results. To some extent, I also find myself using more 'systematic, standardized, and identified' procedures (postpositivist paradigm) (Creswell & Miller, 2000) that may not be considered as open-ended or flexible. Because of the nature of this work, I found myself working in between these two philosophical worldviews.

1.7.3 Ethical consideration

In recognition of doing research meaningfully and ethically, the study was conducted as per the University of Saskatchewan's behavioral research ethics board (BEH-REB) guidelines. Some of the ethical considerations taken into account included informed consent, clear guidelines to methods, confidentiality (in terms of using names in the reports), data storage, risk (although minimal) assessment, and resources to seek mental health safety if needed. With the community, a data-sharing (LiDAR) agreement was also signed that safeguarded the community's ownership of data and findings. Earlier onwards, I also presented the project outline, methods, and implications to the chief and council members in the community. With their approval, the research planning started. Finally, I made sure I was honest at all times, from data collection to results communication, thereby keeping the process as transparent as possible.

1.8 Thesis Structure (Manuscript Style)

The thesis is written in a manuscript style following the guidelines set by the College of Graduate Studies and Postdoctoral Studies. I decided to do a manuscript style thesis to present the methods, results, and discussions for the two-phase project clearly and compellingly. Presenting the findings from the entire project would have been too complex to write in a single paper. Each phase also had its distinctive and exciting results based on the methods used; hence, I considered it essential to give equal emphasis to both by writing two separate manuscripts bookended by an introduction and overall discussion and conclusion chapters. I acknowledge that the length of chapter 3 exceeds that of standard journal requirements and will be adjusted later according to the criteria for publication purposes.

Chapter 1 provides an overview of the current body of knowledge that is directly relevant to this thesis work. The primary purpose of this chapter is to lay the foundation for the project, synthesize linkages and gaps in the literature, and summarize how this thesis will contribute to addressing some of the knowledge gaps. The introduction chapter also describes the format of the thesis, states the research purpose and objectives, and gives an overview of methodological design.

Chapter 2 (the first manuscript) describes the LiDAR-based flood maps created to respond to the community partner's request and fulfill the project's next phase requirements. It demonstrates the application of LiDAR and the Wetland DEM Ponding Model (WDPM) to develop flood extent maps in the Prairie Pothole Region (PPR). It also describes how the community was engaged in the modeling process from the initial phase to evaluating the flood maps. This chapter has recently been published in the *Water* journal but has been revised for the purpose of the thesis.

Chapter 3 is a follow-up of chapter 2 and unpacks social learning from the workshop organized in the community to share flood maps. The chapter introduces social learning as a viable approach for DRR and describes the gap between theoretical and empirical research on social learning. The paper explores Fuzzy Cognitive Mapping (FCM) as a novel tool to measure social learning systematically. The chapter (after editing) would be suitable for submission in *Environmental Modeling and Software.*

Chapter 4, the final chapter, is an overall discussion of the thesis and provides a summary of each objective. It also discusses the methodological, theoretical, and practical contributions of the thesis. Finally, it identifies several limitations and provides direction for future work.

PREFACE TO CHAPTER TWO

"Maps can be useful tools to build a sense of personal responsibility in flood preparedness among citizens and also to empower communities towards informed decision-making as part of an overall flood risk management strategy" (Minano & Peddle, 2018 p.9)

The first objective of the project was to respond to the community's request to create locally relevant spatial flood maps. This included utilizing the community-held LiDAR data and Wetland DEM Ponding Model (WDPM), for creating flood extent maps. Flood maps are essential tools for risk communication, spatial planning, insurance programs (i.e., floodproofing), awareness, and flood management discussions and decisions (Minano & Peddle, 2018). There are numerous approaches for flood mapping, from remote sensing and GIS techniques to hydrological and hydraulic modeling (Brivio et al., 2002; Schumann et al., 2008; Webster et al., 2006; Bharath & Elshorbagy, 2018). WDPM was selected for the thesis because i) it simulated the 'fill and spill' behavior of wetland depressions which are the distinguishing hydrological features of the Prairie Pothole Region (PPR), ii) the modeling process was relatively straightforward requiring only two inputs; DEM and reference depth, and iii) it allowed community-defined runoff scenarios to be tested (i.e., average and extreme runoff events). Besides, conventional flood modeling often requires historical data and are mostly based on stream dynamics (i.e., streamflow, channel width, etc.). WDPM, on the other hand, offered an alternative modeling approach to map flood extent in ungauged basins as well as in regions where stream channels are not present, or in other words, in data-poor regions (Shook et al., 2013). Therefore, LiDAR and WDPM were assumed to produce a detailed representation of the flood extent for Mistawasis Nêhiyawak located in the PPR. In addition to LiDAR, we also used additional datasets such as ALOS DEM and LANDSAT images as potential alternatives for flood mapping in under-resourced communities. These coarser-resolution datasets, hence, provided context for demonstrating results from different spatial datasets for assessing flood extent and evaluating their strengths and limitations. The next chapter presents methods, results, challenges, and community feedback on the flood maps.

Although this chapter has been published as a peer-reviewed manuscript, for the purpose of this thesis, it has been revised and edited as per the comments from the committee members.

CHAPTER TWO: CO-CREATING FLOOD EXTENT MAPS

“Garbage in, garbage out” doesn’t hold true for Indigenous Community flood extent modeling in the Prairie Pothole Region

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Abstract: Extensive land-use changes and uncertainties arising from climate change in recent years have contributed to increased flood magnitudes in the Canadian Prairies and threatened the vulnerabilities of many small and Indigenous communities. Thus, there is a need to create modernized flood risk management tools to support small and rural communities’ preparation for future extreme events. In this study, we developed spatial flood information for an Indigenous community in Central Saskatchewan using LiDAR based DEM and a Wetland DEM Ponding Model (WDPM). A crucial element of flood mapping in this study was community engagement in data collection, scenario description for WDPM, and flood map validation. Community feedback was also used to evaluate the value of the modeled flood outputs. The results showed the utility of WDPM for creating a quick and initial overview of flood extent at a local scale. Given the accuracy of LiDAR, it provided a detailed estimate of accumulation areas or risk-prone regions in the community. Based on community feedback, both LiDAR and WDPM can provide relevant information for community spatial planning and developing risk reduction strategies. The accessibility and cost issues related to LiDAR, however, can hinder its application in rural and Indigenous communities. Therefore, we tested additional spatial datasets for flood mapping that have the potential to provide information such as geographical vulnerability and flood flow direction for communities with limited resources. Regardless of the datasets, our study found community engagement to be valuable in flood modeling and mapping by providing necessary data, validating input data through lived experiences, and providing alternate scenarios to be used in future work. This research demonstrates the applicability of community-engaged flood mapping in the Prairie Pothole

Region (PPR) complemented by spatial data and modeling. The approach used in the study also serves as an important guide for applying transdisciplinary tools and methods for establishing good practice in research and helping build resilient communities in the Prairies.

Keywords: flood risk; flood mapping; LiDAR; spatial modeling; GIS; Prairie Pothole Region; community flood management

2.0 Introduction

Floods are considered to be natural processes (Hellman, 2015); however, in recent years, the global increase in flooding incidents has been associated with climate change (Kourgialas & Karatzas, 2011; Klemas, 2015). Higher numbers and frequencies of floods increase the risk of damaging properties, destroying infrastructures, and reducing the overall well-being of people. Many communities who are perhaps 'accustomed' to flooding and once felt that occasional flooding is part of their lives are at higher risk (Samuels et al., 2006; Hellman, 2015). This narrative stands true for many small and rural communities living in the Canadian Prairies.

The landscape of the Canadian Prairies, which is part of the greater North American Prairie Pothole Region (PPR), is characterized by millions of topographical depressions, also known as potholes (Shook & Pomeroy, 2011; Dumanski et al., 2015). While many of these depressions are hydrologically isolated, they can occasionally connect at times of high overland water flow through a mechanism known as 'fill and spill' (Spence & Woo, 2003; Shook & Pomeroy, 2011). These wetland depressions have high water storage capacity and capture the majority of runoff generated from snowmelt (Wu, 2017). The extensive land-use change in the PPR and uncertainties arising from changing climate, however, have increased flood magnitudes in the Prairies (Dumanski et al., 2015; Wu, 2017). These increases intensify vulnerabilities in rural communities. While in the past rain-on-snow incidents were rare in the Prairies, they are becoming more frequent. The flooding between 2011 and 2016 in Saskatchewan and Manitoba was a result of high antecedent storage and high snowmelt (see Dumanski et al., 2015), and there may have been impacts from rain-on-snow contribution (see Buttle et al., 2016). There is, therefore, a need to create modernized flood risk management tools to support community preparation for future extreme events brought on by the climate emergency.

Flood risk reduction involves identifying and managing hazards as well as the population's vulnerability when confronted with unexpected inundated areas (Samuels et al., 2006). Flood mapping has, hence, become a necessary non-structural measure for flood risk reduction planning at local to national scales (Masood & Takeuchi, 2012; Grimaldi et al., 2013; Bharath & Elshorbagy, 2018; Minano & Peddle, 2018). Topographical features are critical for identifying and determining flood extents (Hawker et al., 2018). Geospatial data such as Digital Elevation Models (DEM) are frequently used in flood mapping because of their ability to display flood extent over large spatial areas (Grimaldi et al., 2013). Many studies have relied on open access DEMs such as SRTM to estimate flood extents (Bharath & Elshorbagy, 2018; Hawker et al., 2018); however; the problem with using coarser datasets is that they are often not adept in capturing the unique hydrology of the PPR (Wu, 2018). Additionally, flood mapping studies rarely consider the depressions as critical hydrological units (Hayashi et al., 2016; Wu, 2018) and instead, are removed to create depressionless DEMs to derive flow paths and connectivity to the nearest stream channels (Senevirathne & Wilgoose, 2013; Chen et al., 2018). This method of conditioning DEM is particularly problematic in PPR where, in many cases, depressions are hydrologically isolated, and flooding is contributed by the fill and spill mechanism (Shook et al., 2013; Bharath & Elshorbagy, 2018).

Furthermore, current hydrologic-hydraulic models for flood mapping are characterized by several issues including their implementation in data-sparse regions (i.e., small and ungauged basins[8]) (Grimaldi et al., 2013; Klemas, 2015) and their flexibility to produce user-defined flood maps (Meyer et al., 2004). The first limitation benefit of the alternative, empirical, and practical approaches to generate flood maps with fewer data requirements (Garousi-Nejad et al., 2019) and the latest remote sensing technologies such as LiDAR DEMs (Grimaldi et al., 2013). The second limitation could be addressed through improved communication between experts and stakeholders (and rightsholders) (Meyer et al., 2004). Improved communication, however, does not only involve disseminating flood maps to the users; it should additionally focus on encouraging participation in identifying flood concerns that will help produce information relevant to local contexts (Minano & Peddle, 2018). These needs exemplify recent calls for transdisciplinary methodologies that allow the integration of different methods and knowledge systems for accurate and relevant flood mapping (Forrester et al., 2015).

Public participation in flood mapping has seen increasing appreciation and acceptance in the last decade, leading to advances in disaster awareness (Gaillard & Pangilinan, 2010), and risk

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[8] Small and ungauged basins refer to areas where precipitation is assumed to be spatially uniform and flow parameters or measurements are not readily available (Grimaldi et al., 2013).

planning and management (Chingombe et al., 2015; Cheung et al., 2016). Innovative tools, data gathering, and processing techniques have provided opportunities for researchers to engage with local people and establish processes that create benefits for local communities (Voinov & Bousquet, 2010; Voinov et al., 2016). New participatory methods for flood mapping and planning promote inclusivity and empower communities to develop their management plans (Castillo-Rosas et al., 2017). The level of public participation in spatial analysis can vary. Stakeholders and community members can measure or provide data to be fed directly into geoprocessing software; help in the interpretation of data or information; provide context, experiences, and knowledge of historical events; put forward opinions and needs; and assess methods, tools or results (Voinov et al., 2016). Public participation in flood mapping, therefore, provides ways to integrate general knowledge, including local spatial experience and Indigenous knowledge with conventional scientific approaches (Agrawal, 1995; Raymond et al., 2010).

In this study, we detail one such integrative participatory approach for flood mapping for an Indigenous community in the PPR. In doing so, we also evaluate the utility of different spatial datasets using a simple diagnostic model; that is, Wetland DEM Ponding Model (WDPM). First, we discuss the opportunities for using LiDAR DEM and WDPM for flood mapping in the PPR. Then we compared the flood extent using both fine (LiDAR) and coarse DEM datasets. For the coarser dataset, we used ALOS DEM and LANDSAT images. The rationale for using two datasets was to evaluate; i) variations in the quality and feasibility of flood extent estimates at the local and watershed scale and ii) the effect of resolution in flood mapping for the rural environment (Garousi-Nejad et al., 2019). The resultant flood maps provided an initial overview of flood extent rather than a detailed analysis of flood dynamics, which was beyond the scope of this research. Instead, we respond to the community's need to have a quick and up-to-date spatial tool that supports community decision making for flood resilience. The three objectives of the paper are to:

1. To create a LiDAR-based flood map for an Indigenous community in the PPR using Wetland DEM Ponding model (WDPM)
2. To integrate community inputs into the flood mapping process to create locally relevant flood extent maps
3. To utilize additional spatial datasets with a coarser resolution for flood extent evaluation as a potential alternative to LiDAR

2.1 Background Definitions

2.1.1 LiDAR DEM for Flood Mapping

Remote sensing (RS) techniques have proven an asset in flood delineation and assessment globally (Brivio et al., 2002; Sanyal & Lu, 2004; Jain et al., 2005; Webster et al., 2006; Klemas, 2015). The current growing significance of RS in flood studies and monitoring comes from the fact that in many parts of the world, gauging stations are either damaged or absent, which results in inadequate ground data to feed into models (Sanyal & Lu, 2004; Klemas, 2015). In addition, RS's additional spatial coverage, and ability to demonstrate flood extent from local to catchment scales is advantageous (Klemas, 2015). A recent RS development, LiDAR system provides opportunities for creating detailed and accurate flood mapping and monitoring in ungauged basins and flat areas like the PPR (Sanyal & Lu, 2004; Wedajo, 2018; Wu, 2017).

LiDAR systems consist of 1) laser scanners usually mounted on an aircraft that send intense laser pulses to survey the landscape, 2) a Global Positioning System (GPS), and 3) an Inertial Measurement Unit (IMU) (Webster et al., 2006; Schwarz, 2010). A detailed description of what LiDAR is and how it works is available elsewhere (Schwarz, 2010; Wedajo, 2018). LiDAR surveys can provide comprehensive and accurate topographic datasets known as Digital Elevation Models (DEM), used for a variety of purposes. Most freely available global DEMs such as Shuttle Radar Topography Mission DEM (SRTM DEM) usually have vertical accuracies of greater than 15 m, whereas the vertical accuracy of LiDAR DEM is generally between 15-25 cm Root Mean Square Error (Sanyal & Lu, 2004; Wedajo, 2018). Global SRTM DEMs were acquired in 2000 and hence, run the risk of not accurately representing current topographic features, especially in places where there have been extensive land-use changes (Schumann & Bates, 2018). Schumann et al. (2008) previously conducted a comparative flood modeling study using SRTM and LiDAR DEM. They found that although SRTM DEM provided useful initial flood information at the catchment scale, it was ineffective in delivering detailed flood mapping at a local scale compared to the LiDAR DEM.

Similarly, Armstrong et al. (2013) compared the flood extent maps generated from SRTM and LiDAR DEM and found that the SRTM outputs are not useful in densely vegetated and low topographic relief areas. LiDAR DEM-based outputs are better at local scales, in flat landscapes, and can additionally be coupled with hydrologic-hydraulic models to simulate flood scenarios that are visually interpretable using GIS. Others have, however, highlighted that the resolution of

DEMs becomes less significant in rural areas, and higher resolution data can cause added computational cost with little performance improvement (Savage et al., 2016a; Hawker et al., 2018). To this end, we use two spatial datasets with different resolutions to investigate the potential spatial extent of flood and flood hazard over the relatively flat PPR landscape.

2.1.2 Wetland Digital Elevation Model (DEM) Ponding Model (WDPM)

The landscape of the PPR of North America is dominated by millions of closed-basin surface depressions, which are remnants from the recent glacial retreat. Most of these prairie depressions are considered to be geographically isolated because they do not contribute to local streamflow (Shook et al., 2013). During wet years when the depressions are filled, however, they may connect to other surface water bodies (ponds, wetlands, and streams) and sometimes result in local flooding (Shook et al., 2014; Wu & Lane, 2017).

The Wetland DEM Ponding Model (WDPM) stimulates the spatial distribution of excess runoff on a PPR landscape (Shook et al., 2014). The original purpose of the model was to understand the complexities of contributing areas of Prairie basins, which is often governed by the amount of water in the depressional features (Shook et al., 2013). WDPM has also been deployed as a diagnostic tool in determining flooding extent, such as in Land and Infrastructure Resiliency Assessment (LIRA) studies in the Canadian Prairies (Armstrong et al., 2013).

WDPM models the fill-and-spill behavior of depressional storages using the Shapiro and Westervelt algorithm (Shapiro & Westervelt, 1992). The full features of the program, along with the description, can be found in the user guide available on the University of Saskatchewan Centre for Hydrology website (www.usask.ca/hydrology/WDPM.php). The program requires two inputs: a DEM in ESRI ASCII (.asc) format and the reference depth of water to be applied over the DEM. This depth of water can either be chosen arbitrarily or reference water depths can be used based on historical flood events (e.g., the Vanguard flood, SK in 2000) and return periods (e.g., 50-, 100- year event) (Armstrong et al., 2013). The model then applies the reference water depth over a DEM uniformly (Shook et al., 2013).

The uniform application of water over a landscape can lead to the simulations being inconsistent with the hydrological processes in the Prairies, such as snow redistributions by wind (Shook et al., 2013). Since the model can determine the final location or distribution of excess water, however, the output can be useful in providing a qualitative description of flooding extent in a worst-case scenario (Armstrong et al., 2013; Shook et al., 2013). The output from the program is a water depth file that can be imported to a GIS program and overlaid on an aerial image, DEM, or other map feature (Shook et al., 2014).

Unlike other conventional drainage algorithms, the Shapiro & Westervelt (1992) algorithm used in WDPM allows water to be drained in more than just one direction. The algorithm used in three modules in the software allows simulation of dynamic changes in the wetland-dominated landscape when water is *added*, *removed*, or *drained* (Shook et al., 2014). This means that the algorithm physically moves the water between the neighboring cells across the DEM iteratively and, therefore, can be extremely slow depending on the size of the DEM, depth of water added, and the type of computer processor used (Shook & Pomeroy, 2011). The model is also not capable of simulating wetland water storage elevations below the amount which were present when the LiDAR survey was performed, and currently, model simulations cannot be executed in real-time (Shook et al., 2013). Nevertheless, WDPM has been proven to be a useful exploratory tool for simulating runoff extent in the PPR and has been applied in both academic and operational purposes (Armstrong et al., 2013; Shook et al., 2013; Growth, n.d.).

2.2 Study site and Datasets Used

2.2.1 The Study Area

Mistawasis Nêhiyawak is a Cree First Nation community located in Treaty 6 Territory, north of Saskatoon, Saskatchewan (Figure 2.1). The community covers an area of 145 km^2 and inhabited by approximately 681 (Statistics Canada, 2016) to 1400[9] people (local reports). In the spring of 2011, following an extremely wet winter and heavy rainfall, the community experienced a significant flooding event. The 2011 flood was described as one of the worst floods since 1955/56. Since 2011, the community has experienced elevated water levels every spring. An example is evident in Turner Lake, entirely contained within reserve boundaries, where the water levels have risen approximately seven feet in five years (Dawe, 2016). The increased water levels have wrecked structures such as dams and levees previously used in the community to prevent flood damage. Localized flooding has resulted in numerous negative social and environmental impacts, including degradation of source water, riparian habitat, road inundation, and displacement of animals that are important to local people (Dawe, 2016). The

[9] Given the historical context of colonization and doing unethical research in indigenous communities, some people in the reserve likely do not respond to census surveys. That may be the reason for discrepancy in the two reported population size.

current flood mitigation strategies are more reactive and technical and include water diversions, berms, and culvert expansions (Dawe, 2016).

In the spring of 2014, the community experienced another major flood. Following the 2014 flood, a Light Detection and Ranging (LiDAR) survey was performed for the community. The LiDAR survey was done to identify water features on reserve and for land-use planning. Due to limited technological capacity and resources, the LiDAR data had not been used until we started our work with the community. Responding to both the community's desire to utilize this spatial data and their focus on adapting to ongoing flooding, we, therefore, processed the LiDAR data and used WDPM to generate community flood maps.

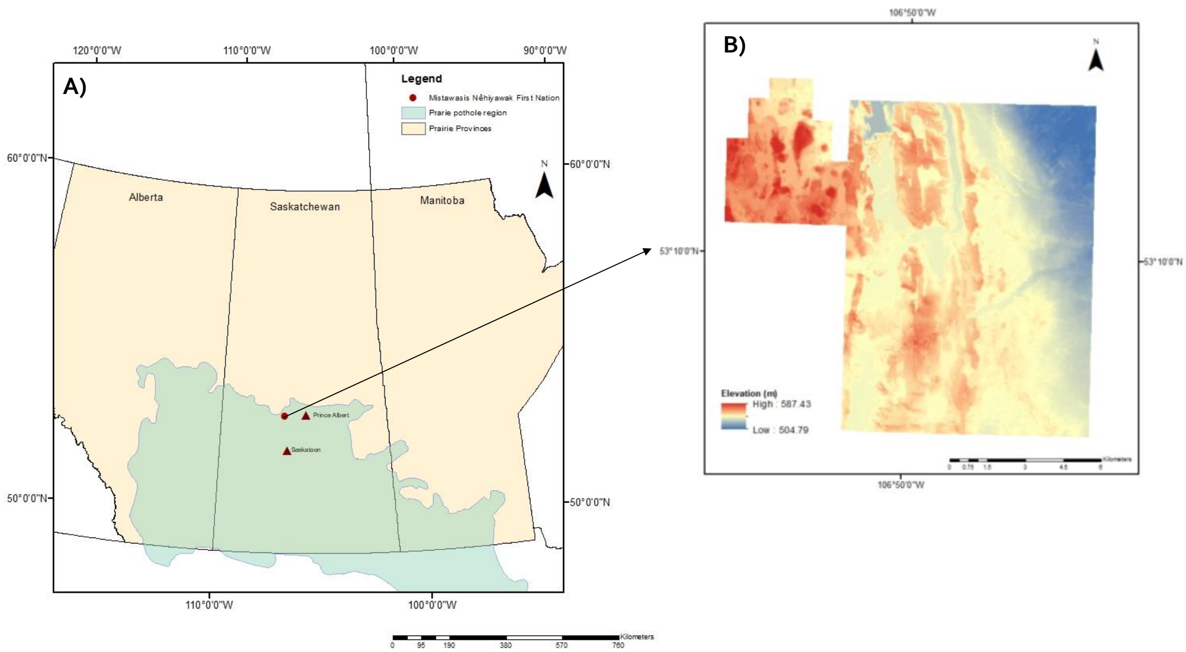

Figure 2.1 Map showing the (A) location of Mistawasis Nêhiyawak First Nation in PPR and B) LiDAR DEM for the community (Projection is UTM 13)

2.2.2 Spatial Datasets

On August 12, 2014, an airborne LiDAR survey was performed for Mistawasis Nêhiyawak by LiDAR Services International (LSI). The LiDAR data was collected using a Riegl LMS-Q780 at the height of 910 m above the ground level with a horizontal resolution of 1 m and a vertical RMS error of 0.036 m. The LiDAR was delivered in a point cloud in LAS v1.2 format referenced to Universal Transverse Mercator (UTM) Zone 13, NAD83 horizontally, and CGVD2013 vertically. An aerial image was also delivered in addition to point clouds. The collection and calibration procedure are documented in detail by LSI (LiDAR services

International Inc., 2014). We acquired this LiDAR data from Mistawasis First Nation on June 20, 2018. The data was used to derive a 5 m resolution Digital Elevation Model (DEM) with the help of the Spatial Initiative Lab at the University of Saskatchewan (Figure 2.2).

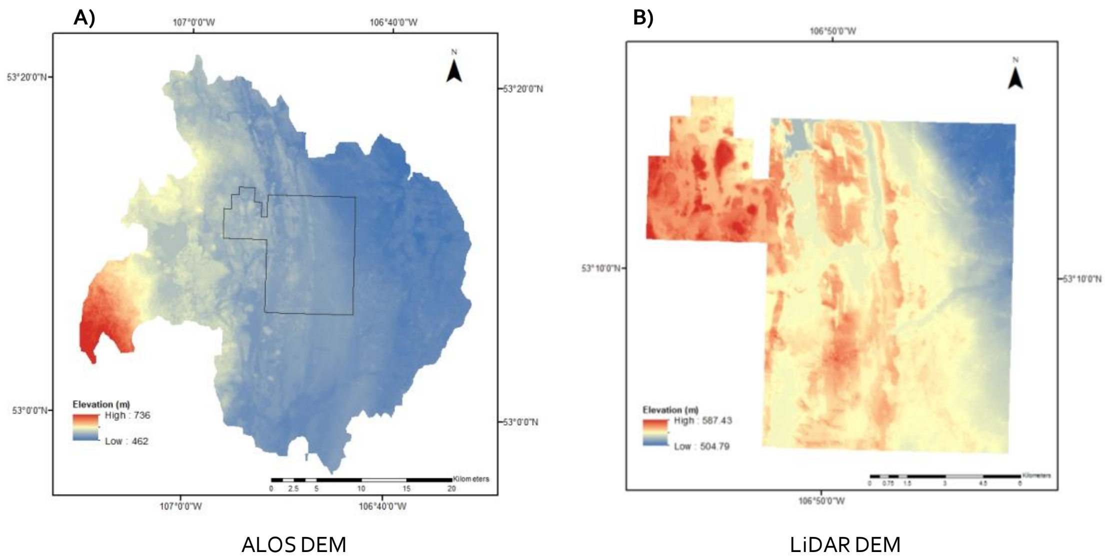

Figure 2.2 Spatial datasets used in the study. A) ALOS/PALSAR DEM for Mistawasis and the surrounding contributing areas (12.5 m resolution), and B) LiDAR DEM for Mistawasis (5 m resolution)

In addition to the LiDAR dataset, we georeferenced the culvert locations in the community with the help of the local Director of Lands. Altogether 52 GPS points were collected at sites where the culverts had been placed. For this study, we were only interested in where the culverts were, not on their physical parameters such as length, the diameter of the culvert pipe, and the bridge span (Li et al., 2013). The culvert points, stored as vector point features, were manually digitized and inserted into the LiDAR-derived DEM using a free open source GIS software called System for Automated Geoscientific Analyses (SAGA) GIS v 6.3.0. The rationale for including the culverts into the DEM was to allow water to be appropriately distributed while modeling and avoiding water backing up as a result of road networks (Armstrong et al., 2013; Lang et al., 2013; Shook et al., 2014). Digitized culvert features represented the potential low elevation point allowing water to flow laterally across these features (Ngula Niipele & Chen, 2019). Therefore, the DEM grids corresponding to the culvert points were changed to the lowest elevation within the same areas (or to the level of flowing water) (Lang et al., 2013; Li et al., 2013; Ngula Niipele & Chen, 2019) (Figure 2.3).

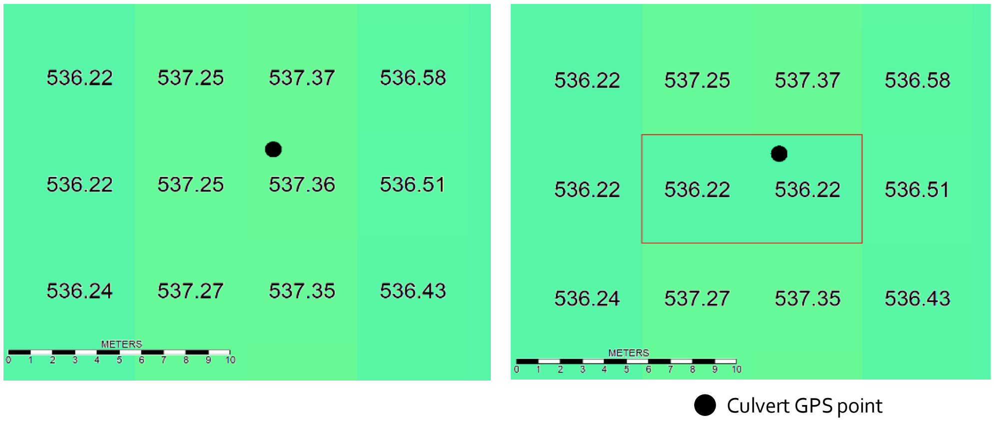

Figure 2.3 Example of a culvert burning process in open source GIS software SAGA. The light green in both images represents a road network in the DEM, while the darker green on either side are waterbodies. The point on the road is a given culvert location. The DEM grids corresponding to the culvert points were changed to the lowest elevation within the same areas (left image)

An open source DEM dataset, ALOS DEM[10], was obtained from the Alaska Satellite Facility (ASF) Distributed Active Archive Center (DAAC). ALOS DEM has a finer resolution (12.5 m) compared to SRTM DEM (30 m) but lower spectral resolution compared to the LiDAR data (Ngula Niipele & Chen, 2019). It is freely available and generally error-free; however, its vertical accuracy is 1 m. It must be noted that a change of vertical accuracy of 1 m can have significant effects on the PPR. We obtained ALOS DEM (Figure 2.2A) covering the entire community and surrounding areas that contribute to runoff during precipitation events. The rationale for using ALOS DEM was to include the basin area for flood extent analysis and highlight the community's geographical location in the basin (Figure 2.4).

Finally, LANDSAT TM images were used to extract and examine the flood extent from the 2011 event that acted as supplementary materials for exploring flood flow direction (Ho et al., 2010). Table 2.1 describes the dataset used in the study.

[10] DEM was obtained using the outline from HydroSHEDS datasets (Lehner et al., 2008). The HydroSHEDS datasets provide various hydrological products that range from local catchment data to global scale. They are found to generate high precision basin and sub basin models (Li et al., 2019).

Table 2.1 Information on datasets used in this study

	LiDAR DEM	ALOS/PALSAR DEM	Landsat 7 TM
Spatial Resolution	5 m x 5 m	12.5 m x 12.5 m	30 m x 30 m
Date of acquisition	20 June 2018	27 February 2019	3 March 2019
Source	Community	https://vertex.daac.asf.alaska.edu/#	https://earthexplorer.usgs.gov/

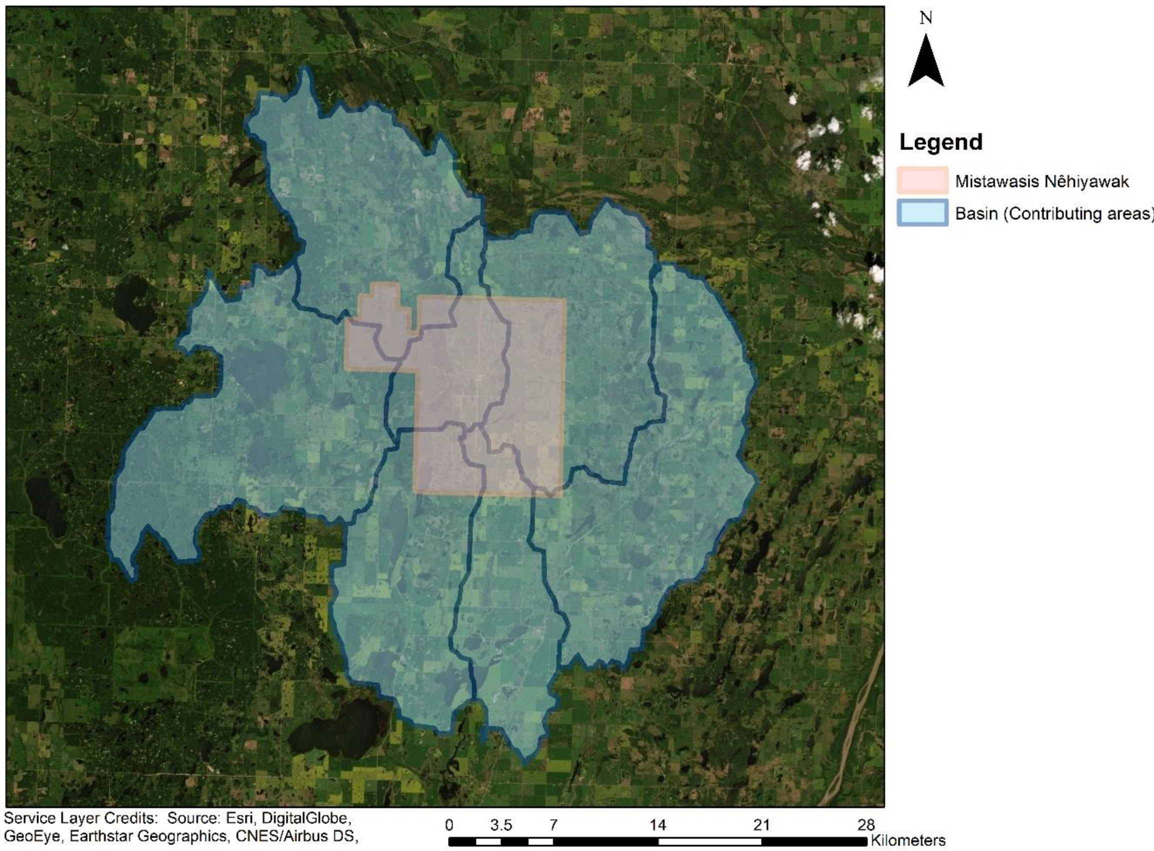

Figure 2.4 Location of Mistawasis Nêhiyawak (highlighted in orange) in the basin (highlighted in blue).

2.3 Methodology for Generating Flood Extent Maps: Overview

Water depths of 10 mm, 20 mm, 42 mm, and 82 mm were used as reference depths for WDPM simulations to observe the flooding extent for different precipitation amounts (Note: precipitation can be rainfall and/or snowmelt as the model does not distinguish between the two). These depths were derived from the interest of the community as they represented minimal, average, and extreme storms. In addition, starting with small amounts of water depth and moving to extreme storm events allowed us to establish more or less the initial water distribution in the

DEM (i.e., fill up permanent wetlands and lakes). The reference depth 42 mm corresponded to the average Snow Water Equivalent (SWE) depth calculated from 38 years (1970–2011) of snow depth data. For deriving this SWE depth, the snow density model described in Sturm et al. (2010) was used. This method was selected because it allowed a quick estimate of SWE using daily snow depth data available from the Environment Climate Change Canada website (Sturm et al., 2010; Jonas et al., 2016;). Existing data from 38 winters (late November to March) were used. The years 2008/09 and 2009/10, which had missing data, were omitted from the calculation. The reference depth of 82 mm corresponded to a 100-year flood event (maximum 24-hour rainfall depth) that was obtained from frequency analyses using the Gumbel distribution method for 38 years of rainfall data (1975–2012) and confirmed with Environment Canada's (2012) Gumbel distribution of annual maximum rainfalls. The reference depth, 82 mm, was applied on top of 42 mm to simulate rain-on-snow event or a worst-case scenario.

The algorithm used in WDPM prevents any of the water applied from leaving the DEM, making the edges of the DEM act as blockades or dams (Shook et al., 2014). Therefore, after adding successive reference depths, the DEMs were also drained[11] to avoid backing up of the water and to mimic natural PPR water cycles more accurately. The Shapiro and Westervelt (Shapiro & Westervelt, 1992) algorithm moves the water in multiple directions and considers all potential pathways for water flow. Thus, for each simulation, the model shows the dynamic changes in the spatial extent of simulated flooding (Shook et al., 2014).

The outputs from WDPM are water depth files which were exported to and further analyzed in ArcMap v 10.6.1 (Esri, Redlands, CA, USA). Water depths obtained for LiDAR DEM were assessed for each reference depth and then classified across six categories based on the inundation depths that corresponded to increasing hazard levels (Masood & Takeuchi, 2012; Ronco et al., 2015; Li et al., 2018). For each inundation depth, percentage of inundated areas were calculated. The output file contained information of water depth in each cell in the DEM. With the water depth information, the inundation area could be calculated. Inundation areas for depth 0–0.5 m, 0.5–1 m, 1–2 m, 2–3 m, 3–4 m, and >4 m was computed using the "Reclassify"

[11] DRAIN module in the WDPM simply causes excess runoff to leave the DEM from the drainage point (i.e. lowest elevation point in the DEM). This prevents water from backing up at the edges of the DEM (Shook et al., 2014).

tool in ArcMap and used for hazard mapping (Masood & Takeuchi, 2012). For ALOS DEM, the same four reference depths were used.

LANDSAT images from 2011 for April 10, 26, May 19 and June 29 (see Appendix A) were also explored in this study to; i) derive flood extent areas from a historical event, and ii) describe the flood flow direction and assess community's vulnerability (Ho et al., 2010). Modified Normalized Difference Water Index (MNDWI) was used for extracting and mapping flood extent (Xu, 2006):

$$MNDWI = Green - MIR/ Green + MIR= Band\ 2 – Band\ 5/ Band\ 2+ Band\ 5$$

MNDWI is an effective method for extracting water compared to other approaches such as Normalized Difference Water Index (NDWI) (Xu, 2006; Ho et al., 2010; Sun et al., 2012; Kumar & Acharya, 2016). This is because water absorbs more mid-infrared (MIR) that is used in MNDWI than near-infrared used in NDWI (Xu, 2006; Ho et al., 2010; Sun et al., 2012). The positive values in MNDWI represented the flooded areas, whereas the negative values indicated the non-flooded areas (Xu, 2006; Kumar & Acharya, 2016). Overall, using three spatial datasets provided opportunities to explore the advantages and limitations of each dataset and discuss their accessibility and application in the local context.

Given this study emerged in partnership with the community and responding to their request was a priority, it was always critical to engage them in this flood mapping study. This was done by updating officials at the Lands department regularly about the progress, co-collecting culvert points, and discussing the runoff estimates for predicting flood extent areas under different scenarios. The results were also shared with the community members in a workshop held on March 21, 2019. A brief presentation was given to introduce LiDAR and its importance, modeling approaches, the comparison of WDPM-generated flood maps versus satellite imagery, and the limitations of our work. We then asked the participants to complete a survey to assess the value of the model outputs[12] for overall community flood risk reduction using a 5-point Likert

[12] Figure 2.4, 2.6, 2.7 and 2.8 were the outputs (images) presented at the workshop. Different images may have different value or utility to different people present at the workshop. Learning and preferences for visual stimulations are well studied in the field of psychology (Palmer et al., 2013). However, in this thesis, all the images were presented as information derived from scientific process. The interest was to understand the value of the tools and results in the context of Indigenous community's flood risk reduction rather than understanding preferences for the images.

scale (1= not at all, 3= undecided, 5= very much) based on questionnaires (see Appendix A) (McLeod, 2008; Garmendia & Stagl, 2010). A focus group (Basch, 1987; Morgan, 1996) discussion after the presentation provided more feedback on the model and outputs. This was done to ensure the modeling was inclusive and transparent (Johnson, 2009). Allowing community members to comment on the model and outputs helped us to gain insights on the value of WDPM-generated flood maps and discuss their viewpoints on the model. The workshop design and survey questionnaires were approved by the University of Saskatchewan (BEH-17-396).

2.4 Results

2.4.1 Evaluation of WDPM: Water Depth and flood hazard map

Runtimes for scenarios of the four reference depths (Table 2.2) were limited by the model's ability to incorporate time step and the range of processes that influence wetland dynamics in the PPR (see Shook & Pomeroy, 2011; Shook et al., 2013; Shook et al., 2014).

Table 2.2 WDPM run summary for different depths of water added

Water Depth Added (mm)	Runtime (hrs.)	Number of Iterations to Converge
10	1.11	160,000
20	1.25	168,000
42	2.68	355,000
82	5.59	711,000

The final spatial distributions of simulated runoff for Mistawasis Nêhiyawak LiDAR DEM are shown in Figure 2.5 for four scenarios. The reference depths for simulations increased the sizes of the wetlands, and the stream in the DEM increased too, indicating that the simulated water was being added to the discrete wetlands in the DEM, as demonstrated in earlier work (Shook & Pomeroy, 2011). The extent of the inundated area increased from almost 18% to 28% of the region of interest (Table 2.3). The inundation extent also increased for increasing depths of water applied to the DEM with a maximum of 28% inundated area when 82 mm water was used (100-year event).

In the future, survey questions could include which results or images from the scientific information was most valuable to help create effective type and scale of information (Gray et al., 2014).

The LiDAR flood extent maps were compared to the aerial photographs taken after the 2011 flood events. Figure 2.6 shows the observed extent of flooding in different parts of the community, including (a) the community as a whole and, more specifically, (b) the village housing areas and designated administrative zones with band office, family center, and other service buildings. The accumulation areas simulated from WDPM fit within the actual accumulation zones on the aerial photographs demonstrating that WDPM can provide an accurate representation of flooding extent and potential "hotspots" or accumulation zones.

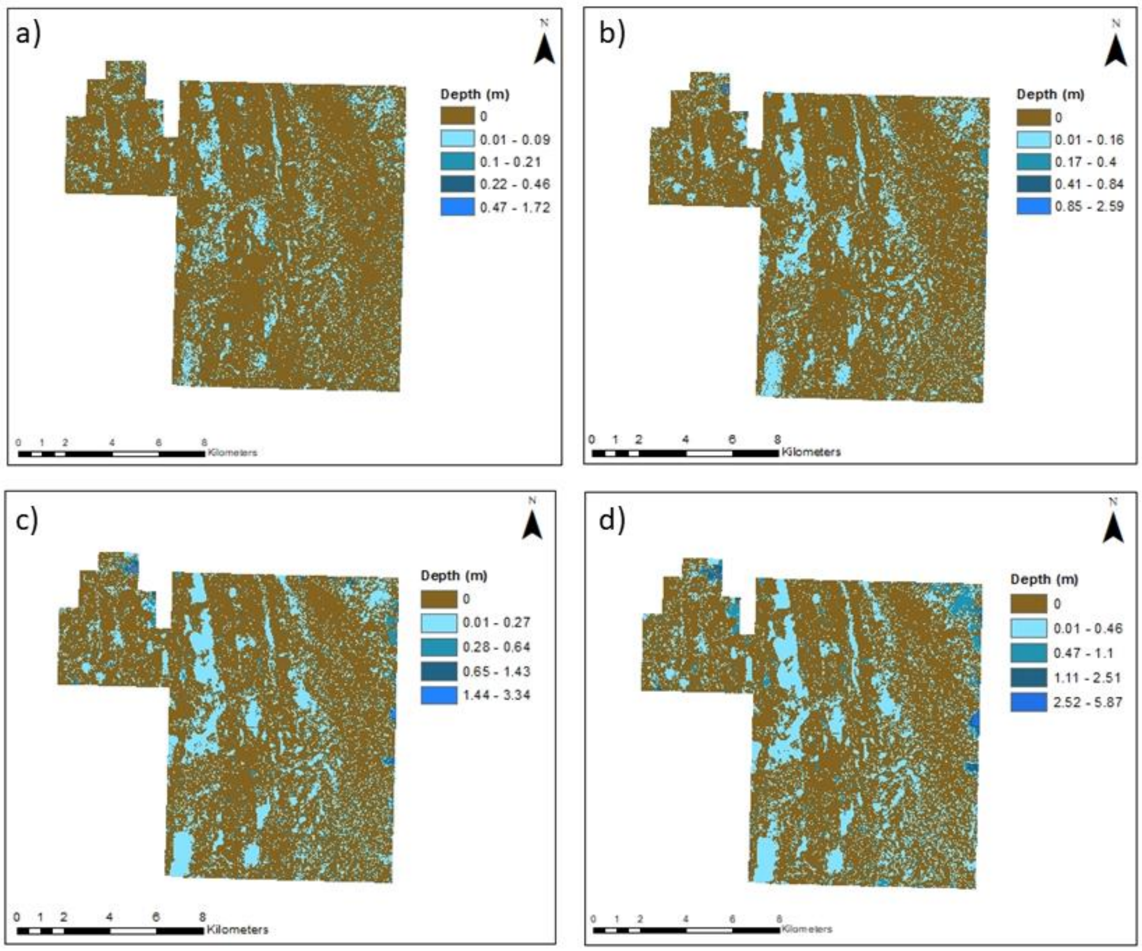

Figure 2.5 Spatial distribution of simulated water depths of 10, 20, 42, and 82 mm shown in a, b, c, and d, respectively. The brown color represents the dry regions, and darker blue represents areas of greatest water depth.

Table 2.3 Analysis of the inundation extent for different depths of water added

	10mm Added		**20mm Added**		**42mm Added**		**82mm Added**	
	Pixels	% area covered with water	Pixels	% area covered with water	Pixels	% area covered with water	Pixels	% area covered with water
No inundation	4935278	82.35	4671455	77.95	4485994	74.86	4318752	72.07
Less than 0.5 m	1053801	17.58	1291389	21.55	1428099	23.83	1445776	24.13
0.5—1 m	3572	0.06	24092	0.40	62928	1.05	173159	2.89
1—2 m	130	0.00	5824	0.10	12718	0.21	42440	0.71
2—3 m	0	0	21	0.00	3018	0.05	8332	0.14
3—4 m	0	0	0	0	24	0.00	2204	0.04
> 4 m	0	0	0	0	0	0	2118	0.04
Total % extent area[13]		**17.65%**		**22.05%**		**25.14%**		**27.93%**

[13] The total percentage of area covered with water represents the wet cells in the DEM or wet areas on the landscape where water will likely get accumulated given there is no infiltration or evaporation (worst case scenario). The remaining percentage is the dry areas on the landscape where water was not added or is not accumulated.

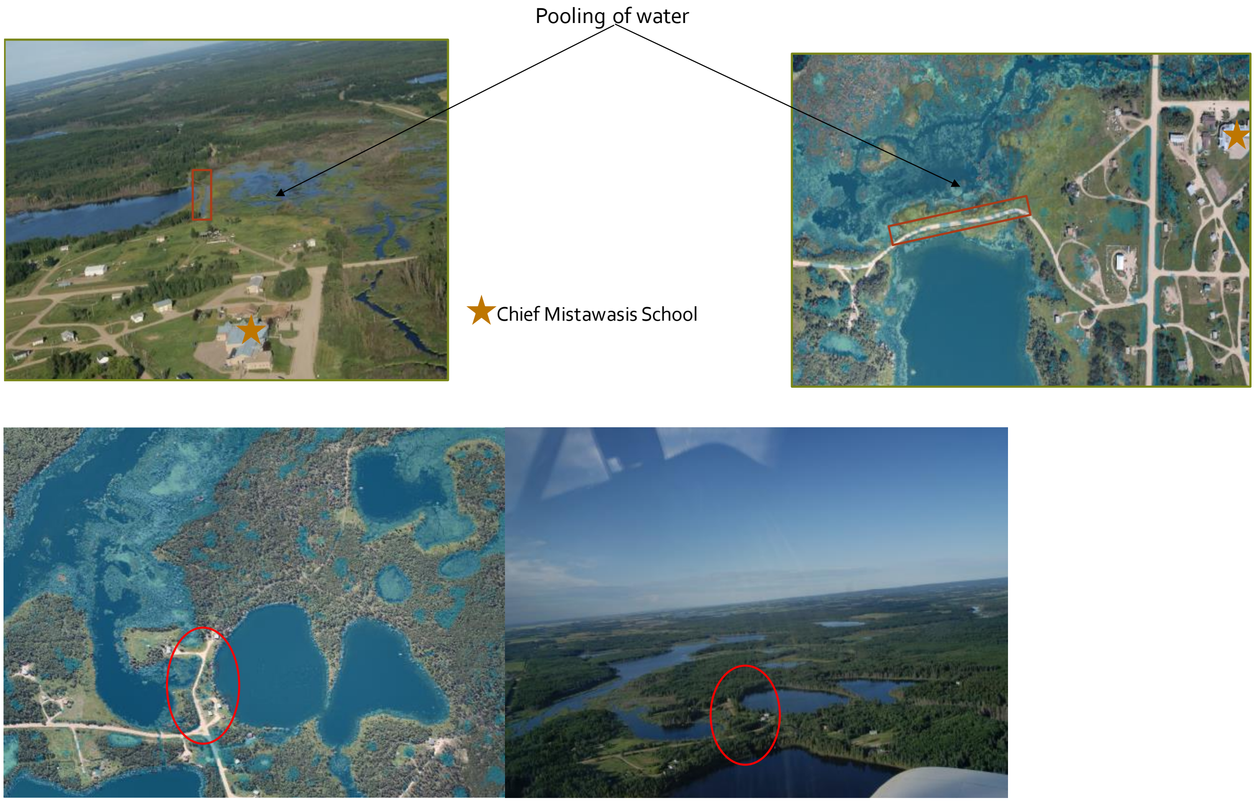

Figure 2.6 Flood extent for a 100-year flood event (i.e., the output from WDPM overlaid on LiDAR aerial image) compared with aerial photographs from 2011 flooding. The top image shows the flood extent near the major administrative area and the major road. The bottom picture shows a flood extent near one of the villages

Finally, with the water depth information, we also created a flood hazard map for the community for a worst-case scenario (i.e., a 100-year flood event). Figure 2.7 is the flood hazard map displaying inundation depth and flood extent as well as community-identified emergency actions such as an alternative route in cases of flooding along the main road and potential evacuation center.

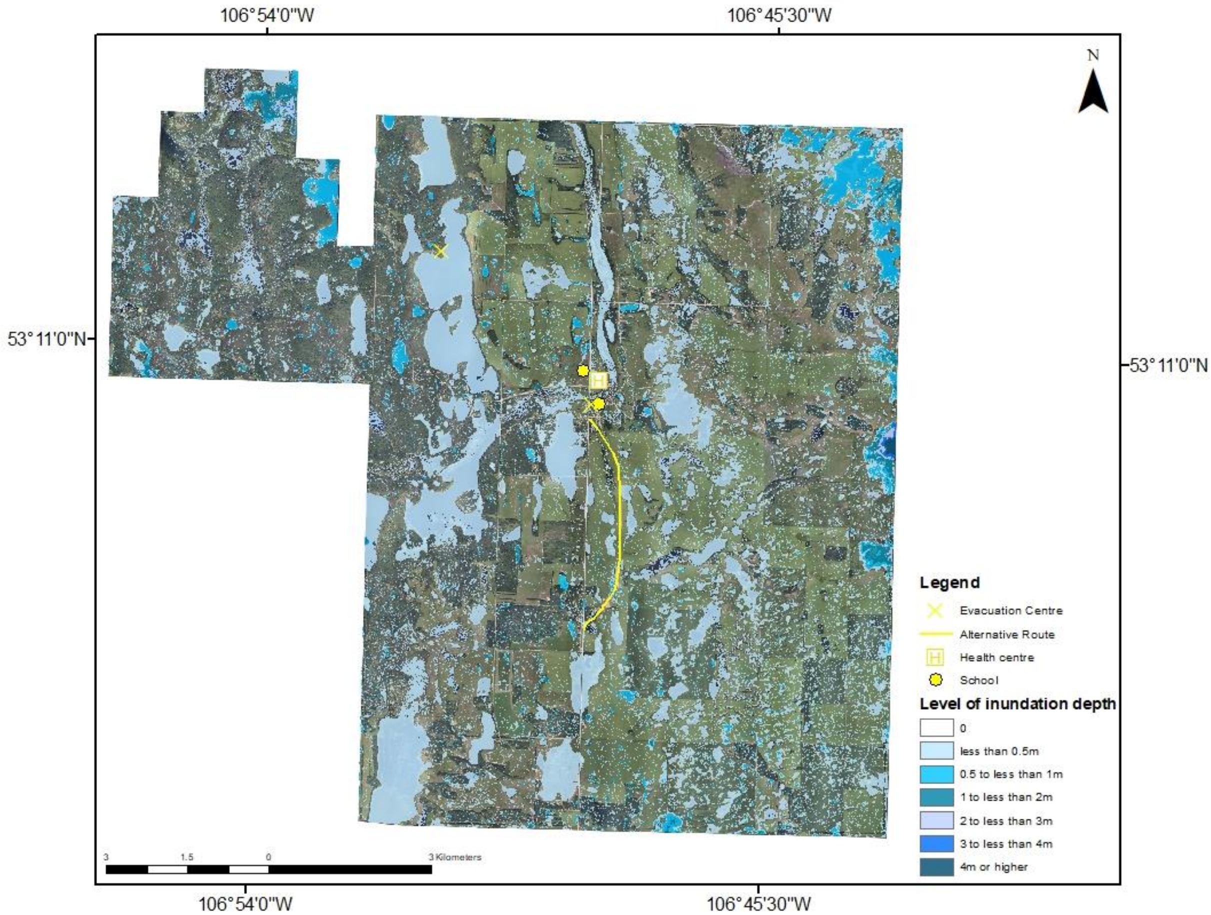

Figure 2.7 Flood hazard map for the community for a 100-year flood event (82 mm runoff depth added to the DEM)

2.4.2 Flood extent areas

Table 2.4 summarizes the total inundation area for the flood extent maps derived from three spatial datasets. The changes in the flood extent, for ALOS DEM, were only observed and apparent for 42 mm and 82 mm. Hence, the flood extents from 10 mm and 20 mm are not reported here. The total inundated regions for ALOS DEM was much lower than the total inundated area covered for LiDAR DEM for the same amount of water added, which was 3767 and 4185 ha for 42 and 82 mm of reference depths. For calculating the inundation area for LANDSAT images, we used the one from May 19, 2011, because it was the closest date to the actual flooding experienced by the community (confirmed with community members). The purpose of estimating inundation areas for the three spatial datasets is not to compare them to one another but to show their differences as a result of the resolution of the datasets. In other words, the choice of spatial datasets and methods will yield different results. It depends on the level of detail needed, and the type of analysis one is doing when selecting the appropriate tools for flood mapping. Additionally, we found that the three different datasets used in this study added complementary information that was not evident from a single method. For example, LANDSAT images were also useful in predicting potential flow direction (Figure 2.7) that highlighted the community's geographical vulnerability.

Table 2.4 Total inundation area of WDPM output using two different DEMs and satellite image

	WDPM using LiDAR DEM		**WDPM using ALOS DEM**		**Landsat 5 TM**
Reference depths	42mm	82mm	42mm	82mm	May 19 2011
Total Inundation area (ha)	3766.97	4185.07	1610.47	2134.13	1353.60

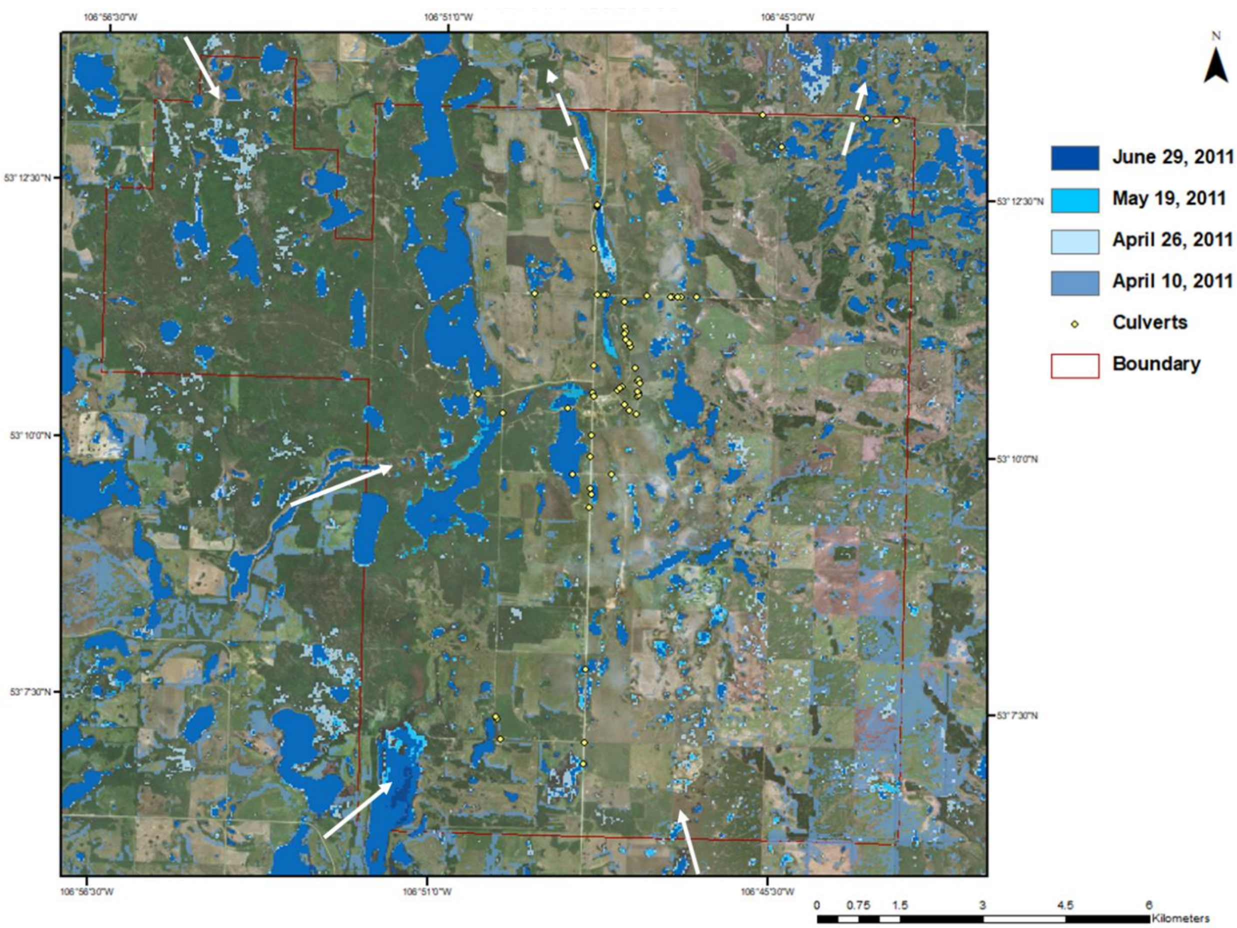

Figure 2.8 Flood extent from 2011 extracted from LANDSAT 7 TM and overlaid on the aerial image. The pre- and post-flood images were used to assess the runoff from contributing areas and derive potential flow direction (i.e., water entering and leaving the community) that was later confirmed with community members in the workshop. The solid arrows represent potential directions for incoming water, and the dashed arrows represent possible outlets.

2.4.3 Evaluation of Flood Maps: Community Reflection

The workshop attendees represented personnel from different sectors in the community, including leadership, Elders, lands division, public affairs, health care, education, and water and climate change-related project managers (N=9, gender: F= 5, M=4). Attendees completed an open-ended survey (Appendix B) and focus group discussion after the workshop to assess the relevance of the model-generated flood maps for community decision support. A summary of the survey results is shown in Table 2.5. Despite the limitations of the data and model, attendees, in general, found the model utility valuable for flood management and preparedness in the community.

Table 2.5 [14]Workshop attendees' responses (N=9) to the relevance and significance of the model and model-generated flood maps

Survey Question	Very much	Moderately	Feedback
To what extent does the evidence presented support your experience with flood concerns in the community?	57%	43%	Shared experiences of how in 2011 the same roads were muddy and people had difficulty getting to work.
To what extent do you trust the evidence?	86%	14%	
How useful do you find the evidence to address flood concerns in your community?	86%	14%	Use more scenarios (culverts vs. no culverts, flash floods, multi-hazard impact) Need more data (LiDAR) for supporting emergency response planning

Focus Group Discussion:

Most people in the workshop were interested in the extent of flooding rather than an estimate of flood depth and velocity. They were curious to see what the extent of flooding in their community, in worst-case scenarios, would be or in similar amounts to the flooding experienced elsewhere in the PPR.

[14] Typically, in social science research anything under 100 people is not presented as a percentage. Here, however, the percentages were presented to protect the confidentiality of the participants in a very small group who could be known to others in the community. Although the total number of respondents were 9, an elder chose to do a combined survey because of eyesight issue and the texts were too small to read.

…in the ends of like a flash flood, you get crazy amount of precipitation over like few hours, kind of how other places did. Would the model give you an estimate of how it would look...that would give us more of an outline of something that would happen in the case of flash flood. (P6)

The flood maps also allowed participants to visualize how different parts of the community may be impacted in case of extreme flood events.

…we travel on certain roads so we can see where the [flood] impacts are but having the picture of the whole reserve, there are places that we don't go and don't know have been impacted. (P8)

Finally, the flood maps generated insightful dialogue for preparing for future extreme events in the community and the need for data and studies to support preparedness.

…it opens my eyes to the importance of planning and being prepared. We need to do more in our preparation and in the studies and fill in all the blanks (P3).

Overall, validating the flood maps with local experience allowed us to gain insights on how future flood modeling studies can support small and rural communities in the PPR. These insights can inform model developers in selecting relevant parameters and scenarios for supporting flood management decisions.

2.5 Discussion

2.5.1 Evaluation of WDPM

Given the complexity of hydrological processes in the PPR, the WDPM presented in our case study demonstrated an alternative and empirical approach to flood mapping in small and data-sparse regions. The rationale for using WDPM was to utilize the community-held LiDAR data for identifying potentially flooded areas under different conditions. We found that WDPM can be used with both fine and coarse DEMs; however, the computational cost when using finer DEM can increase significantly. With finer precisions DEMs such as LiDAR DEM, it is possible to produce detailed flood maps for different runoff scenarios and provide information such as connectivity of water bodies, water accumulation zones or 'hotspots' and water depth in each cell that can be further used for hazard mapping (Sanyal & Lu, 2004; Wedajo, 2018). It must be noted that WDPM is not a flood model and cannot be used to predict future flooding events. It is neither a hydrological nor a hydraulic model. Hence, it cannot be used to estimate the flow rate or other hydrological processes unique to the PPR (Shook et al., 2014). Several well-developed modeling approaches have been proposed and reviewed for detailed analysis of flood dynamics such as distributed hydrological models (Unduche et al., 2018), hydrodynamic methods (Werner, 2004; Bharath & Elshorbagy, 2018), and integrated modeling (Judi et al., 2018). In the context of the Prairies, however, the strength of WDPM lied in its ability to simulate the fill-and-spill mechanism and, therefore, produce an accurate final spatial distribution of excess water on the Prairie landscape (Shook et al., 2014; Bharath & Elshorbagy, 2018). With land-use information for the community, it may also be possible in the future to calculate percentage areas covered with water for different land-use types (e.g., agricultural, residential, administrative.), but this was not within the scope of the current study.

There are, however, some limitations to the model. Although WDPM provided a simple modeling approach to improve flood mapping for the PPR, the model execution time is slow. The runtime depends on the DEM size, tolerance, and processor used, which can make WDPM computationally expensive at present. In our case study, we found that running WDPM with a powerful processor could reduce the runtime for the model at the expense of computations efforts. Though WDPM was computationally expensive, the community overall expressed its value in providing relevant information to them. Preprocessing the DEM can also be challenging (e.g., breaching roads at culvert points) depending on the DEM size. Because the model cannot establish the initial water distribution in the depressional storages when the DEM is created, it is important to establish the initial water distribution before estimating the flooding extent. This process requires access to an aerial photo of the community from the fall or late summer before the LiDAR survey is done and adding and removing water from the DEM by ‘trial and error’ so that the water distribution more or less matches with the aerial photo (Shook et al., 2014). It can, however, be challenging to acquire aerial images for specific times of the year, which was the case in this study, and can take a lot of time trying to match the water distribution qualitatively.

Finally, runoff estimates for WDPM scenarios were generated using straightforward approaches such as either using arbitrary reference depth or rainfall frequency like in previous studies (Shook et al., 2013; Armstrong et al., 2013). For future works, runoff estimates for WDPMs which consider a range of PPR hydrological processes can be used. The Cold Regions Hydrological Model (CRHM) can produce robust runoff estimates (Pomeroy et al., 2007) transferable to WDPM to create an accurate and detailed spatial representation of flooding in the PPR. There is an ongoing effort to integrate CRHM’s outputs, including runoff for different watershed classification and evaporation changes, with WDPM. Doing so would account for the losses in the reference water depth due to processes such as evaporation, infiltration, and snow redistribution. However, currently, this integration is not feasible.

2.5.2 Strengths and limitations of three spatial datasets

Although the main interest of this study was to utilize the community-owned LiDAR data for exploring potentially flooded areas under different scenarios (i.e., minimum, average, and extreme precipitation events), we also explored other spatial datasets and approaches to produce relevant flood information for the community. The major limitation with LiDAR data in our study was its boundary (or edges) that acted as dams and caused excess water to pool near the edges. This limitation was addressed to some extent by using the *drain* function in the model that allowed the water to drain through the lowest elevation on the DEM. Additionally, with no data for the contributing areas, the reference depths applied on the LiDAR assumed that precipitation was generated locally (i.e., within the community boundary) without any impact of the surrounding areas. Therefore, we thought it was essential to include DEM for the contributing areas (i.e., basin) and used ALOS DEM for this purpose.

For the same runoff estimates, the inundation area was higher for LiDAR DEM compared to ALOS DEM. Given the two DEMs vary in terms of their spatial resolution, the inundation areas will likely differ; nevertheless, the two DEMs showed drastically different flooded areas. The edges of LiDAR DEM may have accounted for higher values. As the community is taking steps to collect LiDAR for the basin, it will be interesting to see if contributions from surrounding areas make a difference in the potential flood extent. Previously, Hawker et al. (2018) also suggested using multiple DEMs to understand the differences in the spatial distribution of flood extent to address the uncertainties in topography. Others also agree that more research is needed to compare the spatial distribution of flooding extents for a range of DEMs across Canada to help determine appropriate resolution for flood mapping (Bharath & Elshorbagy, 2018). Regardless of its coarse resolution and limited vertical accuracy, the benefit of using ALOS DEM in this study was that it highlighted the geographical location of the community (i.e., given that they are in the middle of the drainage basin). Furthermore, not all communities have access to LiDAR, and while ALOS DEM does not have the precision and accuracy of LiDAR, it can perhaps help some under-resourced communities fill the data gap until high-accuracy DEM such as LiDAR is made open access (Hawker et al., 2018).

Alternatively, other geomorphological approaches such as flood mapping using LANDSAT images can be an economical method for deriving flood extent, particularly in cases of data-gaps (Ho et al., 2010). It can, additionally, provide complementary information to the model generated flood maps. For example, in our study, while ALOS DEM identified the location of the community in the basin, LANDSAT images highlighted the geographical vulnerability by showing the potential direction of runoff from the surrounding areas. While we used a simple and accessible MNDWI approach to extract flooded areas, there are automated approaches that are known to improve the accuracy of extracted water features (Notti et al., 2018). The challenges with using satellite images, however, for flood mapping include; i) accessing high-accuracy satellite images can be costly (Hawker et al., 2018), ii) preprocessing the images can be time-intensive primarily if the images consist of clouds, iii) low-resolution images are often not adequate for mapping small inundated areas, and iv) flood analysis requires access to pre- and post-flood images (Notti et al., 2018).

All three datasets used for flood mapping had several strengths and limitations. LiDAR can provide accurate and detailed flood mapping in unique topography like the Prairies; however, given the community's interests and capital, other alternatives can provide preliminary insights to flooding concerns as well.

2.5.3 Community engagement in flood mapping

Having up-to-date information on flood inundation extent and hazard is beneficial in rural and Indigenous communities in the PPR for their spatial planning and emergency preparedness. Producing flood maps in most cases is a technical process using hydrological and hydraulic models (Landström et al., 2011). The evaluation of flood maps by the end-users, however, is rarely done. In our study, we found that community participation in flood mapping can be inclusive of local experiences and memories which can be valuable in evaluating the model-derived flood maps and provide direction for future works. Furthermore, an explanation of data and modeling limitations also helped in establishing transparency in the process, which is a vital aspect of engagement (Voinov & Bousquet, 2010). Similar findings have been confirmed by other participatory modeling studies (Cockerill et al., 2004; Carmona et al., 2013). Interestingly, the discussions on the flood maps also led to the understanding that the community is keen on collecting more data in the future. The feedback from community members also provide opportunities for improving flood maps using transdisciplinary methods to combine local and Indigenous knowledge of flooding and blend them into model-derived flood maps (e.g., identifying high impacted areas, risk perceptions, locating control structures) (Butler & Adamowski, 2015; Doong et al., 2016; Castillo-Rosas et al., 2017).

Doong et al. (2016) highlighted the importance of stakeholder engagement for improving flood mapping. In our study, engagement processes in flood mapping were initiated in earlier stages. Participants were involved in collecting data (i.e., culvert mapping), defining scenarios for the model, and evaluating the utility of WDPM-generated flood maps for community flood preparedness. Other studies have also described the importance of engaging stakeholders in preliminary stages of any modeling process to increase the trust and legitimacy of modeling outputs (Cockerill et al., 2004; Olsson & Berg, 2009; Voinov & Bousquet, 2010). The feedback from the participants in the workshop shed some light on their preferences for flood maps, which can help in the selection of modeling scenarios and risk mitigation strategies in the future (Castillo-Rosas et al., 2017). Their main feedback included having more data for the surrounding areas in the future for detailed flood mapping, using historical events in other communities in the PPR as scenarios, and modeling the effect of having control structures vs. no control structures. Furthermore, others have noted that integrating community-specific spatial flood information can empower local and Indigenous communities to take actions, develop locally relevant adaptation strategies and build resilient communities in the era of climate change (Agrawal, 1995; Butler & Adamowski, 2015; Castillo-Rosas et al., 2017; Castleden et al., 2017).

Finally, the results and findings from our study are based on only one community in the PPR, which makes it difficult to say that the utility of WDPM in other regions will be equally high. There are cases, however, where WDPM has been used in community planning (Armstrong et al., 2013). Given the growing importance of LiDAR, communities across the Prairies need access to it. In communities where spatial data is available, WDPM can provide quick initial overviews of potential flood extents and assist communities in assessing their vulnerabilities to extreme flood hazards in the future. Community feedback is valuable for developing scenarios for future modeling works and for creating locally relevant information. While in our study, we only evaluated the land covered with runoff estimated from WDPM, future work can include economic evaluation flood damage (e.g., roads, buildings, risk to people, etc.). However, for this, more rigorous modeling work may be needed. Nevertheless, we hope the methodology we have used in our work could contribute to supporting flood resilience and management in rural and Indigenous communities in the PPR.

2.6 Conclusions

Increasing climate uncertainty and land-use changes have led to an increase in extreme flooding events across the PPR, leaving many rural and Indigenous communities vulnerable to the negative impacts. Acknowledging the unique PPR topography, LiDAR is emerging as a promising tool to represent flood extent at local and basin-scale accurately and precisely. In this work, we used a spatially focused modeling tool, WDPM, and LiDAR DEM to create flood maps for Mistawasis Nêhiyawak to support their flood risk reduction initiatives. The use of LiDAR DEM provided a detailed estimation of flood extent (i.e., drainage to trace pathways of runoff over the landscape and impacts of roads on water pooling). Additionally, we used open access coarser-resolution datasets, including ALOS DEM and LANDSAT images, to evaluate flood extent. The two datasets provided additional insights into the flooding concerns in the community, such as the geographical vulnerability of the community in the basin. While LiDAR can provide a detailed and accurate prediction of potential risk areas under different scenarios, this can be an expensive investment. Despite the computational limitations of WDPM and expenses related to LiDAR, the community found the information to be valuable. We also found community engagement to be relevant for co-producing data, providing feedback, and guiding future work. In general, up-to-date spatial datasets, flood simulations, accurate and detailed flood hazard maps will be important for designing flood management strategies for many communities across the PPR. Our study demonstrates the feasibility of using spatial datasets and alternative empirical modeling approach to identify flooding hazards in a small community.

Lessons from our study draw on the significance of the participation of local and Indigenous communities in flood modeling and mapping studies as contributing both to better science and reconciliation by scientists. Based on this, we provide four recommendations:

1. Participation of public, local, and Indigenous communities is possible in otherwise traditionally top-down modeling practices and contributes to good practice in doing research. It also meets the calls of others doing community-engaged research or participatory research with local and Indigenous communities (Castleden et al., 2008; Butler & Adamowski, 2015; Manttyka-Pringle et al., 2017; Patrick et al., 2017; Bradford et al., 2018).

2. Engagement with communities facilitates in filling some of the data gaps, overcoming unideal or incomplete data, and uncertainty in modeling. In our case, we overcame data deficiencies by getting access to the community-held data, co-collecting culvert points, and co-validating flood maps. Furthermore, engagement can lead to the creation of innovative modeling approaches, generation of new knowledge, and, ultimately, the practice of science that is relevant to greater society (Landström et al., 2011).
3. Use of spatially focused tools in small, rural and Indigenous communities in the PPR can provide valuable information for identifying vulnerable regions, better spatial plans, and accordingly, develop better response or management strategies for floods (Armstrong et al., 2013).
4. Access to LiDAR could improve the estimation of flood extent and flood risk. It would help to plan efficient management strategies and reduce the cost of flood damage and recovery in the long run. But until LiDAR is made open access, other spatial datasets with coarser resolution can provide complementary flood information in small and rural communities.

In the future, more technical rigor can be applied to generate runoff estimates for runoff simulation using physically-based hydrological models that can improve the accuracy of flood mapping in the PPR. Moreover, with additional information such as population, land-use types, and infrastructures, WDPM generated flood maps also have the potential to provide an economic evaluation of flood damages in the communities.

PREFACE TO CHAPTER THREE

we are living in the midst of this rapid and deep transition, so we cannot predict its outcome. But we can help to create the conditions and the intellectual tools whereby the process of change can be managed for the best benefit of the global environment and humanity (Funtowicz & Ravetz, 1993 p754.)

WDPM had strengths and limitations, as described in the previous chapter. However, the value of modeling efforts and outputs was that it enriched the dialogues in the workshop (Voinov & Bousquet, 2010; Basco-Carrera et al., 2017). In that sense, LiDAR and WDPM were not used as predictive tools for flood risk mapping in this thesis. Instead, they were used as communication tools to foster engagement, learning, and reflection among community members.

Additionally, while the flood extent maps were what community had requested, it was also necessary to take the dialogues beyond just spatial flood maps. Therefore, it was essential to incorporate methods and tools that facilitated community members to think about the present and future actions using not only physical parameters but also human parameters (or perceptions) of flood risk reduction. This next chapter unpacks the social learning that happened in the workshop in which we shared the spatial maps and applied other participatory processes (e.g., participatory mapping). The chapter also introduces fuzzy cognitive mapping (FCM) as a novel tool to represent the individual and collective knowledge of lay experts and for measuring social learning in the context of community flood risk reduction.

CHAPTER THREE: ASSESSING SOCIAL LEARNING

Can social learning be measured? Applying fuzzy cognitive mapping (FCM) to unpack social learning in disaster risk reduction

Abstract: Social learning and its relation to disaster risk reduction (DRR) have been increasingly highlighted in the literature. However, contested conceptualization and limited empirical research have hampered its application in DRR. In this paper, I present a simple methodological framework to evaluate social learning, both quantitatively and qualitatively. First, I provide a review of how social learning is conceptualized across disciplines, followed by a description of fuzzy cognitive mapping (FCM) as a novel method to measure it systematically. Then, using an example from a participatory workshop organized for sharing flood extent maps, I provide the results from the application of the framework. Social learning was evaluated in three ways: whether learning occurred, what processes fostered it, and the outcomes of learning. From the results, I found that i) social learning was observed in the workshop, ii) sharing experiences and stories from past events fostered learning, and iii) awareness on the role of emergency planning in DRR was found to be a significant outcome of learning. The proposed method to evaluate social learning will address critical issues raised by scholars in the past and contribute to filling gaps in empirical research. Unpacking social learning will help in designing practical research approaches to DRR that emphasize knowledge sharing, two-way communication, and reflexivity.

Keywords: DRR, social learning, mental models, fuzzy cognitive mapping (FCM), Indigenous Knowledge, participatory processes,

3.0 Introduction

Disasters risks, much like many of the current natural resources management issues, are ‘wicked’ in nature. Coined by Rittel and Webber (1973) almost 40 years ago, wicked problems are constructed of complex human-environment relationships, uncertainties in knowledge and multiple perspectives in terms of defining the nature of a problem and finding a relevant solution (Thompson, 2011). The latter is evident in the conceptualization of disaster risks. On the one hand, ‘objective’ approaches describe risk as a measurable (i.e., in terms of severity and occurrence) factor with known potential outcomes (Smith et al., 2000). At the same time, incomplete datasets, or their relevance to people's preferences account for the uncertainties in knowledge-making (*ibid*, 2000). On the other end, the ‘subjectivist’ approach takes into account risk perception[15] based on how people construct their lived realities and previous encounters of disasters (Renn, 2004). Hence, environmental, social, and psychological factors all complicate disaster risk reduction (DRR) (Smith et al., 2000; Renn, 2004; Avvisati et al., 2019). To deal with this, participatory approaches that are flexible, adaptable, and inclusive of knowledge of all social constructs will become vital.

The growing body of literature highlights the benefits of participatory approaches (Pahl-wostl, 2002; Armitage et al., 2008; Reed., 2008; Newig et al., 2010; Ison et al., 2013; Akamani, 2016). These benefits range from improving saliency, relevancy, and credibility of knowledge making (Cash et al., 2004; Hassanzadeh et al., 2019), the inclusion of different types of knowledge and experiences (Agrawal, 1995; Turner & Clifton, 2009; Bradford et al., 2019), fostering community-based disaster planning (Samaddar et al., 2015) to social learning (Garmendia & Stagl, 2010; Henly-Shepard et al., 2015). Over the past few decades, social learning, in particular, has been frequently cited as a critical outcome of participatory approaches (Webler et al., 1995; Muro & Jeffrey, 2008, 2012; Reed et al., 2010; Diduck et al., 2010b; Benson et al., 2016; Garćia-Nieto et al., 2019).

Theoretically, social learning allows representation of different perspectives, sharing knowledge and experiences, reflecting on each other’s values and interests, building trust, and developing a shared understanding of a problem (Muro & Jeffrey, 2012). Ison et al. (2013) even describe social learning as an ‘innovative response’ to wicked problems. Despite being cited as a critical governance mechanism, there is limited empirical research to support its role in DRR (Henly-Shepard et al., 2015; Samaddar et al., 2015; Nguyen et al., 2016). This limitation comes from differences in its conceptualization (Van Der Wal., 2013) and lack of methods and tools to measure it systematically in a participatory context (Reed et al., 2010). Reed et al. (2006) and Didham (2015) highlighted that social learning evaluation often tends to confuse with examining conditions necessary for learning, for example, degree of participation. However, participation does not always lead to social learning (Akamani, 2016). Hence, the role of social learning remains unclear and even undermined in participatory approaches (Ison et al., 2013). Therefore,

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[15] Perception refers to individual’s mental processes responsible for dealing with and managing incoming external information that helps them understand their environment (Renn, 2004). Risk perception is concerned with what individuals consider to be a risk and the whys behind it. The whys can be answered by people’s definition of risks, assessment of severity of disasters and how they chose to respond to it (Avvisati et al., 2019).

the purpose of this paper is to unpack social learning and its role in DRR. For this, I present a systematic but simple method to measure social learning, quantitatively and qualitatively, by using an example from a participatory workshop organized for sharing flood extent maps in a First Nations community. In particular, I focus on three critical questions posed by scholars: 1. Why is there a lack of evidence of social learning as an outcome of the participatory process? 2. How do we know the extent to which it occurred (i.e., what processes fostered or inhibited learning)? And 3. What are the outcomes of learning itself (Muro & Jeffrey, 2008; Reed et al., 2010; De Kraker, 2017). The objectives of this paper include:

I. Present fuzzy cognitive mapping (FCM) based methodology on measuring social learning processes and outcomes.
II. Contribute to the ongoing empirical research in social learning to enhance its application in DRR.

3.1 Social Learning: A contested concept or innovative mechanism?

"A good theory is not static but amenable to revision as new empirical data are introduced or alternative theoretical perspectives challenge previous conceptualizations" (Farnsworth et al., 2016)

It is beyond the scope of this research to review and reflect on all social learning concepts (see Muro & Jeffrey, 2008; Didham, 2015). In this section, I discuss some fundamental learning theories that have influenced participatory natural resources management (NRM) and DRR domains.

Social learning received great prominence in the 1960s in cognitive and social psychology. Albert Bandura's (1977) individual learning is the most cited theory in social learning literature. Bandura described social learning as behavioral learning occurring through an individual's internal cognitive processes and external environmental influences (e.g., observation of others behaviors, social norms). Social learning theory in cognitive psychology explained that individuals learn by modeling the actions through observing, memorizing, and imitation (Bandura, 1977; Muro & Jeffrey, 2008), or in other words, they learn from their peers and society (Didham, 2015). Hence, learning comprised of iterative feedback between 'cognitive, behavioral, and environmental' factors (Muro & Jeffrey, 2012). Bandura's notion of learning *in* rather than *within* a social context, however, has been criticized for being too narrow in a participatory context (Pahl-Wostl, 2002; Muro & Jeffrey, 2008). Social learning theories in later years highlighted the process of knowledge-making rather than behavioral changes (Ison et al., 2013).

From an organizational management perspective, social learning is described by single and double-loop learning (Argyris & Schön, 1978). Single-loop learning is demonstrated by acquiring new skills and practices (Argyris & Schön, 1978; Keen et al. 2012). Garmendia and Stagl (2010) referred to this learning as incremental changes in cognitive knowledge (e.g., adopting new information or facts) without necessarily changing underlying assumptions. At an organization level, single-loop learning involves using existing rules, strategies, and techniques for problem-solving (Medema et al., 2014). In the context of DRR, this may evoke more reactive responses, for example, building dykes for flood protection. Changing or reexamining assumptions indicate a new learning depth known as double-loop learning. This is similar to Webler et al. (1995) description of learning related to developing a mutual understanding that leads to shared social knowledge (Keen et al., 2012). Double-loop learning is more than problem-solving; it is examining the existing rules and norms to correct the outcomes of an action (Medema et al., 2014; Henly-Shepard et al., 2015), for example developing proactive approaches to DRR such as flood management planning. Feedback between single and double-loop learning creates space for innovation; an example would be bringing different forms of knowledge and perspectives into decision-making than typically used (Diduck, 2010a).

Organizational learning was further developed by Flood and Romm (1996) to include the notion of reflexivity in learning and called it triple-loop learning (Scholz et al., 2014). Triple loop learning occurs when the learner transforms their underlying assumptions resulting in broader behavioral and societal transformations (Keen et al., 2012; Henly-Shepard et al., 2015). It is about reflecting on double-loop learning and coming to a new understanding of why we ought to do things differently; in a way, it is learning about learning. This triple loop learning can result in the creation of new practices, paradigms, and policies. Later, Wenger's C*ommunities of Practice* (1998) extended on the loop learning to explain that learning is a *"social process that is situated in a cultural and historical context*" (Farnsworth et al., 2016 p.3). In this sense, real-world experiences of people play a critical role in understanding how and why people learn.

Experiential learning theory by Kolb (1984), influenced by the philosophical underpinnings of John Dewey, helped unpack the learning process in a social context (Didham et al., 2015). This learning theory emphasizes the role of communication and experiences in learning (Pahl-

Wostl, 2002). Social learning, hence, occurs through sharing lived experiences of people, reflecting on it, and transforming it to create new understanding, knowledge, or action (Didham, 2015). Experiential learning, hence, results in developing shared understanding through the cycles of observing, reflecting, and restructuring of assumptions (Didham et al., 2015). This learning model may be beneficial in answering *how* people learn in a social context.

In adaptive management and resilience studies, social learning (also referred to as anticipatory learning) occurs in two temporal scales (Pahl-Wostl et al., 2007; Holling, 2004; Henly-Shepard et al., 2015). In immediate time scales (short-to-medium), social learning occurs among groups of people who are directly engaged in the participatory process, for example, learning about adaptation strategies for flooding (Didham et al., 2015; Henly-Shepard et al., 2015). Over longer time scales, learning may shift from engaged groups to broader structure or institution that may lead to the development of long-term adaptation strategies, collective knowledge, and social memory (Holling, 2004; Henly-Shepard et al., 2015).

More recent learning concepts in participatory NRM involve components of earlier learning theories including epistemic (i.e., ways of knowing), cognitive, relational (e.g., relationship building, adopting collective interests) changes and reflexivity at individual and collective scale (Webler et al., 1995; Reed et al., 2010; Garmendia & Stagl, 2010; Ison et al., 2013; Scholz et al. 2014; Bentley Brymer et al., 2018). Learning and knowledge making is recognized as an integrated and intuitive process (Habermas, 1981; Baker et al., 1997; Pahl-Wostl, 2002; Scholz et al., 2014). Western paradigms, however, often contradict this notion of learning by emphasizing the value of objective and factual knowledge over alternative perspectives in decision-making. The reality is social learning is possible when factual knowledge and subjective perceptions go hand in hand to create space for deliberation, reflection, and transformation (Pahl-Wostl, 2002).

To conclude, social learning theories are diverse. The heterogeneity of social learning theories hampers conceptual clarity and analysis, hence, impeding our understanding of whether learning occurs in a participatory context (Reed et al., 2010), and what processes enhance or impede learning (Muro & Jeffrey, 2012). Some believe that there is a need for a more rigid and standardized conceptualization of social learning for its operational use. For example, Reed et al. (2010) explained that the diversity of social learning theories hinders its application in collaborative governance. Garmendia and Stagl (2010) resonated with the viewpoint and described the contested understanding of social learning leads to skepticism in its adoption and application.

On the other hand, others argue that the differences in the conceptualization of a phenomenon or problem provide opportunities for innovation (Ison et al., 2013), integration of different perspectives (Gober et al., 2013) and flexibility in enriching and evolving our knowledge and understanding (Farnsworth et al., 2016). Therefore, acknowledging the differences in learning perspectives *"opens the way for development of new knowledge about social learning rather than limiting this knowledge"* (Ison et al., 2013 p.41). Reflecting and drawing in the synthesis of social learning theories, I intend to unpack the social learning process using the concept of mental modeling.

3.2 Mapping Social Learning: Tracking changes in mental models

In the context of participatory approaches, the Reed et al.'s (2010) definition of social learning captures the different conceptualizations from earlier learning theories (e.g., learning as an individual and collective process, role of communication, etc.). Given the participatory nature of the research, I used three criteria for measuring social learning from their definition:

I. There must be a change in understanding at an individual level,
II. The shift in understanding has to go beyond the individuals to wider social unit or communities,
III. Change in understanding on the parts of individuals and groups must be as a result of social processes (i.e., interaction, deliberation).

In this study, I first investigate cognitive (e.g., knowledge-making, changes in views) and relational changes (e.g., relationship building, sense of community) at an individual level (unit of analysis) and then discuss learning outcomes at a community level. For the first criteria, I assessed social learning as information accumulation, formulation of new knowledge, and development of shared understanding. For the second requirement, it is challenging to evaluate the diffusion of learning to wider societal units (Webler et al., 1995; Scholz et al., 2014). While I acknowledge that this is an integral part of the learning process, I evaluate not how learning extended to the community scale rather discuss the outcomes of social learning in the workshop.

3.2.1 What are mental models?

A mental model, coined by psychologist Kenneth Craik (1943), is the internal (and partial) representation of a complex problem held by individuals (Pahl-Wostl, 2007; Biggs et al., 2011). Mental models are developed through an individual's internal (cognitive) and external (environmental) factors such as their values, beliefs, previous experiences, training, and social norms (Biggs et al., 2011; Moon et al., 2019). Hence, our mental models shape how we create an understanding of our external world or reality.

Mental models allow people to select, process, filter, interpret and create explanations and reasoning about a complex problem (Pahl-Wostl, 2007; Gray et al., 2014). Humans are capable of selectively processing incoming information based on analogies drawn from similar instances in the past to create specific responses and behavior (Pahl-Wostl, 2007). Such a selective process also means that we can sometimes disregard information that challenges our beliefs (confirmation bias[16]). In other words, a person's mental model may remain unchanged or could be modified when new information supports their beliefs (Biggs et al., 2011). Others claim, however, that because mental models are naturally dynamic, context-dependent and are not a complete representation of the reality, they can evolve through learning (Jones et al., 2011; Scholz et al., 2014; Moon et al., 2019). This resonates with conceptual change theory posited by Posner et al. (1982) describing individual's ability to 'assimilate[17]' and 'accommodate' new information (similar to experiential learning) to develop understanding and knowledge structure for reasoning (Piaget, 1983; Gray et al., 2015). A mental model, therefore, can be an essential tool to evaluate the contribution of factual knowledge and subjective perception of the learning process (Pahl-Wostl, 2002; Biggs et al., 2011).

Learning occurs within one's mental model. The increment in knowledge or single-loop learning can be examined by eliciting one's mental model and observing how it changes when given new information (e.g., news articles, stories) (Biggs et al., 2011). Mental models can also

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[16] Confirmation bias is a tendency to process information that confirms a person's preexisting assumptions whereas dismissing or ignoring any information that contradicts their assumptions (American Psychological Association, nd).

[17] The word assimilation can have a negative connotation given the history of aboriginal assimilation policy. Assimilation meant to 'train' aboriginal peoples (particularly those with fair skin) to absorb them into white society (Armitage, 1995). Acknowledging the history of this word, I am using the term in the context of conceptual change theory where assimilation means to absorb information.

be shared and exchanged to correct any previously held misconceptions and increase understanding between the groups (Moon et al., 2019). Shared mental models may develop through an iterative process of interaction between individuals or groups until a shared conceptualization of a problem is generated (double-loop) (Biggs et al., 2011; Scholz et al., 2014). Both learning types occur within our cognitive domain (Peschl, 2007). Triple-loop learning, on the other hand, extends beyond one's cognition and concerns changes in behaviors and attitudes or, as Peschl (2007) describes, must have a profound shift at an existential level. When people's understanding converges to represent the collective interest of the group, it may even lead to new paradigms or policies (triple-loop) (Pahl-Wostl, 2002). Hence, mental model elicitation and sharing can help empower individuals and groups through an iterative knowledge-making process over time that allows them to adapt to the changing conditions, provide ownership of the planning and develop empathy (Biggs et al., 2011). Utilizing this concept of mental modeling and conceptual change, I present a fuzzy cognitive mapping (FCM)-based methodology to elicit individual mental models and measure social learning in a DRR context.

3.3 Overview of fuzzy cognitive mapping (FCM)

Robert Axelrod (1976) was the first to use[18] cognitive maps to represent subjective knowledge of lay experts (Christen et al., 2015). Cognitive maps consist of directed graphs showing a causal relationship between variables. These directed graphs, however, lacked the description of the degree of effect one variable had on another or, in other words, they were binary (Özesmi & Özesmi, 2004). A decade later, Bart Kosko (1986) added weights to the directed graphs transforming binary cognitive maps into fuzzy cognitive maps (FCM). The weighted relationships in FCM made a range of detailed analyses possible such as quantitative assessment of key variables, comparison of mental models, and scenario simulations (Kosko, 1986). For clarity, scenario simulation in FCM is not a quantitative prediction of real-world parameters but an evaluation of how a system may change under a given scenario based on human perceptions (Kosko, 1986; Giabbanelli et al., 2017).

Over the years, FCM related studies have increased and expanded to a range of disciplines (Figure 3.1) (Papageorgiou & Salmeron, 2013). Despite the steady increase, majority of FCM

[18] Tolman (1948) was the first to coin the term cognitive map but its application was first demonstrated by Axelrod (1976)

studies are still found in highly technical journals focusing on technical improvements of the method using 'toy' problems[19] such as applying machine learning for knowledge extraction as opposed to knowledge elicitation from people (Papageorgiou & Stylios, 2008; Jetter & Kok, 2014). Kosko's (1986) vision of FCM was that it would be a method to not only represent but also model social, political, and environmental systems based on subjective human perceptions (Jetter & Kok, 2014). Yet, the application of FCM in fields such as environmental or decision sciences, remain low partly because of the reason that publications, where FCM appear, are too technical (*ibid*, 2014). Although still somewhat limited, there is an increasing trend in using FCM to represent real-world problems over the last decade. These range from ecosystem management (Özesmi & Özesmi, 2003; Solana-Gutiérrez et al., 2017), policy analysis (Strickert et al., 2010; Christen et al., 2015) to disaster risk reduction, adaptation and resilience (Gray et al., 2014; Henly-Shepard et al., 2015; Chandra & Gaganis, 2016).

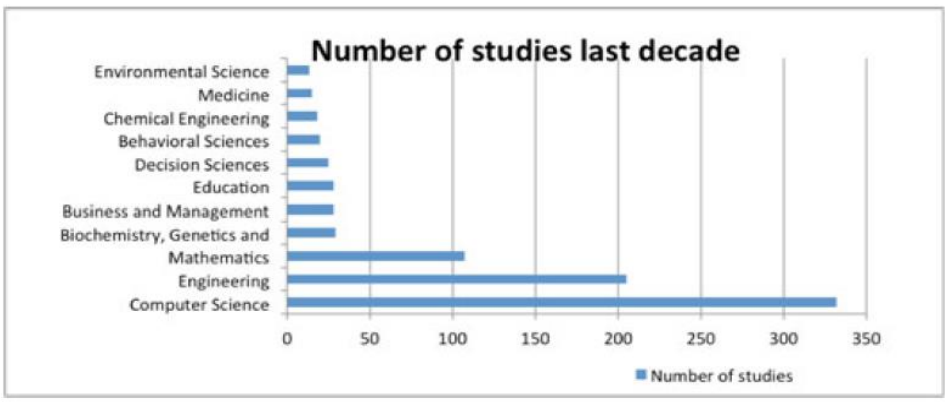

Figure 3.1 Number of FCM studies from 2000-2010 (Used with permission from Papageorgiou & Salmeron, 2013)

FCMs can serve four important functions (Codara, 1998; Papageorgiou & Salmeron, 2013). First, for understanding the reasoning for human behavior and actions (explanatory). Second, for dealing with wicked problems through the integration of multiple perspectives (strategic). The third purpose relates to self-reflection on one's interpretation of a situation and possibly the correction of misconceptions (reflective). The fourth function is for *prediction* (or

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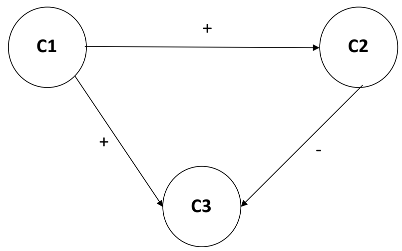
[19] A toy problem is a simplified version of a real-world problem often used as means to test new methods, prototype or show improvement in a method, algorithm or technique. E.g., toy problems in artificial intelligence can include puzzles and classical games (Semantic Scholar, nd).

reasoning more appropriately) of how a system may change based on a person's current actions. FCM is also beneficial in cases where scientific knowledge is incomplete, but there is rich local and Indigenous knowledge available and when public participation is necessary or mandated (Özesmi & Özesmi, 2004). In addition, unlike other modeling methods such as structural equation modeling and system dynamics (see Özesmi & Özesmi, 2004 p. 45-46), FCM is developed intuitively, flexible, and easy to understand by lay experts (Van Vliet et al., 2010). As a participatory method, the outcomes are not the sole purpose of FCM development, rather social learning that is initiated by participation and communication with others is one of the most important benefits of the FCM development process (Reckein et al., 2013). Collectively, these attributes of FCM has contributed to its growing popularity as a participatory modeling method over the years (Mendoza & Prabhu, 2006; Van Vliet et al., 2010; Gray et al., 2014; Voinov et al., 2018).

3.4 FCM structure and simulation process

While the process for developing FCM may vary depending on the purpose of the study (e.g., individual vs. group), the foundation of the FCM structure is the same (Figure 3.2a). FCM structure and inference are based on neural networks theory (Kosko, 1986; Strickert et al., 2010; Papageorgiou & Salmeron, 2013) and are represented through causal relationships between key concepts (or 'nodes') that are linked through directed and weighted arrows (Jetter & Schweinfort, 2011). For example, in Figure 3.2a, the arrow going from C1 to C2 shows that C1 affects C2, and the '+' sign explains the causal relationship between concepts C1 and C2 (i.e., when C1 increases C2 increases too). Similarly, the '-' sign denotes the decreasing effect (i.e., increase in C2 leads to a decrease in C3). In addition to the direction and causal nature of the relationships, strength is assigned to the arrows, often in the range of -1 to 1. Once the FCM is completed, it can be coded to an adjacency matrix for further analysis (Figure 3.2b).

a)



b)

	C1	C2	C3
C1	0	+0.8	+1
C2	0	0	-0.7
C3	0	0	0

Figure 3.2 FCM graphical and mathematical structure. a) Graphical representation of causal relationships between concepts, and b) adjacency matrix coded from FCM represented in a)

Matrix calculation can be used for simulating simple policy or management options (or sometimes also referred to as ‘what if’ scenarios) (Kosko, 1986; Özesmi & Özesmi, 2004; Gray et al., 2012; Jetter & Kok, 2014). The simulation process provides a means to evaluate how the current state of the system might change under the desired policy options. The simulation starts with each concept in the FCM represented as a neuron in a neural network (Figure 3.3) (Strickert et al., 2010; Jetter & Schweinfort, 2011). The neuron can take a range of values or membership in between [0,1] hence the term ‘fuzzy’ (Jetter & Schweinfort, 2011). The interval [0,1] is known as ‘activation level’ (Papageorgiou & Salmeron, 2013); when a neuron is activated, it is given a value of 1, which means that the concept is given highest consideration in the FCM (Strickert et al., 2010). In Figure 3.3, a neuron receives inputs (i_n) from other neurons in the network.

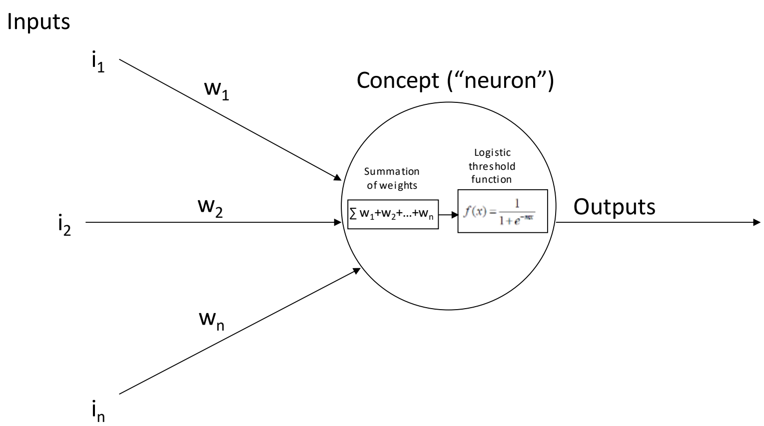


Figure 3.3 Simulation process through the neural network. A concept is represented as a single neuron with inputs (in) coming in from other neurons in the network. A neuron is activated through the summation of the weights (w_n) attached to the connections.

The path between the inputs (i.e., other neurons) and the receiving neuron consists of weights (w_n) representing the strength of the connection between the neurons (Strickert et al., 2010). The initial state vector (A) for the neuron is the summation of the weights from all the inputs. The initial weights are identified and assigned by the people drawing the maps. The summation of the inputs is often normalized using a logistic function to bound the output in the range of [0,1] to enhance the understanding and qualitative evaluation of causal relationships between the concepts (Özesmi & Özesmi, 2004; Strickert et al., 2010; Papageorgiou & Salmeron, 2013). Next, the initial vector (A) is multiplied by the adjacency matrix (Figure 3.2b), and the process is repeated through numerous iterations until a steady-state or equilibrium is achieved (i.e., there is no change in the outputs or the minimum error difference between subsequent vector state of a concept is 0.001- 'residual error') (Özesmi & Özesmi, 2004; Papageorgiou & Salmeron, 2013). Although very rare, the system can also go into a chaotic state especially in cases of small and data-sparse models (Jetter & Schweinfort, 2011), but in most cases (including in our analysis) steady state is reached within 20-30 iterations (Özesmi & Özesmi, 2004; Gray et al., 2012).

Steady-state is used as a reference to evaluate the effect of various policy options. The method involves first clamping the desired concepts at a high activation level (1) while leaving other concepts as they are (i.e., status quo) (Özesmi & Özesmi, 2004; Strickert et al., 2010; Gray et al., 2012). The difference between the final value of each concept under the desired policy option and the steady-state provides information regarding the anticipated changes in the system under the simulated policy option. If the difference is negative, it means there is a reduction in the variables state, whereas a positive value indicates an increase in the variable state compared to the status quo (Solana-Gutiérrez et al., 2017). Care should be taken, however, when interpreting this relative difference. The quantitative states of the concepts under a given scenario simulation are not to be used as predictions in the real-world rather to understand the behavior of the system relative to other concepts in the FCM with respect to the knowledge and experience of the person drawing the map (Papageorgiou & Salmeron, 2013; Jetter & Kok, 2014). The simulation outputs are insights into how a person or group anticipates changes in the system. Even with this, it is essential to note that FCM is only a small representation of how people think they understand a situation. In other words, FCM is drawn based on human perceptions of how a system works.

3.5 Context for FCM development

Mistawasis Nêhiyawak, a Cree First Nation community, is located in Treaty 6 territory, north of Saskatoon. Although Mistawasis has been experiencing high water levels since 2006, the flooding frequency and severity have increased over the years. In 2011, the community experienced one of the worst flooding after the 1955/56 flood. Immediate response and recovery strategies after 2011 flooding comprised of water diversion, berms, and mitigation strategies such as culvert expansion (Dawe, 2016) (local reports). After experiencing another spring flooding in 2014 (though not at the scale of 2011), Mistawasis had LiDAR survey done in the fall of the same year. The purpose of LiDAR was to generate a better understanding of runoff impacts and for community development (e.g., spatial planning). Therefore, in response to the community requests, LiDAR-based flood maps were created (see Chapter 2). The flood maps were then shared with the community members in a workshop held on March 21, 2019. In the context of DRR, providing information does not equate to risk awareness or adoption of proactive approaches (Paton, 2003). On the contrary:

> *"…it is not information per se that determines action, but how people interpret it in the context of experiences, beliefs and expectations that develop in and are sustained by the community and societal contexts in which they live in (Marris et al., 1998; Rippl, 2002)" (Paton, 2007 p.370)*

Hence, instead of just communicating the flood maps (which is more 'top-down' approach) in the workshop, it was important to see what and how people learn with the information that they have access to. In this context, this study was experimental and exploratory. I used FCM to first elicit flood risk perception of individuals present in the workshop and then to capture the conceptual changes after each deliberative activity. Social learning, however, was not limited to the FCM but was also apparent in the conversations, as we will see in the results later.

3.6 Methods and materials

3.6.1 Data co-creation: Phases for FCM development

Each individual was provided with a 14 x 22 inches white poster sheet and a unique colored pencil to distinguish among individual FCMs. Before drawing FCM, the researcher also explained and demonstrated the process using an unrelated example (road accident). This was done to make FCM familiar to the participants and provide clarity on drawing relationships between variables, including assigning weights (Table 3.1) (Özesmi & Özesmi, 2003; Chandra & Gaganis, 2016).

Table 3.1 Causal relationships between variables in FCM interpretation

Strength connection by the number	**Strength connection interpretation**	**Interpreted crisp weight**
1	Very weak	0.1
2		0.2
3		0.3
4		0.4
5	Moderate	0.5
6		0.6
7		0.7
8		0.8
9		0.9
10	Very strong	1

The participants then developed FCMs in four phases corresponding to three deliberative activities in the workshop (Figure 3.4). The phases for individual FCM[20] development included:

Phase I: The question used to draw initial FCM was: "In the context of flooding in your community, what are the most important things that come to your mind?" (Özesmi & Özesmi, 2003). This initial FCM represented risk perception held by individuals. To make the process simple, we asked the participants to list the variables first, and then think about how the variables affected each other (nature of the relationship) and, based on that, assign weights to the relationship. We gave participants 15—20 minutes for the initial FCM development.

[20] Individual FCM means each participant drew one FCM in four phases throughout the workshop. Four phases FCM does not mean that four separate FCM were developed rather individuals continued to draw on the same FCM in four phases during the workshop.

Phase II: The first deliberative activity in the workshop was a group discussion facilitated by participatory mapping. The purpose of the discussion was to understand the participant's perspectives on how flooding had changed over the years (in terms of frequency and magnitude). A community spatial map[21] was laid on the discussion table for context. Following the activity, participants were asked to add or remove any new concepts or connections to their FCM based on the discussion.

Phase III: The second workshop activity was presenting the flood maps (Thapa et al., 2019). In the presentation, the researcher also explained scientific terminologies such as LiDAR and DEM and gave an overview of the model and limitations of the work (see Chapter II for limitations). Following the presentation, we asked participants to comment and provide feedback on the results. After the feedback, participants were again asked to modify their FCMs.

Phase IV: At the end of the workshop, a final group discussion was done to reflect on the knowledge and information shared during the day. Following the discussion, participants were asked to make final modifications to their FCM if they wished to.

Colored pencils were used to differentiate learning during each phase for each participant. Once the FCM was completed for one phase, the pencils were changed to a new color, and photographs of FCMs were taken (Figure 3.4b). This was done to help in analysis, for example, to track when certain concepts were added to the FCM. The entire workshop, as well as individual activities, were audio-recorded.

[21] Spatial map here refers to two-dimensional representation of an area of landscape that consisted information of features such as roads, water bodies, buildings, etc. These spatial maps represent the physical geography of a region. FCM on the other hand is the graphical representation of causal relationships defined by individuals.

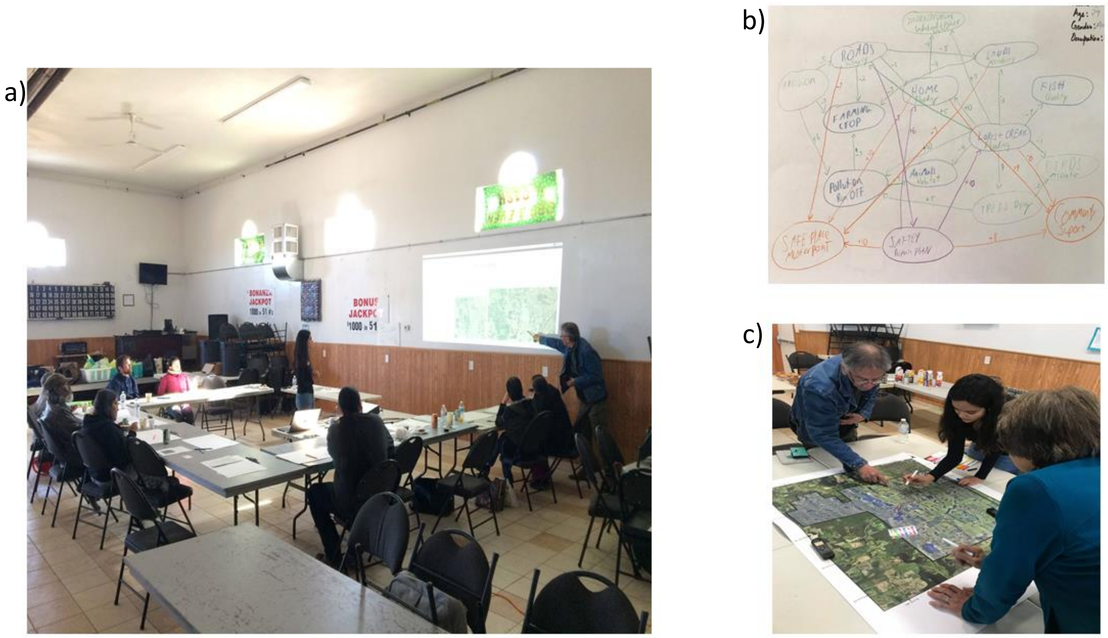


Figure 3.4 Participatory workshop activities: a) LiDAR-based flood maps presentation b) FCM developed by one participant, and c) participatory mapping for activity

3.6.2 Data analysis

FCMs were analyzed quantitatively and qualitatively. Quantitative analysis included FCM structure and scenario evaluation. The qualitative inquiry included condensation of FCM concepts and using workshop discussions to understand the underlying reasons for the quantitative results from FCMs (Christen et al., 2015). Original individual FCMs were compared for conceptual changes with respect to the number of concepts and connections added in four phases (increment in knowledge). The original FCMs are the ones developed by participants at the workshop that had not yet been processed for further analysis (Figure 3.4b).

After quantifying conceptual changes, the original FCMs were condensed qualitatively to blend the total number of concepts that were highly related to one another into upper-level categories of a similar theme (Samarasinghe & Strickert, 2013; Gray et al., 2014; Mehryar et al., 2017). In doing so, the new weights attached to the upper-level category were achieved by adding the total weights of the concepts making that particular upper-level category (Samarasinghe & Strickert, 2013). For example, concepts ‘housing conditions,’ ‘mold,’ and ‘home damage’ frequently appeared in the FCMs. Hence, they were combined to create a new variable called ‘housing damage’. The weights from the three concepts were then added to attain a cumulative weight for variable ‘housing damage.’ In addition to common concepts in original

FCMs, I also analyzed group discussions to interpret and describe upper-level variables (see Appendix C & D). Several rounds of condensation were done to ensure that interpretation from original maps was preserved. Condensation process makes it easier to analyze FCM structure, especially when there are multiple FCMs available (Gray et al., 2014). Combining multiple FCMs with too many concepts and connections can result in complex, difficult to interpret maps (Mehryar et al., 2017). The condensed individual FCMs were then aggregated into a total social group FCM (TSGFCM) (Özesmi & Özesmi, 2004). This was done to compare the structure of different FCMs (i.e., original, condensed, and total) and to use for scenario simulations. Additionally, TSGFCMs provide a better representation of collective or social knowledge (Özesmi & Özesmi, 2004; Samarasinghe & Strickert, 2013; Solana-Gutiérrez et al., 2017).

Graph theory indices allow structural analysis and comparison of FCMs. For this, FCMs are first coded into adjacency matrices. Then the indices such as density, complexity, and variables types are evaluated. Structural density indicates the degree of connectivity in the map or in other words, how sparse (low density) or connected (high density) the maps are (Özesmi & Özesmi, 2004). Variable types, transmitter (driver or forcing variables), receiver (state or utility variables) and ordinary (or hereafter referred to as neutral) variables were evaluated using the ratio of outdegree to indegree since the variable types are the function of outdegree and indegree (Özesmi & Özesmi, 2003; Strickert et al., 2010). Outdegree represents the total connections going out of a concept (i.e., row sum of absolute values of a variable) and indegree represents the total connection coming into the concept (i.e., column sum of absolute values of a variable) (Strickert et al., 2010). The threshold ratio set for the variable types as decided by participants and the researcher were: for transmitter variables greater than 1.3, for receiver variables less than 0.75 and between 0.75-1.3 for the neutral variables. Using the threshold ratio instead of assuming zero indegrees or outdegrees helped in better representation variable types (Strickert, 2011). Complexity was then calculated using the ratio of the receiver to transmitter variables (R/T).

For simulation purposes, the condensed upper-level variables were further clamped to four distinct themes. The four themes were developed subjectively based on the interpretation of the condensed variables. They were then validated against the workshop dialogues and also with DRR relevant literature (Strickert et al., 2010; Haase, 2013; Chandra & Gaganis, 2016; Giordano et al., 2017). Each condensed variable in the high-level theme was clamped at a high activation level during the simulation (described in section 3.4.2). For example, simulation for “flood damages" involved clamping five condensed themes 'housing damages', 'health concerns', 'impact on shoreline', 'road damages', and 'wildlife and natural resources', at 1 and leaving others as status quo (i.e., 0). Questions regarding the calibration of the model may arise in FCM simulations. It is, however, important to note that the FCM model is a representation of a person's perception of a problem, it cannot be validated against the 'accepted truths' or quantitative data (Mehryar et al., 2017). Moreover, *"…[people] may draw cognitive maps that emphasize different parts of a system based on their experiences, which need not imply that some maps are wrong or less representative than others….They are qualitative models that do not yield outputs directly measurable in nature"* (Özesmi & Özesmi, 2004, p. 57).

All FCM structural and scenario analysis was done using the R package 'FCMapper' (Turney & Bachhofer, 2016). The audio-recordings from the workshop activities were transcribed to validate the quantitative changes in FCMs, including scenario outcomes. Using the quantitative and qualitative analysis of FCM, social learning was then evaluated (Table 3.2).

Table 3.2 Social learning analytical framework adapted to the study context (adapted from Scholz et al., 2014)

Requirements for social learning	**Type of learning**	**Key indicator**	**Analysis**
1. Change in understanding on the part of individuals involved	a) single-loop learning b) double-loop learning	a) Change in mental models (conceptual changes) b) Increased similarity between mental models	<u>Quantitative Analysis</u> New concepts and relationships added or removed (# of concepts and connections at different points) Similarity coefficient -most mentioned variables -most central variables
2. Change in understanding occurs through social interaction	Single-, double-learning	New concepts emerging in personal FCM or concepts removed	<u>Qualitative Analysis</u> Change in the concepts in individuals maps corroborated by group discussion and related activities
3. Change in understanding goes beyond individuals and takes hold within-group or community	Double-loop learning (developing shared understanding)	Scenario simulations Social learning outcomes	Develop a shared understanding of the situation (shared social knowledge) Social-relational outcome: Increased understanding of the issue/awareness Developing a sense of community

3.7 Results and analysis

3.7.1 Participatory workshop and Participants

The total number of participants from the workshop was 10, including nine community members (see section 2.4.3 in Chapter 2) and an advisor (assistant professor). The sample size turned out lower than expected. Some managers and officers who had confirmed their participation initially had to prioritize their attention to dealing with infrastructural issues in the community at that time. Understandably, because of the limited resources in small communities many times, people's hands are full because they often have multiple roles in their community (Hanrahan & Dosu, 2017). Nevertheless, I wanted to report it here because this also highlights one of the challenges of doing community-engaged research.

At the end of the workshop, I gathered nine FCMs from 10 participants (an Elder requested to do the map with another participant). Due to already small sample size, any FCM that was completed for more than one phase was considered for analysis. Of nine FCMs, two completed only the first two phases, but they were still considered for analysis with the assumption that no learning was acquired after that. Therefore, the findings from this study should be interpreted and used with caution, given that this research was exploratory. Yet, the small sample size is often favorable in participatory processes (Garmendia & Stagl, 2010; Scholz et al., 2014). Newig et al. (2010), for example, recommended 8—15 as an ideal size for learning-based processes because large group sizes can often hamper the learning process.

3.7.2 FCM analysis and outcome

The nine original FCMs consisted of a total of 137 concepts and 201 connections. The condensation process generated 25 condensed themes (Appendix D). The 25 themes were mostly derived from the interpretation of all the 137 concepts in original FCMs but also based on the theme's relevance to the Mistawasis (Özesmi, 2006). Graph theory indices helped analyze and compare the structural properties of original, condensed, and total social groups FCMs (Table 3.3). The purpose of comparing the structural metrics of the FCMs was to demonstrate how certain indices are increased or reduced during condensation and aggregation processes. For example, the average number of concepts in the original individual FCMs was 15.22±9.18, which was reduced to 10.56±4.30 in the condensed maps. Similarly, variables types (i.e., transmitter, receiver, and neutral) were also reduced in the condensed maps, although there was not much difference in neutral variables. Interestingly, there was a slight increase in the density and connections/concepts ratio in the condensed maps. The higher density in the map suggests more connectedness on the map. The complexity in the condensed map decreased (statistically insignificant) as the number of receiver variables decreased in the condensed maps.

The total social group FCM represents the collective knowledge of the participants. Overall, the structural metrics in the TSGFCM was higher compared to the original individual and condensed FCMs except for the complexity, which was reduced because of an increase in the transmitter variables in the FCM.

Table 3.3 Comparison of structural metrics of individual original FCMs, condensed FCMs, and TSGFCM

Structural Metric	**Individual Original FCM**	**Individual Condensed FCM**	**TSGCM**
Number of maps	9	9	1
Number of connections	27.57±12.62	19±9.99	133
Connection density	0.13±0.07	0.18±0.06	0.21
Number of concepts	17.29±9.46	10.56±4.30	25
Number of transmitters	6.33±4.15	4.44±2.19	12
Number of receivers	7.33±4.21	4.56±2.07	7
Number of neutrals	1.56±2.24	1.56±0.88	6
Connections/concepts	1.55±0.50	1.75±0.52	5.32
Complexity (R/T)	1.27±0.44	1.11±0.42	0.58

3.7.3 Evidence of Social Learning

<u>Requirement 1a: Change in mental models (conceptual changes)</u>

Evidence of change in mental models was derived from comparing the average changes in concepts and connections in four phases of FCMs (Figure 3.5). The average number of concepts and connections in the initial FCM was 9.33 ± 3.00 and 11.11 ± 5.44, respectively. Following the second phase, the average number of concepts and connections in the FCMs was 11.67 ± 5.05 and 16.11 ± 8.21, respectively. After the third phase, the average number of concepts and connections accumulated at 14.43 ± 8.00 and 22.00 ± 9.18, respectively. The final phase FCM yielded an average of 17.29 ± 9.46 concepts and 27.57 ± 12.62 connections.

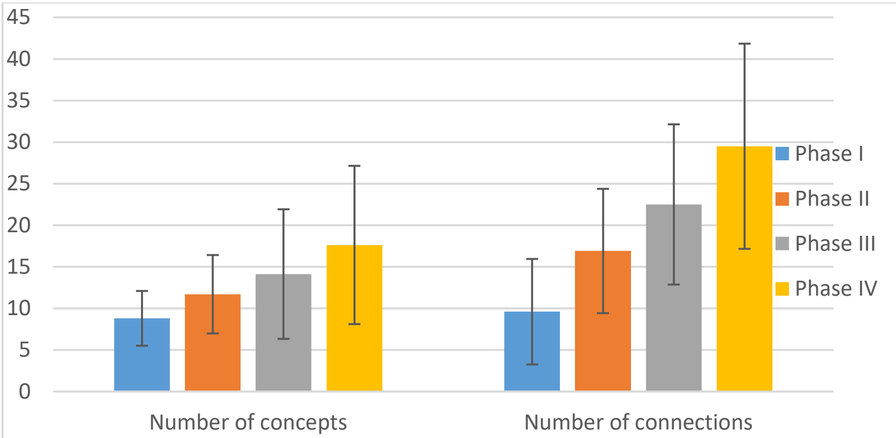


Figure 3.5 Average changes in the number of concepts and connections in the original individual FCMs

In addition to the increase in concepts and connections, the description of concepts also shifted in some FCMs. For example, the two FCMs developed by the health care workers initially described flood risk at a household scale with concepts such as 'gather family,' 'safety of family' and 'preventing basement flooding' in their FCMs. The concepts shifted towards the broader community at each phase with the emergence of concepts such as 'being aware and knowledgeable of floods,' 'preparedness for future event,' 'communications, 'being informed and updated,' and 'muster stations.' In participatory processes when existing knowledge and understanding often fail to explain the issue, individuals may reorganize their previously held concepts and introduce new concepts that are more detailed and describe the problem being discussed (Biggs et al., 2011; Jones et al., 2011; Scholz et al., 2014; Moon et al., 2019).

Requirement 1b: Increased similarity between mental models

The increased similarity between mental models was evaluated using the similarity coefficient (i.e., most mentioned variables and centrality) (Özesmi & Özesmi, 2004). The first and final phase condensed FCMs were used to analyze the increasing similarity of understanding. Figures 3.6 and 3.7 unpack the 25 condensed variables. Each condensed variable (represented by a bar) is made of participants and the number of concepts in their maps that were combined to create the variable. For example, in Figure 3.6, the variable 'housing damage' was created by combining six concepts from six participants, with each stack representing a participant (e.g., P3 had one concept that represented housing damage, and P5 had one and so on).

Comparing the most mentioned variables pre and post-workshop highlighted two things: i) the most important variable for participants, and ii) the significance of how the variables changed throughout the workshop. For instance, in the first phase FCM (Figure 3.6), the top three most mentioned variables were ‘survival needs,’ ‘land-use activities in flood-prone areas’ and ‘housing damages.’ In terms of the number of individuals that contributed concepts to the condensed variables, ‘housing damages’ was the most mentioned variable, with six participants followed by ‘land-use activities in flood-prone areas’ and ‘survival needs’ with five participants each. In the final phase FCM (Figure 3.7), the top three most mentioned variables were ‘cooperation and coordination,’ ‘feeling of safety’ and ‘health concerns.’ However, in terms of how many people had mentioned the concepts similar to the variables, ‘cooperation and coordination,’ ‘emergency planning,’ ‘flood protection from control structures’, and ‘housing damages’ were the most mentioned variables (i.e., six participants had these variables in their FCMs). Individuals also saw the role of ‘wetlands and lakes’ to be an important part of flooding in the final phase. Compared to the first phase FCMs, the variables on the right corner of the x-axis appeared more in the final phase FCMs. The variables in the right corner represented requirements for long-term planning (see Table 3.5). This indicated there was a shift in the FCMs from initially representing a perceived risk to preparedness actions at the end. At the same time, it also showed increased similarity in understanding between individuals that there is a need to be prepared for future extreme events. These emergent changes in FCMs were the result of discussions that happened during the activities.

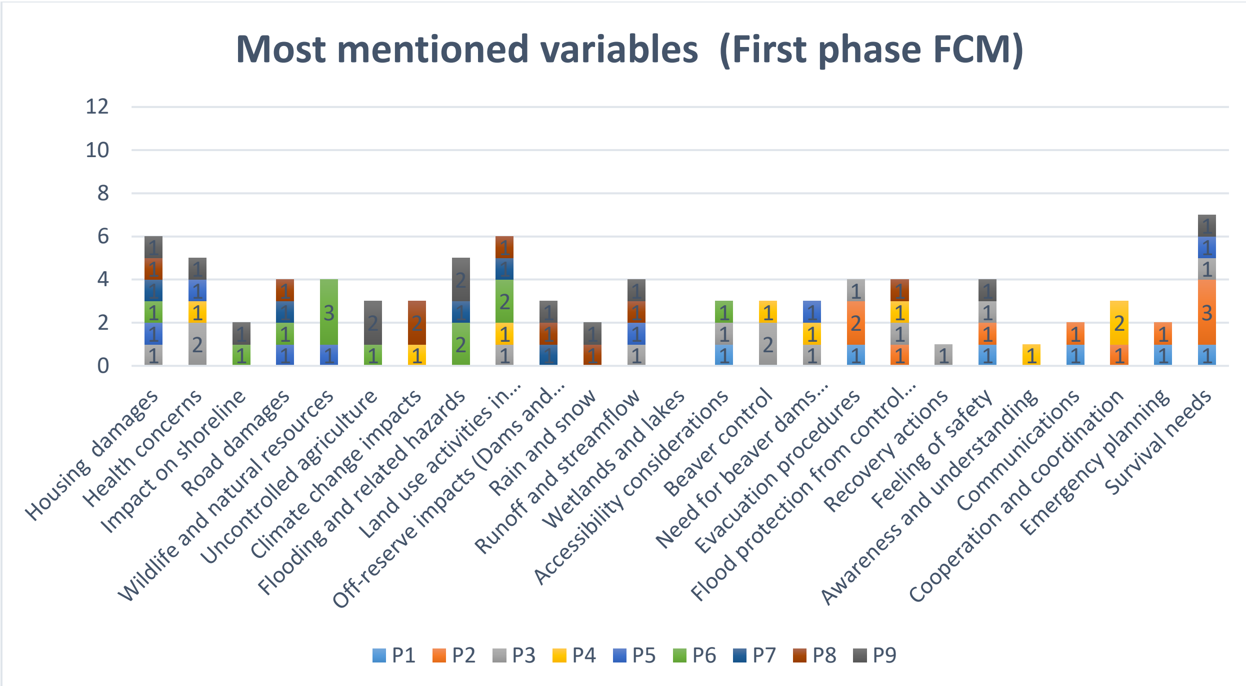


Figure 3.6 Most frequently mentioned variables in the first phase condensed FCM. The color of the bars represents participants, and the numbers in the bars represent the number of concepts in their original FCM that were similar to the corresponding condensed variable.

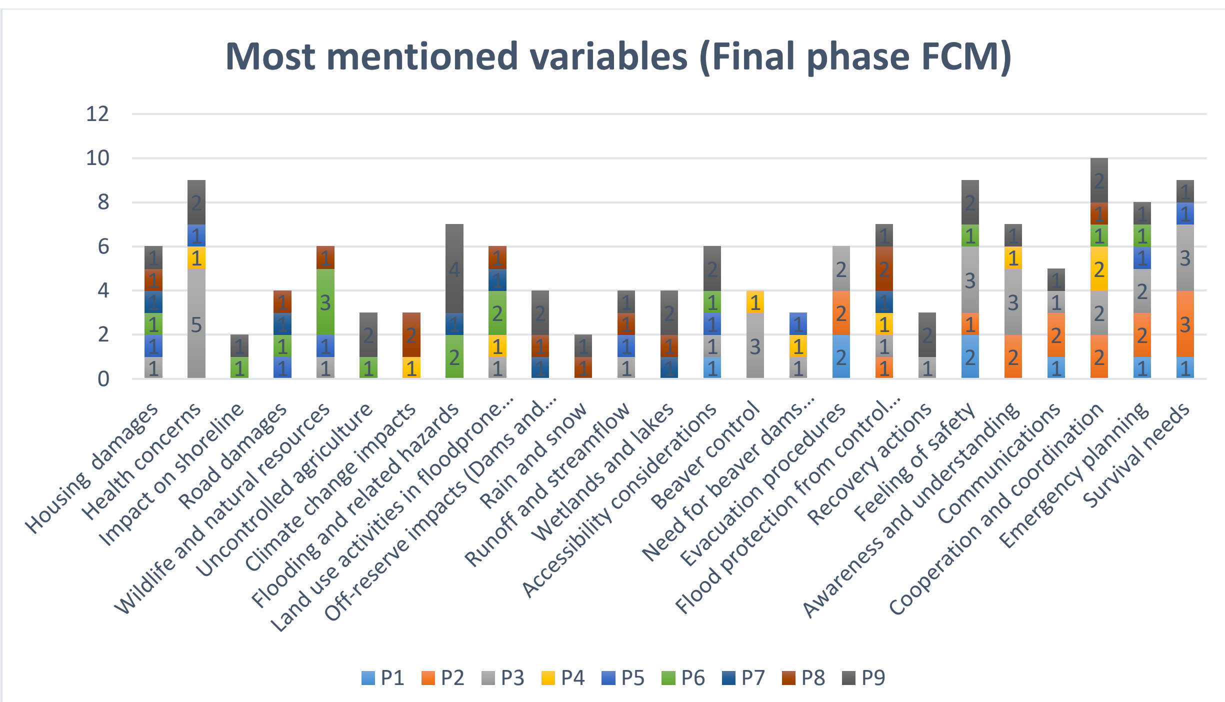


Figure 3.7 Most frequently mentioned variables in the final phase condensed FCM

Requirement 2: Change in understanding occurs through social interaction

Concepts that were added in the FCMs after each phase (i.e., workshop activity) were verified against the transcripts from discussions. The results are summarized in Table 3.4 below.

Table 3.4 Summary of discussions and key concepts in FCMs following the discussions

Workshop Activity	Emergent discussions	Key concepts in FCM after activity
Group discussion + participatory mapping	"Tempers would fly. We would be [saying] "what the hell do we do," it's not "what do we do." It's "what the hell, look at this! What now? Phone Indian Affairs, phone somebody! Oh, it was stressful." (P4, Band council and former chief) "We're still pretty much unprepared…although we do have all these factors [culverts] to mitigate it, but if it was to happen again we don't have the emergency response plan so if any of these things fail and we do get a flooding again there's no plan for it." (P6, Lands technician officer) "Yeah, us people on the east side of the main road we don't have to worry. We are 4-5 feet above the creek level" (P7, Public affairs)	'stress' 'anxiety for future flooding' 'community anxiety' 'emergency preparedness' 'emergency plan' 'emergency planning never tested' 'control of water level' 'being aware and knowledgeable of floods'
Flood maps presentation	"doing an emergency response plan like redoing one or revisiting our old one and I'm wondering if we could include getting that LiDAR data, surrounding water basins included in them (P6, Lands technician officer)	'Mistawasis data' 'partnerships and alliances 'wetlands fill and spill'
Final group discussion	"…in preparedness plans or for insurance purposes, like this communication, the radio is seen as an asset in times of emergencies for insurance purposes" (P8, Special projects coordinator) "…you see it [flooding] on TV, and you just take it for granted: oh it's not gonna happen to us you know, in our community, and yeah it was all different today, just more awareness" (P2, Health care worker)	'communications' 'make use of radio as communication' 'muster stations' 'safe places' 'community support' 'being informed and updated'

Requirement 3: Change in understanding situates within-group (developing shared understanding)

For the third requirement, changes in TSGFCM was used as an indicator for assessing changes in understanding as a group because it represented the collective knowledge of the participants. Figure 3.8 shows differences in the centrality of variables between the first and final phase TSGFCM. Centrality measure gives an insight into how significant a variable is in terms of its influence on the structure of FCM (Özesmi & Özesmi, 2004). By comparing the centrality of variables for TSGFCM, we can see how the significance of variables changed as participants continued to learn about flooding in the community. The variables ‘emergency planning’ (also see Box 3.1), ‘awareness and understanding,’ and ‘cooperation and coordination’ showed a drastic increase in centrality from first to final phase TSGFCM. Similarly, the importance of environmental factors such as ‘wetlands and lakes,’ and ‘wildlife and natural resources’ also increased in the final phase.

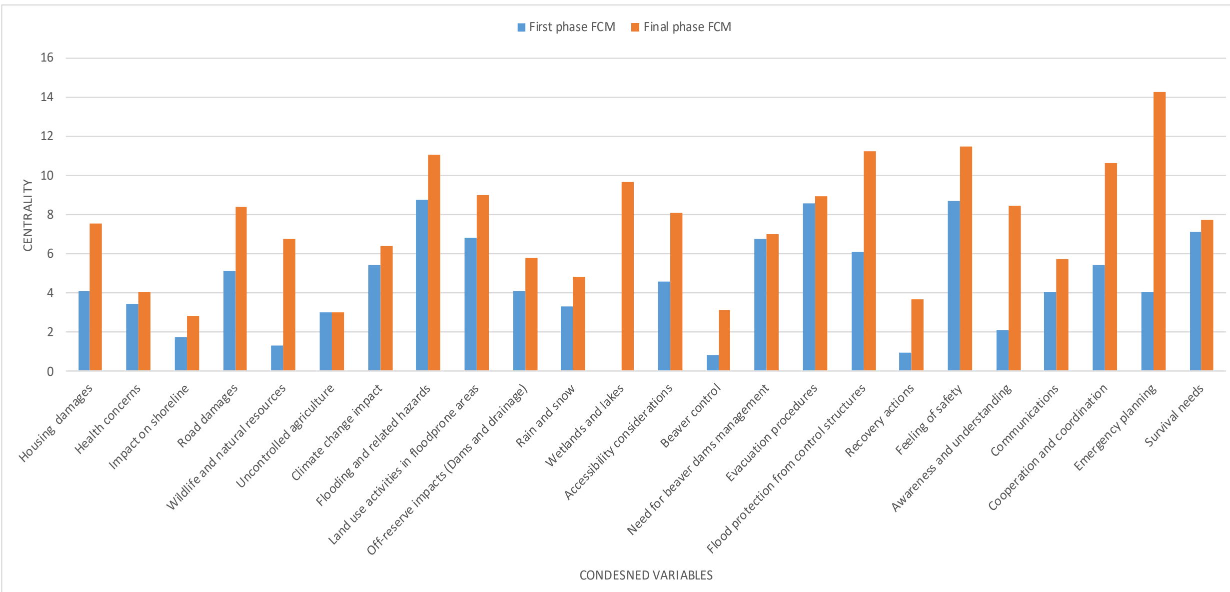


Figure 3.8 Centrality of condensed variables in the TSGFCM before and after the deliberative workshop activities

<u>*Scenario evaluation:*</u>

The four high-level themes in Table 3.5 were used to simulate four separate scenarios based on the collective or social knowledge represented by TSGFCM. Scenario A and B represented the worst-case scenario where the negative impacts of flooding and potential causes of flooding are at a high level. Scenario C and D examined the preparedness, where short-term coping abilities and long-term preparation are at a high level.

Table 3.5 High-level themes generated from the clustering of 25 condensed themes based on qualitative interpretation

Scenario	High-level theme	Description	Clamped concepts set at high activation level (1)
A	Flood damages	The immediate and long-term damages to the social, economic, and environmental well-being of the community.	Housing damages Health concerns Impact on shoreline Road damages Harm to wildlife and natural resources
B	Flood exposure	Factors that will increase the likelihood of flooding event to occur in the community and the hazards associated with it. These include both natural, physical factors as well as human drivers.	Uncontrolled agriculture Climate change Flood and related hazards Off-reserve impacts Land-use activities in vulnerable areas Rain and snow Runoff and streamflow Wetlands and lakes
C	Coping ability	Refers to the short-term responses or measures that will potentially help mitigate the harmful effects of flooding in the community.	Evacuation procedures Flood protection from control structures Beaver control Accessibility concerns Feeling of safety Recovery actions Need for beaver dams management
D	Preparation and response	Long-term preparedness measures that will likely strengthen local flood management strategies. It also includes the relative importance of having good communications and organization between different people and groups within the community as well as across other institutional bodies for flood preparedness.	Awareness and understanding Emergency planning Survival needs Communications Cooperation and coordination

Scenario A: increment of flood damages (see Appendix E)

An increase in the flood damages decreased flood protection from control structures, feeling of safety, and increased accessibility considerations. Group discussions helped shed light on why flood protection from existing control structures may not be effective. Like in 2011, structures may not be big enough for more extreme events in the future, *"the culverts weren't big enough to take all the water" (P4, Band councillor).* The decrease in the feeling of safety meant that when the flood damages are severe, community members felt less safe for themselves, their family, and their neighbors. Similarly, increment in flood damages increased the need for further recovery actions such as road maintenance or restoration of shorelines. Evacuation procedures such as boats to access dryland, evacuation during flooding also increased when the flooding damages such as road damages increased in the community. Increase in road damages also showed an increase in accessibility concerns, such as accessibility to community members, limited access, and roads to access parts of the community:

> *We were stuck in. Our road was impossible. (P4, Schoolteacher)*
>
> *So, if there's a flood, she wouldn't be able to come to work (PN 11, Elder)*

<u>Scenario B: increment of flood exposure (see Appendix F)</u>

When the flood exposure in the community increased flood damages increased as well. The increases in housing damages, road damages, health concerns, and impact on the shoreline are straightforward as they are likely to get worse with extreme flooding events. Similarly, an increase in recovery actions, need for beaver dam management, survival needs, evacuation procedures, accessibility considerations, cooperation, and coordination, and a decrease in the feeling of safety was observed in this scenario. The increase in wildlife and natural resources was, however, counterintuitive. The outcome supposed that increasing flood risk did not necessarily impact the ecological system, which included concepts such as 'bird's migration', 'fish quality', and 'wildlife safety'. This reflects the need for further clarification with the participants for the concepts and changes. Like in the previous scenario, flood protection from control structures also decreased. Some participants explained that current control structures might not handle extreme flood events or in many cases even make things worse with extreme failures (e.g., dam failures in Mississippi, USA, and Vajont, Italy):

> *…again, for future extreme events, that Band-Aid [culverts and drainage] will hold up to some degree, but if things are worse than what we've experienced in our lifetime, we need a bigger Band-Aid. And, we don't have a fix for that-100 year event for-even on another 50-year event (P8, special projects coordinator)*

Scenario C: increment of coping ability (short-term measures) (see Appendix G)

Scenario C examined the changes that occurred when the coping capacity of the community is at a high level. The most significant changes included a decrease in road damages, housing damages, impact on the shoreline, runoff and streamflow, land-use activities in flood-prone areas, and survival needs. It also increased awareness and understanding, cooperation and coordination, and emergency planning, which means that short-term measures for coping with flooding incidents resulted in the enhancement of long-term adaptation strategies. It was also interesting to see the enhancement of health concerns and flooding and related hazards (E.g., lakes and creek flooding, rivers and creek level, erosion, fire, etc.). While the direct cause and effect relationship between these variables is not apparent, having short-term measures perhaps still could not address the stress and anxiety for future flooding events as some FCMs and discussions did indicate being anxious when moving to shelter places or when being evacuated:

> *When 2014 fires happened, a lot of people ended up in Saskatoon, which can be quite a shock to people coming from a northern remote reserve. But the folks who went to Beardy's had a completely different experience, very positive experience of going to another community and being sort of held by that community, sharing recipes and sharing culture. (P9, advisor)*

> *But even as you say sometimes, that may not be great numbers, but it might be bringing two or three families as a whole unit here and take care of them because I know being evacuated to the cities quite often sometimes families are broken up and separated and go to different places. (P6, Lands Technician)*

Scenario D: increment of preparation and response (long-term measures) (see Appendix H)

Scenario D simulated the changes that occurred when the long-term preparation and response requirements of the community are high. Interestingly, increasing the long-term measures for flood preparedness increased the short-term coping ability of the community including evacuation procedures, feeling of safety (e.g., shelter places, muster stations, safety check), flood protection from control structures, accessibility considerations (e.g., roads to access parts of community, accessibility to community members, lands accessibility) and beaver control. The outcomes from this scenario also showed a decrease in road damages, housing damages, health concerns while enhancing wildlife and natural resources. The overall flood exposure was also reduced, for example, a decrease in the impact of runoff and streamflow, off-reserve impacts, climate change impacts and rain, and snow. The outcomes indicated better spatial planning through reduced land-use activities in flood-prone areas (e.g., building houses in risk areas, farming, and property damage). Overall, Scenario D performed the best in terms of showing how taking long-term measures to be prepared can result in reducing the flood damages, offsetting the impacts causing increased flood exposure, and taking necessary actions for increasing the short-term coping abilities of the community. It also reflects the collective and converging direction of learning among participants as they continued to learn the importance of preparedness in the workshop:

> *…opens my eyes to the importance of planning and being prepared. We need to do more in our preparation and in the studies and fill in all the blanks (P3, project coordinator).*

3.8 Discussion

3.8.1 Evidence for Social learning

There is a growing body of literature highlighting the significance of social learning in DRR (O'Brien et al., 2010; Henly-Shepard et al., 2015; Nguyen et al., 2016; De Kraker, 2017; Murti & Mathez-Stiefl, 2019). Empirical research on social learning, however, is still limited (Garmendia & Stagl, 2010; Ernst, 2019). Lack of standardized conceptualization of learning (Reed et al., 2010) and the methodological approach (Muro & Jeffrey, 2008, 2012) are often cited as the major causes of this limitation. Limited evidence on social learning hampers its operationalization despite its benefits (Beers et al., 2016). Drawing on social learning theories from multiple fields, I presented an FCM-based methodology to observe, measure, and describe the social learning process and outcomes. Social learning was evaluated by utilizing the concept of changes in mental models. Mental models can evolve through learning, and that was the basis for the analysis (Pahl-Wostl & Hare, 2004; Jones et al., 2011; Gray et al., 2014; Henly-Shepard et al., 2015; Aminpour et al., 2020). Then using the three requirements for social learning described by Reed et al. (2010), the overall evaluation of social learning was done.

<u>Requirement 1: Change in understanding on the part of individuals involved</u>

Changes in understanding were evaluated by comparing conceptual changes in individual FCMs across four phases. The results showed an increasing number of concepts and connections, indicating individuals acquired new information at each phase. Initial FCM developed by individuals at the beginning of the workshop demonstrated their perception of flood risks based on their prior experiences. At each phase, after that, individuals modified their FCMs by adding new concepts and connections. They absorbed information (assimilation) and integrated it into their prior understanding (accommodation) to create new knowledge or understanding (Posner et al., 1982; Scholz et al., 2014; Ernst, 2019). This process of acquiring information is also known as single-loop learning, or that the acquisition of new facts, skills, and knowledge has been confirmed by others (Webler et al., 1995; Schusler et al., 2003; Garmendia & Stagl, 2010; Bently Brymer et al., 2018). At each phase, individuals reflected on the information and experiences shared at the workshop and integrated it to improve their understanding of not just flood risk but also being prepared for flooding. This showed evidence of single-loop learning among individuals in the workshop (Reed et al., 2010; Henly-Shepard et al., 2015; Ernst, 2019). But how do we know the information acquired by individuals occurred through participation in the workshop, or how do people learn in a participatory context? Hence, to explore the second requirement of social learning, I analyzed discussion patterns using transcripts of the workshop to document changes in learning patterns.

Requirement 2: Change in understanding occurs through social interaction

The results revealed that changes in FCMs were related to the changes in communication patterns in the workshop. Our findings also align with others who have analyzed social learning based on communication patterns (Beers et al., 2016; Benson et al., 2016; Bentley Brymer et al., 2018). Interestingly, communications that provided more opportunities to share experiences enhanced social learning. For example, participatory mapping resulted in the most concepts and connections being added to the FCMs. Participatory mapping activities were also described as an effective means for social learning in other studies as they provided more opportunities for asking and answering questions and learning from one another (Bentley Brymer et al., 2018; Garćia-Nieto et al., 2019). The spatial map was a common communication tool for people to interact, deliberate, and reflect on experiences of others that was easier to visualize and translate into forming new knowledge (Garćia-Nieto et al., 2019). Verbal communication, such as sharing personal stories or experiences, plays a critical role in the refinement of mental models, and fosters social learning (Biggs et al., 2011). Experiential learning is observed when people connect to and reflect on the concrete experiences of others to integrate it to restructure their assumptions (Kolb, 1984; Didham, 2015). This process of reflecting and restructuring of one’s own assumptions leading to changes in the structure of the FCMs resulted in a new learning loop; that is, double-loop learning (Garmendia & Stagl, 2010; Henly-Shepard et al., 2015).

The mode and direction of communication can also influence social learning (Pahl-Wostl, 2002), although research on it has been limited (Beers et al., 2016). In this study, while group discussions resulted in the accumulation of more concepts in FCMs, the mono-directional presentation of empirically-produced flood maps by an expert only minimally changed the FCMs. Only three new concepts were found in the FCMs post-flood map engagement, out of which only one concept was directly related to the presentation, while the other two were related to relationships (e.g., partnerships and alliances). The FCMs showed that two-way communication enhanced learning while one-way communication impeded learning (Bently Brymer et al., 2018). A contributing factor may be the technical nature of the presentation that is unfamiliar or relevant to the type of audience present at the workshop (Garmendia & Stagl, 2010).

This finding highlights the importance of building models with stakeholders and rightsholders to ensure that the modeling process and outcomes are transparent, comprehensible, and relevant to their needs (Voinov et al., 2018). Finally, although not explicitly represented in the FCMs, social learning also occurred through informal discussions in the workshop (Box 3.1) (Beers et al., 2016; Garćia-Nieto et al., 2019).

<u>Requirement 3: Change in understanding are best situated within-groups for developing a shared understanding</u>

Changing the personal perception of a problem and developing shared understanding is frequently cited as a key outcome of social learning (Webler et al., 1995; Muro & Jeffrey, 2012; Scholz et al., 2014; Ernst, 2019). The final phase FCMs showed that individuals had accumulated several shared variables in their FCMs, indicating the converging direction of learning (shared social knowledge). In other words, they had sufficiently integrated the concepts discussed during the workshop to develop shared concepts (Scholz et al., 2014). In the context of DRR, a collective understanding of a problem can lead to joint actions such as building long-term goals and management plans (Steyaert et al., 2007; Henly-Shepard et al., 2015; Nguyen et al., 2016). As in this study, awareness and need for preparedness or emergency planning was something that was reflected in all the FCMs as well as in the dialogues at the workshop (see Box 3.1). The outcomes of this new shared social knowledge were also observed from the scenario simulations. Generally, the outcomes from the scenarios demonstrated the participants' desire to move away from the negative consequence of flooding to a preferred state (long-term preparedness requirements). The relationships were, however, not always direct and obvious.

Increasing the coping ability (i.e., by providing short-term measures), increased the health concerns. It seemed inconsistent with previous discussions that emphasized increasing the coping capacity of communities to reduce disaster risks (Berke, 1995; Smith, 2003; Hilhorst et al., 2013; Sinthumule & Mudau, 2019). Unpacking the themes underscoring coping abilities helped identify why there might be an increased health risk. The relationship between evacuation and health, if we look from the perspective of physical safety, should be a direct one (i.e., evacuating people from flood dangers should protect people from injuries). The discussions shed light on other health impacts associated with evacuation, such as increased stress and anxiety because of dislocation to a city or non-Indigenous communities based on what had happened with other First Nations. For example, the 2011 ‘superflood’ in Manitoba led to the displacement of more than 4000 First Nation peoples (Thompson, Ballard, & Martin, 2013). The Lake St. Martins First Nations was one of the permanently displaced communities and had expressed several novel health concerns; that is, emotional distress, worry, and anxiety were found to be profound and long-term (*ibid*, 2013). Research and knowledge on the mental health impacts of flooding in Indigenous communities are still somewhat limited (Berry et al., 2010; Ford et al., 2010; Thompson et al., 2013). Collecting and disseminating information regarding mental health issues would not only help provide appropriate health care to affected people and communities but also inform climate action policies (Hayes et al., 2019).

Although the scenario outcomes were not always apparent, the discussions from the workshop provided insights on why specific outcomes may have happened. Others have also previously indicated that the analysis of the simulation results should be interpreted qualitatively and should be used to continually refine the community model as they learn from past experiences, new knowledge, and information (Özesmi & Özesmi, 2004; Solana-Gutiérrez et al., 2017). The next step involves taking the results from the scenarios back to the community and reflecting on the outcomes. We expect that this further step can aid in not only validating the results but also extend social learning as they examine and reflect on the outcomes of each scenario (Henly-Shepard et al., 2015).

Box 3.1: From risk perception to risk preparedness: Unpacking emergent learning

It is often thought that social learning leads to ‘desired’ outcomes (Harrison & McIntosh, 1992; Pahl-Wostl, 2006). In contrast to this idea, some scholars emphasize learning that is ‘emergent’ (Beers et al., 2016). As such, it shifts or transforms the perception of a problem (Collins & Ison, 2009). This approach of social learning leads to an understanding of not just about a problem but also the context as a whole, which can result in innovative and alternative actions (Ernst, 2019). In this case, I consider proposed actions by the participants (‘action in discourse’) as opposed to real-world actions (Beers et al., 2016).

The first workshop activity, group discussion, involved exploring whether flooding in Mistawasis had changed over the years or not. One of the participants who was also the chief in 2011—12 quickly answered, *‘it sure has” (P5)*. She then started explaining the 2011 flooding and shortly few others began mapping it out on the community map. Interestingly, the mode of discussion at some point shifted from mitigation strategies community adopted in response to the 2011 flood to lack of planning for preparing for future extreme events. In the FCM, emergency planning was found to be the most important variable by the end of the workshop (Figure 16) even though it was not explicitly a unified opinion of the group. Looking closely at the transcript, initially, only one participant had shared his thought on planning *“…[if] we do get flooding again there's no plan for it” (P6)*. The combination of sharing 2011 flood event and viewpoint on the need for preparedness planning seemed to provide *“meaningful context for interaction, interpretation and integration”* (Jacobs & Coghlan, 2005 p. 118) of ideas that were readily accommodated by others (Figure 15 & 16) (Beers et al., 2016).

By the end of the discussion, participants’ conceptualization of flooding had already shifted towards preparedness actions. But not all transformations were captured by the FCMs. The conversations revealed more about participants’ thoughts about alternative actions than the FCMs, for example, one participant suggested, *“who would be the contact person to ask for help other than community members. We need to discuss that” (P11)* and although not explicit in the FCMs, everybody agreed that it was important to determine roles and responsibilities. Similarly, just looking at the changes in FCMs, learning was not explicit when it came to flood maps communication. But, the conversations suggested otherwise:

P8: …major events, the last one was 50 years ago in 56’ but that time period may become shorter…we may have flooding in 10-15 years-worst flooding!

P5: Yeah it’s very likely now that you see we’re sitting right in the middle of that water.

Feedback on flood maps also reflected on other alternative actions for planning, *“[thinking] about doing an emergency response plan, like redoing one or revisiting our old one, and I'm wondering if we could include that LiDAR data surrounding water basins included in them” (P6)*. Even ideas regarding data sharing policies were proposed as a future strategy, *“…connect this data [LiDAR] with the RM lands in between and that can be in some ways maybe a demonstration to the province: here's the potential benefit for it” (P8)*. At the end of the workshop, more people expressed that disasters like floods are uncertain, *“it [flooding] can happen anywhere at any time!” (P2)* but they also acknowledged the importance of being prepared *“the importance of community participation in emergency preparedness plan. Kind of gets me scared there is no plan in place” (P3)*. Emergency planning was never a ‘desired’ outcome of this process but something that emerged during conversations and quite a significant one. This research demonstrated how social learning is a discursive process and relevant to DRR in terms of anticipating, mitigating and preparing for extreme events (Folke et al., 2005; O’Brien et al., 2010; De Kraker, 2017).

3.8.2 Comments on the methodological approach

FCM was found to be a useful tool for collecting mental models and tracking changes in them and visualizing outcomes of these changes. Participants expressed on the feedback form that FCM helped them connect their ideas and thoughts, and piece together the information they initially missed. The reflections from the participants highlight the strengths of FCM as a bottom-up, participatory method. Alternatively, FCM can also be used to prepare lay experts to communicate complex model information by giving them the power to analyze what they already know vs. what is unknown (‘hidden problems’) (Mehryar et al., 2017). In this case, LiDAR-based flood maps showed the community’s geographical vulnerability to flooding, which they related to their understanding and experiences. As a result, the workshop generated enough interest in collecting LiDAR of the entire watershed for detailed and accurate flood mapping (Thapa et al., 2019).

There are, however, some methodological limitations of FCMs. Qualitative condensation can lead to loss of detail from the original maps as the number of concepts is reduced in the process. The outcome of the process, ‘lossy-consensus’ (Özesmi & Özesmi, 2004), results in ‘outlier’ concepts that are either disregarded or considered insignificant (Mehryar et al., 2017). Part of this problem is that there is no standardized method for condensation (Gray et al., 2014). Over the years, new methods are being proposed for making condensation a more credible and less subjective process (Strickert et al., 2010; Obiedat & Samarasinghe, 2016; van Vliet et al., 2017) however, these require rigorous technical knowledge. The mixed-methods approach can be an alternative way to offset some of these challenges of condensation (e.g., FCM and group discussions).

3.8.3 Limitations and Future direction

Besides a small number of participants, some left in the middle of the workshop, and others experienced fatigue. Hence, only those participants who can commit to the entire process should be selected or supports such as scribes, and more breaks could be provided. To provide some relief to the participants, if the workshop becomes too long, either cutting down the workshop activities or scheduling the work over a number of days could be considered.

It is important to note that this was exploratory work intended not to draw conclusions but to provide an innovative approach to conceptualizing social learning (Beers et al., 2016). The study also contributes to the on-going methodological advancements in social learning research (Muro & Jeffrey, 2008; Garmendia & Stagl, 2010; Ernst, 2019). While the analysis of social learning involved reflecting on multi-loop learning, this study was only able to provide evidence of single- and double-loop learning. Whether triple-loop learning was achieved or not would require follow-up with the community over more extended periods (longitudinal assessment) (Beers et al., 2016). Moreover, evaluation of triple-loop learning is based on changes in paradigms, policies, or practices (Pahl-Wostl et al., 2013). It is, however, methodologically challenging to illustrate the relationship between learning and changes in paradigms (Ernst, 2019). Nevertheless, the fact that Mistawasis now has a draft emergency plan and wants to make it relevant to the community's realities as well as test the plan shows shifting perceptions or triple-loop learning (Biggs et al., 2011). The shift in community's reliance on just the structural responses to more long-term planning and behavioral responses also acknowledges the 'wicked' nature of disasters; that, there is no one 'optimal' solution rather complementary actions for dealing with them (McEntire, 2007; Thompson, 2011; Ison et al., 2013).

3.9 Conclusion

The growing importance of social learning in disaster risk reduction (DRR) is frequently highlighted in the literature, but empirical research on social learning is still limited, primarily due to methodological challenges. This study presented an FCM-based methodology to provide evidence on overcoming some of the issues related to the social learning process raised by scholars in the past (Muro & Jeffrey, 2008; Reed et al., 2010). In light of this study:

i. Social learning was observed in a participatory setting,
ii. Participatory processes helped in developing shared understanding (shared social knowledge) among individuals. Interestingly, discursive interactions were found to influence social learning,
iii. Sharing personal experiences fostered social learning, highlighting the significance of having two-way communication as opposed to one-way,
iv. FCM helped unpack the social learning process, however, it is best to complement it with other qualitative methods to clarify the underlying reasons for quantitative changes in FCMs.

Social learning requires a diversity of perspectives to develop innovative and long-term solutions for DRR. The solutions, however, should not be imposed as optimal solutions instead be updated over time as new information becomes available or new challenges are encountered. The collective FCM from this study can provide that starting point for representing current social knowledge that can be updated over time, as more people are included in the dialogue.

CHAPTER FOUR: OVERALL DISCUSSION AND CONCLUSIONS

4.0 Introduction

The growing urgency of climate change is putting pressure on established science; that is, a single 'dominant' knowledge framework is no longer sufficient to support locally-based disaster risk reduction (DRR). Instead, alternative approaches are needed for blending different forms of knowledge to foster social learning, create new understandings, and find new ways to deal with the impending crisis (Hewitt, 1983; Garmendia & Stagl, 2010; O'Brien et al., 2010; Hilhorst et al., 2013; Dintwa et al., 2019). In this study, I presented a participatory research approach to integrating the preferences of a First Nation community in flood risk mapping. The approach consisted of collecting spatial and human perceptions of flood risks in the community. Within this context of collecting and sharing knowledge and experiences, an emergent but the necessary objective was to develop a methodological approach to evaluate social learning. This final chapter discusses key insights related to each of the research objectives. I also comment on the methodological contributions and their practical implications for the current DRR scholarship. Lastly, I provide concluding remarks and outline future works as a continuation of this research.

<u>Objective #1: Integrate community inputs into spatial data and modeling process to create locally relevant flood extent maps</u>

Key learning: WDPM can provide an alternative approach for flood mapping in small Indigenous communities in the Prairies

For the first objective, spatial data and modeling techniques (i.e., LiDAR and WDPM), were used to create flood extent maps for Mistawasis. Flood mapping in the Prairies is complex. On the one hand, diagnostic tools such as WDPM can provide quick initial overviews of potential flood extents (Armstrong et al., 2013). On the other end, community feedback is needed for not only validating the flood maps but also for guiding future modeling works (Butler & Adamowski, 2015; Doong et al., 2016; Voinov et al., 2018). Within the first objective, I wanted to explore two critical questions in extending community-engaged scholarship in flood modeling and mapping *i) are these tools beneficial to help address community flood concerns, and ii) are these tools flexible enough to engage the community in creating locally relevant flood information* The key findings are summarized in Table 4.1.

Table 4.1 Summary of key findings related to objective one

Key Questions	Key findings
i) Are modeling tools beneficial to help address community flood concerns?	Based on the questionnaires and discussion, people found the information valuable for identifying and addressing flood concerns. Some participants also thought that having such flood maps helped them visualize potentially flooded areas in different parts of the community.
ii) Are the modeling tools flexible enough to engage the community in creating locally relevant flood information	Engagement in otherwise 'top-down' modeling process was established since the initial process, from data co-collection, determining runoff scenarios to co-validating model-derived flood maps. Keeping the modeling process transparent, a key criterion for participation in modeling studies was ensured through communicating modeling limitations.

The model, WDPM, was flexible to a certain extent that it provided community described scenarios to be tested (e.g., minimal to extreme runoff events). Similarly, the outputs could also be validated against community members' experiences and their value in flood risk reduction in the community. But is it flexible enough for the community to use it in the future? While WDPM in itself is simple to use, the data preprocessing and manipulating, and extracting outputs from WDPM require much more technical rigor. Furthermore, unlike other participatory modeling tools (e.g., participatory GIS and system dynamics model), WDPM was neither built with the community nor could it be manipulated as a community's interests (Voinov et al., 2018). Hence, in that sense, WDPM was only flexible and allowed community's involvement in selective steps.

Finally, because of the value given to the objective and factual knowledge over subjective perceptions, when it comes to learning, (Pahl-Wostl, 2002; Paton, 2003; Cook & Overpeck, 2018) I used the information produced for objective one to evaluate social learning using a novel FCM-based methodology.

<u>Objective #2: Explore to what extent social learning is influenced by participatory processes including communicating scientific knowledge</u>

Key insight: emergent discussions (learning) can transform perceptions and actions rather than the idea of learning as a deliberate process to achieve desired outcomes

The theoretical notion of social learning is a critical outcome of the participatory process, but there is limited empirical evidence to support it (Reed et al., 2010; Muro & Jeffrey, 2012;

Ernst, 2019). This provided the basis for my second objective. Moreover, because I was going to share the model-derived flood maps with the community, I used it as a context for evaluating social learning in a participatory setting. In particular, I focused on three critical concerns raised by scholars in the past: *i) no clear evidence of social learning as an outcome of a participatory process, ii) what processes foster or inhibit social learning, and iii) what are the outcomes of social learning?* The key findings for each of the question are summarized in Table 4.2 below:

Table 4.4 Summary of key findings related to objective two

Key questions	Key findings
i) no clear evidence of social learning in participatory processes	Social learning was observed in the workshop. This was evident in three ways. First, there was an overall increase in understanding of the flood risk concerns among individuals in their community. Second, change in this understanding was related to the changes in communication patterns in the workshop, which meant learning was facilitated by social processes (i.e., communication, interaction). Third, there was a shift in perception of flood risk at different scales and the development of shared understanding among individuals.
ii) what processes foster or inhibit learning (source of learning)	The mode and direction of communication can foster or inhibit social learning. Sharing direct experiences and having a visual aid (e.g., participatory mapping) for describing the experiences facilitated two-way communication and hence, fostered social learning.
iii) what are the outcomes of learning	Both relational (i.e., developing a sense of community) and cognitive (i.e., increased awareness, reflecting in others views and developing common views) changes in thought patterns (Muro & Jeffrey, 2012) were observed as key outcomes of social learning. But an unanticipated emergent outcome was the notion of disaster planning for both risk reduction *and* long-term preparedness. Emergency planning was never put across as a 'desired outcome' of the research but something that emerged during conversations and had quite a significant impact on people's conceptualization of risk. This emphasizes social learning as a natural and discursive outcome of participatory processes rather than a desired one.

O'Brien et al. (2010) purport that the function of social learning in the context of DRR will have three critical roles, i) give significance to all knowledge types, ii) recognize that the future may be different than perceived, and iii) learn to do things differently (shift in practices). Findings from this research support these roles (practical implications described in Box 4.1). First, this research used western and Indigenous knowledge to co-create complementary flood information with continuous community engagement. In the process of co-creating the information, community members acknowledged and anticipated that things might be different in the future:

P8: …major events, the last one was 50 years ago in 56' but that time period may become shorter…we may have flooding in 10-15 years-worst flooding!
P4: Yeah, it's very likely now that you see we're sitting right in the middle of that water.
P2: It [flooding] can happen anywhere at any time!

At the same, they expressed alternative actions or approaches to face the unknowns:

P6: [thinking] about doing an emergency response plan, like redoing one or revisiting our old one, and I'm wondering if we could include that LiDAR data surrounding water basins included in them.

P3: opens my eyes to the importance of planning and being prepared. We need to do more in our preparation and in the studies and fill in all the blanks.

This iterative and reflexive learning process will be important for bringing transformative changes in how we approach DRR research and practice (Cornwall & Jewkes, 1995; Walker et al., 2002; Pahl-Wostl et al., 2007; Akamani, 2016; De Kraker, 2017). In this research, I evaluated social learning in an immediate time scale, gathering data on learning that occurred among individuals who were directly engaged in the participatory process (Didham et al., 2015). But I also reflect on how this learning shifted from the workshop to the community level in terms of developing an emergency plan (see Box 4.1) and building collective knowledge for future actions. Hence, I was able to demonstrate learning over longer time scales (*ibid*, 2015). In the next section, I discuss how the method used in this study can be beneficial, in particular for collective knowledge generation and preserving that social memory.

Box 4.1: Moving forward: Mapping the community's DRR initiative

The flood of 2011 has been a significant event in terms of shaping flood risk reduction initiatives in Mistawasis Nêhiyawak. Structural measures (e.g., culverts) were an immediate response and reaction to mitigate 2011 flood impacts. 'Band-aids' such as structural measures are often the preferred approach when it comes to DRR (single-loop learning) (Biggs et al., 2011; McPhillips et al., 2018). Previous studies have shown that changes in flood management practices are an evolutionary process; one quite often triggered by severe flood incidents (O'Brien et al., 2010; Pahl-Wostl et al., 2013). While the immediate response to severe disasters leads to short-term recovery and coping abilities, they also provide opportunities for reflection and learning over time to reformulate alternative strategies (O'Brien et al., 2010; Pahl-Wostl et al., 2013; Henly-Shepard et al., 2015).

Since 2011, Mistawasis has been working on strengthening their flood resilience through actions such as expanding their drainage studies, LiDAR surveying, and installing bigger culverts. This shows the community's commitment and initiatives to be self-sufficient when it comes to managing disasters. However, it is also true that the future scale and severity of disasters such as floods remain primarily unknown and some of the reactive measures maybe 'stretched to breaking point' in extreme cases (O'Brien et al., 2010). This was something that was put forward by some of the participants in the workshop. While few people expressed the importance of planning, earlier in the workshop, it resonated with other's beliefs too. By the end of the workshop, everyone acknowledged the importance of pre-disaster planning (not just floods but also fire and power outage). Many scholars have previously emphasized the role of disaster planning at a community level for enhancing ownership (Cornwall & Jewkes, 1995; Kelman et al., 2011; Sinthumule & Mudau, 2019) and strengthening resilience (O'Brien et al., 2010; Stewart & Rashid, 2011; Murti & Mathez-Stiefel, 2019). This shift in understanding or awareness on the issue in itself demonstrated new learning in the workshop; that is, double-loop learning (Biggs et al., 2011; Muro & Jeffrey, 2012).

Following the workshop, the community actively pushed forward the idea of redoing their earlier emergency plan (from 2011). They worked with the Saskatoon Tribal Council (STC) to create a draft of the community emergency management plan. In the meeting we had with the local lands committee in November 2019, it was decided to customize the draft plan to make it relevant to the community's needs and preferences. Some of the things that came about in the meeting were based on the findings from this study for example, to have clear outline of roles and responsibilities in the plan and test it. This is a transition in risk reduction policy at the community level and demonstrates triple-loop learning (Pahl-Wostl, 2013). It can be hard to illustrate the relationship between triple-loop learning and changes in paradigms (Ernst, 2019). However, I see this as an important step towards a transformative change (Figure 4.2) in DRR.

4.1 Methodological summary: Diversity for change

DRR has been particularly distinguished and simplified into two dominant paradigms. The 'behavioral/hazard' paradigm was driven by the dominant scientific knowledge (White, 1945; Gaillard & Mercer, 2012; Gall et al., 2015), referred to as the 'physicalist' paradigm (Hewitt, 1983). On the other end, the 'vulnerability' paradigm advocated for more context-based, inclusive and bottom-up approach to risk reduction (Hewitt, 1983; Gaillard & Mercer, 2012; Jackson et al., 2017). It can be argued that the hazard paradigm continues to dominate the current disaster scholarship and practices (Jackson et al., 2017). It is also true, however, that such a dichotomy of knowledge paradigms hinders translating the 'knowledge to action' (Gaillard & Mercer, 2012). Jackson et al. (2017) write, *"Simplifying disaster studies into this dichotomy, however, runs the risk of oversimplifying a complex set of literature and concepts"* (p. 358). Hence, dealing with the complexity of disasters needs not only changes in perceptions of how we respond to them but also modifications in how we initiate those changes. This research explored an emergent and integrated methodological approach to initiate the changes in applied DRR scholarship. Using multiple methods from different disciplinary approaches, this thesis showed the value added by each method to enhancing and capturing social learning in DRR. The rationale for using a mixed-methods approach was expansion (i.e., using different but complementary methods for inquiry), triangulation (i.e., for convergence and corroboration of results) (Greene et al., 1989), and blending a diversity of views to break the dichotomy of knowledge (Bryman, 2006; Schoonenboom & Johnson, 2017).

The three purposes of mixing methods existed throughout the thesis, in no particular order. For example, spatial data (LiDAR) and modeling approach (WDPM) was used to create a flood extent map to provide insights into spatial characteristics of flooding such as inundation area, vulnerable sites in the community. As such, the modeling tool served to explore spatial aspects of flood risk (expansion purpose). Flood maps are commonly used tools in disciplines such as hydrology and geography; hence, in the production of flood maps, I use the perspectives and theoretical foundations from physical sciences (diversity of view purpose). However, the modeling tool and outputs did not capture the 'experiences, perspectives, and histories' of community members (Ritchie & Lewis, 2003, p. 3). Therefore, social sciences methods such as fuzzy cognitive mapping (FCM) were used to explore participants' perceptions and ways of thinking about flood risks (expansion, triangulation, and diversity of view purposes). Although

FCM provides a systematic method to collect and share viewpoints, it does not offer rich qualitative insights. Therefore, I used and analyzed group discussions in workshops to qualitatively interpret the quantitative results from the FCMs (triangulation), referred to as ‘putting meat on the bones’ (Bryman, 2006; Schoonenboom & Johnson, 2017). Through all of this process, each of the methods served to enhance and measure social learning for improving disaster risk reduction, resilience, and adaptation.

In terms of participatory methods, FCM provided a bottom-up approach that engendered greater participation and transparency compared to the LiDAR-WDPM produced outputs. This is not to say one method is better than the other because both WDPM and FCM had their strengths and limitations. But the point here is that for a complex problem, no one tool, method, or solution will suffice. Instead, it is important to acknowledge that we need multiple tools and knowledge systems to incorporate different perspectives for dealing with complex issues (Strickert, 2011). As physical, human, societal, and ecological factors continue to become more intertwined, there is a need for an integrated approach in which tools from different disciplines can be integrated into one framework to provide holistic and sustainable solutions (Gall et al., 2015). While it is crucial to develop new tools and technologies and optimize models to produce a better understanding of the physical system (single-loop learning), it is also equally important that such tools and models to be co-created with stakeholders, rightsholders and community partners that integrate their values, beliefs, and knowledge (double-loop learning). This will require coordination between both top-down and bottom-up processes (Pahl-Wostl et al., 2013). This integrated flood (and disaster) risk reduction approach can provide decision support tools to propose new and informed policies, norms and practices (triple-loop learning); ones that are informed by credible science and human values (Pahl-wostl, 2002; Pahl-Wostl et al., 2013; Gall et al., 2015). This sort of the transformative change in disaster scholarship is what will be important to break the knowledge divide and derive inclusive, collaborative, and action-oriented pragmatic research practices (Gaillard & Mercer, 2012).

4.2 Limitations

The thesis had several limitations. In this section, I summarize the limitations of overall methodological design, each of the methods, issues relating to scale, and social learning theory.

The limitations of the methods have been described in-depth in the chapters they appear; here, I revisit them briefly.

4.2.1 Problem with methodological design: decolonization within a western research paradigm

The thesis did not seek to be decolonizing; however, I attempted to find ways to include the community meaningfully in several stages of the research. I was also careful not to let my bias influence the interpretation of people's perspectives (i.e., using multiple methods for triangulation). However, I acknowledge that the methodological design is informed by the Eurocentric worldview applied in an Indigenous context. Wilson (2008) argues that the methods and theories derived from western knowledge are often 'incompatible' with the Indigenous worldviews. But at the same time, the 'format' of western research guidelines can limit the decolonization of research, especially in some disciplines more than others (Datta, 2018). The standardized methods, tools, theories, language, and rigor needed in western research has challenged the decolonization of this research (*ibid*, 2018).

Nevertheless, I intended to adopt some aspects of decolonization in my research, reflecting on the lessons from previous scholars (Smith, 1999; Wilson, 2008; Kovach, 2010; Datta, 2018). Some of the things I did as a researcher was being informed of historically oppressive research practices, honouring the community's values by attending ceremonies, gatherings, and important events, and being culturally and ethically responsive through university guidelines as well as guidance from community partners. Nevertheless, conscious choices can be made in future works in terms of decolonizing research that does not extract knowledge but accounts for greater social justice (Smith, 1999; Wilson, 2001; Creswell, 2014). This will require the researcher to sit down with people from communities, build meaningful relationships, and co-develop the entire project through an Indigenous lens. This often requires considerable time and resources and can be challenging to achieve within the scope of a master's program.

4.2.2 Issues with methods and scale

There are several limitations to each of the methods used in the thesis. They are described in detail in the chapters they appear. Key issues with the spatial modeling method and WDPM were slow execution times, require accurate runoff depths from rigorous hydrological models and its assumptions about roads and edges of DEMs as blockades or dams. Furthermore, the flood extent maps produced were static – they were meant to represent a flood extent at a point in time. However, one of the feedbacks received in the workshop was to show the spatial variation of flood duration for several days post-flooding. Having this information would help decision-makers manage resources, especially with regards to the ’72 hours’ rule in responding to a disaster or emergency (Van Manen et al., 2015; Hoffmann & Muttarak, 2017). This indicates future works are needed in developing tools that support the community’s preparedness efforts over the flooding period.

As for the FCMs, several authors have pointed out several limitations with the method including participant’s biases (Kosko, 1992b), the scenarios in FCM can provide insights on what happens to the system but does not tell much about the why’s (Kim & Lee, 1998; Özesmi & Özesmi, 2004) and explanation of non-linearity and time delays (Papageorgiou & Salmeron, 2015). The first limitation was mitigated because part of the study was to gain insight into what information is selected by participants to accommodate their assumptions for learning (Gray et al., 2014). For the second limitation, group discussions in the workshop helped unpack quantitative changes in the FCM. This shows how the integration of methods can help offset the weaknesses of others. The third limitation relates to capturing the dynamic nature of disasters. Papageorgiou & Salmeron (2015) reviewed several extensions to FCMs that, theoretically, tackled the issue of time function in FCM. Some of them include rule-based FCM (Carvalho & Tome, 2001) that incorporates time delays in the model and dynamical cognitive networks (Miao et al., 2001) with non-linear functions for quantifying simple linear cognitive maps and fuzzy time cognitive maps (Park & Kim, 1995) which also accounts for time lags between causal relationships. All of the proposed extension to FCMs theoretically addresses the time lag issues of FCM; however, they come with mathematical functions often too complicated for researchers who are not from the information systems domain. Some studies have used a ‘hybrid’ modeling approach incorporating FCM with other modeling methods such as agent-based modeling (ABM) to tackle some of the scale issues (Giabbanelli et al., 2017). In addition to these limitations, particularly relevant to the thesis, FCM can be intimidating if the participants are not familiar with the method.

Furthermore, the vagueness of some of the concepts and hesitancy in deriving strengths of relationships may have influenced the FCM interpretation (Malek, 2017). Lastly, FCM is one method to represent people’s belief systems, and other methods may yield different results

(Aminpour et al., 2020). Despite the limitations, FCM has recently been proposed as a method for 'leveraging the collective wisdom' of a wide array of experts for accurately representing complex systems (Aminpour et al., 2020). This highlights the growing popularity of FCM in studying complex systems.

Limitations associated with focus groups included getting everyone to participate in the discussion. Many scholars have also highlighted this as a significant drawback of focus groups where some participants may not feel confident to share their knowledge in a group (Gibbs, 1997; Smithson, 2000; Queirós et al., 2017). Hence, focus groups are often recommended to be paired with other methods that allow an individual's perspectives to come through, such as interviews (Gibbs, 1997). In this thesis, I used it with FCM.

In summary, all models (and methods) are imperfect, but they are valuable in enriching our inquiry and building knowledge on a context by offering variety (Strickert et al., 2010). It is through variety in methods, perspectives, and knowledge we will be able to address some of the issues in DRR scholarship, including bridging knowledge gaps, turning knowledge into action, and initiating holistic responses to disasters.

4.3 Understanding DRR through social learning theory

A critical theoretical contribution of this thesis was reevaluating social learning and its implication in DRR. Social learning theory was crucial to the thesis to demonstrate the value of diversity (in knowledge, methods) and to enhance behavioral responses to disasters that are complementary to structural responses (O'Brien et al., 2010). I reviewed this shift in response strategies in Mistawasis (see Box 4.1). However, it is important to note that Mistawasis has been working on strengthening their resilience in the past through structural measures as well as collaborative efforts such as their 'Honor the water' movement. It is hypothesized that the shift to more behavioral responses (i.e., emergency planning) would have happened eventually. What I want to emphasize is the importance of creating routine learning spaces (Figure 4.1) to reflect on past experiences and build on new information to act as a catalyst for shifting practices.

O'Brien et al. (2010) extended the conventional DRR framework to incorporate the learning loops. It emphasized that building resilience is an iterative process, and the 'transition and learning' zone is what is needed to reflect on whether we are doing the right things (double-loop learning). The outcomes of this learning can lead to a change in norms, practices, and paradigms (triple-loop learning) for strengthening resilience. Hence, we must create these transient spaces for learning through collaboration and, more importantly, placing Indigenous (and local) people together to act ‘as agents for change’ in the DRR context as opposed to ‘clients’ (Petal et al., 2008). This thesis created one such routine learning space that allowed community members and researchers to exchange ideas, reflect on past actions, identify gaps, and create novel solutions. Emergency planning, an emergent learning outcome, was put forward as a necessary agenda and presented to the chief and council following the workshop, by few officers and managers present at the workshop. As a result, Mistawasis is in the process of creating a community-focused multi-hazard emergency plan, which will also be tested once completed.

While I only focused on Mistawasis for this work, social learning has to go beyond local to institutional level to bring changes to local and global flood risk policies. This will require Mistawasis to work together with its partners, including the RMs, provincial, and the federal government, to bring institutional reforms (Pahl-Wostl, 2002; Pahl-Wostl et al., 2013). It is a daunting task to overcome the rigidity of institutional norms and practices, but the fact that Mistawasis has reinforced their DRR strategies with long-term actions such as community-based emergency planning is a transformative change in disaster practice, hence a lesson in itself. The tools and knowledge co-created with the community can be an important point of discussion to share with the partners and get the conversations going at all scales. Finally, transformative changes do not happen suddenly; they require a balance between short-term coping abilities (scenario C in chapter III) and long-term preparedness actions (scenario D) (Birkmann & Von Teichman, 2010; Chelleri et al., 2015; Henly-Shepard et al., 2015). Addressing this temporal scale of DRR will be critical in building adaptation goals for communities and building their resilience to changes in climate patterns (Figure 4.1) (Chelleri et al., 2015).

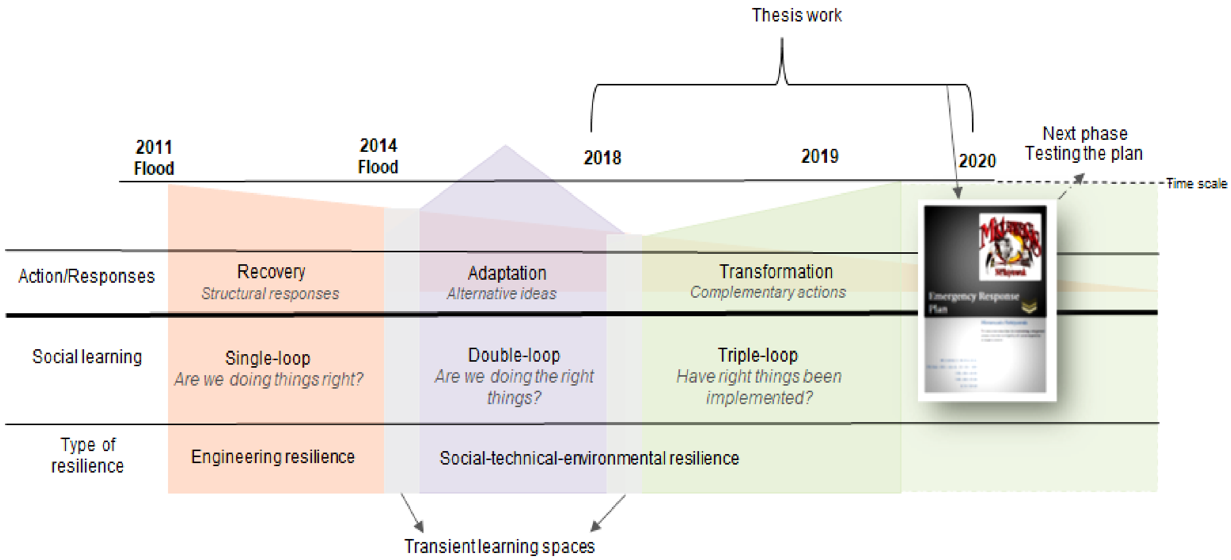


Figure 4.1 Mapping flood risk reduction transition in Mistawasis Nêhiyawak over a temporal scale. The figure highlights the overlap between structural, adjustment and behavioral (transformative) responses denoting that they will have to co-exist for resilience building (adapted from Chelleri et al. 2015)

4.4 Concluding remarks and future works

I started this thesis reflecting on the ideologies of pioneers in the field of DRR, who each contributed to changing the paradigm of disaster research and practices. This thesis resonates with their ideologies of making science tangible, pragmatic, and democratic by introducing novel methods. The integrated and participatory research approach used in the thesis was an attempt to rethink how we approach and deal with wicked problems such as DRR. In doing so, I applied, tested, and evaluated each of the methods used in the thesis in the context of increased flooding issues in Mistawasis Nêhiyawak. Hence, the thesis contributes to enriching knowledge in methodological and contextual areas. While the knowledge gained in this research is context-based, the research approach and methods can be transferred to other research areas.

A crucial part of the thesis was to demonstrate and evaluate the social learning process and outcomes and contribute to its operational use in DRR. The philosophical foundation of using the social learning lens in the thesis was not for 'educating' people rather learning to see things from multiple frames of references, which sometimes can come across as 'uncomfortable', but is needed for creating innovative solutions as opposed to ideal ones. Hence, I also emphasize the need to bridge the knowledge gaps by introducing theories and methods from different disciplines and insights gained from empirical data. Finally, the thesis is in no way perfect, and it should be viewed as a novel approach for calling upon variety: variety in knowledge, variety in methods, and variety in actions/responses. We have witnessed disasters, at the local and global scale, become more extreme in this century, we need to reflect on our actions and ask hard questions: are we doing things right, are we doing the right things, and have the right things been implemented? It is practically and ethically important to focus on more action-oriented and community-based approaches in which communities are not buried with information or imposed solutions; instead, preferably, emergent solutions are initiated by communities.

The thesis has also shed light on some important issues that need further thought. For example, the mental health aspects of disasters risks need more attention and will require future work. The issues related to scale mismatches, including spatial scale issues and limited local climate change data for accurately addressing regional and local DRR issues will become more complex as climate change advances (Birkman & Teichman, 2010). The temporal scale issues will require evaluating short-term or immediate strategies for dealing with extreme events against long-term adaptation strategies (*ibid*, 2010). While this thesis specifically used social learning theory to DRR to understand *what* and *how* people learn in a social context with different types of information (i.e., scientific and local knowledge), some conversations that happened in the workshop also highlights the importance of understanding *why* different people in the same community perceive disasters risks differently. Few community members initially did not worry about disasters because they always had someone else to deal with such a crisis. Future research can, therefore, focus on unpacking the cultural factors (i.e., values, beliefs, and norms) that influence people's perception of risk and how they respond to it. Integrating cultural aspects of an individual's risk behavior can be complemented by scientific knowledge to strengthen the community's overall preparedness behavior. Learning-based processes integrated into community-based DRR can be a way to unpack the 'natural', social and cultural aspects of disasters.

Lastly, more integration is needed across wider governance networks, including the RMs, provincial, and federal governments, for evaluating current DRR practices and policies. As for our continued work with Mistawasis, future efforts involve using a scenario-based approach to test the emergency plan in four stages including; a community tabletop exercise with the emergency management committee, a within-community simulation, a community, and RM simulation, and finally, a community, RM and provincial simulation.

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APPENDIX A

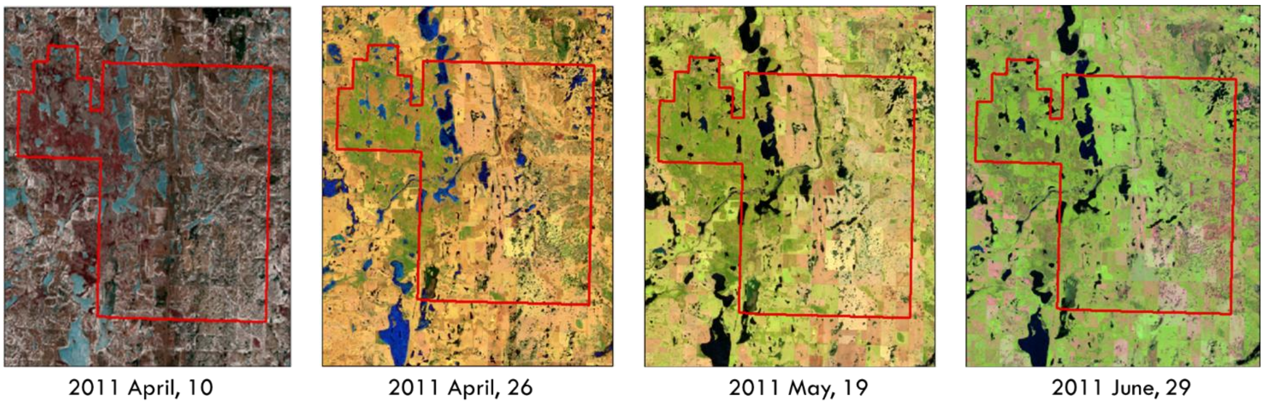

Figure A.1 LANDSAT 7 TM Images from 2011 for water extent extraction

APPENDIX B: Survey questionnaires: Evaluating Scientific Evidence- Flood Maps

1. To what extent does the evidence presented support your experience with flood concerns in the community?

Not at all: 1 : 2 : 3 : 4 : 5 : very much

2. To what extent do you trust the evidence presented?

Not at all: 1 : 2 : 3 : 4 : 5 : very much

If not, what was the primary reason for it?

_____ Error in data

_____ Does not include my area of interest in water issue

_____ Biased towards one particular viewpoint

_____ Too simple and does not capture the complexity in the community

If other, please indicate below:

____

3. How useful do you find the evidence to address flood concerns in your community?

Not at all: 1 : 2 : 3 : 4 : 5 : very much

If not, can you comment on why the evidence was not valuable?

____

APPENDIX C: Description of condensed variables used in fuzzy cognitive maps

1. **Accessibility considerations:** Accessibility considerations indicate the need to have restriction-free, easy and timely access to people and safe places in the community in the event of flooding. The concepts under this upper-level theme included reference made to physical facilities for accessibility such as roads and boats to access safer areas, and inaccessibility concerns such as 'limited access'. Impact on accessibility is one of the major indirect impacts of flooding (Green et al., 2017). Disruptions to accessibility can have an impact on people's day-to-day lives such as getting to work as explained by participants in the workshop. It can also affect the efficient implementation of emergency response actions (Morel & Hissel, 2010).

2. **Awareness and understanding:** Community-level awareness can help reduce losses and cost of flooding, guide how people respond to emergency situations, increase acceptance of prevention strategies, and ensure effective safety response procedures (Cubelos et al., 2019). Therefore, awareness and understanding consist of concepts identified by participants that refer to education, experience, and understanding of vulnerabilities such as 'awareness on water table drainage', and emphasis given to the need to be aware of hazard issues for example 'being aware and knowledgeable of flooding'. It also consisted of access to information that will likely increase the understanding of participants such as availability of data, and knowledge of response actions at times of flood.

3. **Beaver control measures:** Consist of concepts that discuss the need to control the beaver population in the community using both lethal and non-lethal actions such as using dynamite or trapping. Therefore, beaver control measures mean temporary measures and alternatives to isolate or remove the beaver population from the community. Such temporary measures are enhanced by proper beaver dam management, which has direct consequences for flooding (Kambietz, 2003).

4. **Climate change impacts:** Include concepts describing the role of climate change in general such as 'climate change' as well as probable consequences of observable changing environmental conditions that may lead to increased water level or flooding in the community such as 'extreme weather' and 'impact of weather conditions on creek level rise'.

5. **Communications:** Refer to having good communication practices at times of flood emergencies. These included general concepts such as 'communication' to specific communication tools such as 'cellphone battery for communication', 'radio', and 'telephone'. One participant also demonstrated, in his FCM, the need to have 'communication plan' for effective emergency communication strategies.

6. **Cooperation and coordination:** Describe the need to extend and strengthen relationships with other institutions and communities to enhance the community's coping ability and capacity to deal with flooding. These consisted of concepts such as 'coordination with the RMs', 'partnerships and alliances' and 'support from other communities'. One participant had 'unwillingness to flood people downstream' as a concept which refers to having a sense of responsibility towards other communities as well. Other concepts suggested the need for community participation, cooperation, and support at times of emergency. Coordination was also a theme that constantly came up during the group discussions where participants mentioned instances where they have had support from Indian Affairs in the past at crucial times, and the need to have better communication and coordination with their neighbors, i.e. RMs of Leask and Canwood.

7. **Emergency planning:** Comprise of concepts related to plans and programs needed to deal with major emergencies. The concepts ranged from individual, household to community-scale written procedures or guidelines such as 'family escape plans', 'emergency plan', 'multi hazard plan', and 'safety response plan'. It also consisted of concepts that indicate the need to be prepared for emergencies such as 'findings ways to deal with flooding', 'emergency preparedness', and 'preparedness for future events' which again indicate the need to have good emergency plans.

8. **Evacuation procedures:** Describe the immediate response actions and facilities needed to vacate and move people out of flood emergencies such as 'evacuation during flooding', 'transportation', 'first response', and 'gather family'.

9. **Feeling of safety:** Include concepts that describe the act concerning the safety of family, friends, infrastructure or safety of all beings inclusively. More importantly, it indicated the need for a known and accessible safe area(s) that people know of and can gather in the event of flooding. These included 'muster stations', 'safe place', and 'normalized muster points'. Threats to safety were also included under this theme such as having poor indoor quality.

10. **Flood protection from control structures:** Describe the measures necessary or used to protect, prevent or reduce the negative consequences of flooding. This included concepts ranging from taking simple and non-invasive measures to protect from flooding such as 'clearing snow to prevent basement flooding' and enhancing 'natural drainage' to more structural and technical measures such as having 'culverts', 'proper drainage on roadways', 'controls for water level' and 'local drainage projects'.

11. **Flooding and related hazards:** Comprise of concepts that inherently describe the probable agent or source that can cause potential damage to people, property, or the

environment. In other words, concepts that describe the source of danger or emergencies such as 'lakes and creek flooding', 'rivers and creek level', 'flooded houses', and 'flooded roads'. There were other concepts related to hazards that may be followed by a flooding incident in the community such as 'erosion', or 'fire' because of dead trees and dry environment during summer.

12. **Health concerns:** Include the immediate dangers as well as long-term effects of flooding on human health. The concepts under this theme ranged from health concerns in general such as 'health problems', and 'community health', and indirect health effects such as 'illness' and 'lung infection' caused by molds. Although not explicitly described, the long-term health impacts may be described by concepts such as 'stress' and 'anxiety' related to flooding.

13. **Housing damages:** Simply refer to the damage caused to the houses from floodwaters. The general concepts referred to damage to houses such as 'home damage' and specific damages caused to the internal conditions of houses such as 'mold'.

14. **Impact on shoreline:** Consist of only two concepts related to the impact of flooding on the shoreline vegetation, particularly trees. However, shoreline damage came up frequently during discussions as an important impact of flooding in the community.

15. **Land-use activities in flood-prone areas:** Demonstrate the related human activities, for example, use of the land for infrastructure and property development in high flood risk areas. The concepts under this theme mostly signified the role infrastructure location and changing human activities play in increasing the flood hazards in the community. Overall, it represented the knowledge of risk areas in the community to reduce the future flood risk and damages to life and property

16. **Need for beaver dam management:** Are management strategies specifically to control the beaver dam for flood prevention. The concepts ranged from the presence of 'beaver dams' to specific actions required to regulate the dams including opening or destroying the dams.

    There were two main reasons for using beaver dam management as a separate theme from beaver control measures. First, there are stricter regulations for the removal or destruction of dams compared to other beaver control measures (LORC & OMNR, n.d). Second, the theme acknowledged the role of extended coordination (with other RMs) needed for dam management compared to beaver control which, based on FCMs, can be explained as an action to be carried out within the community.

17. **Off-reserve impacts (dams and drainage):** Describe general and specific upstream activities that can potentially result in flooding in the community such as 'opening the dam' and 'upstream drainage'.

18. **Rain and snow:** Simply mean the rain and snow activities that have the potential to increase the magnitude and frequency of flooding. Although, the theme consisted of only two concepts, precipitation activities (severity and intensity) are one of the major causes of flooding. In addition, these were influenced by other themes in the maps (e.g. Climate change impacts) as well as had an influence on others (e.g. runoff and streamflow, flooding and related hazards).

19. **Road damages:** Describe the damages caused to the road infrastructures in the community by floodwaters. The damages included general concepts such as 'road conditions from washouts' and 'potholes and ruts in roads'. The extent of damages to roads was identified to hinder accessibility considerations and hence, timely evacuation procedures.

20. **Runoff and streamflow:** Represent the contribution of excess runoff of water on the land surface (e.g. 'overland flow') and water bodies (e.g. 'streamflow') that may result in flooding hazard.

21. **Recovery actions:** Consist of necessary short-term and long-term actions to restore or rebuild the impacted areas after a flooding incident such as 'machineries for road maintenance' and 'restoration projects'. In addition, it also consisted of a singular concept that can be interpreted as a hindrance to recovery actions, one that can make recovery a lengthy process. For example, when emergency planning is not tested, it can delay the process of getting back to normal activities difficult after an emergency.

22. **Survival needs:** Means having access to basic survival requirements during times of emergencies. Having access to clean water was the most mentioned survival needs for people. Other key survival requirements included having emergency food and a backup generator for cooking and heating. Overall, survival needs meant that resources are available for people to feel secure during a flood event because they are able to survive with emergency food, water, and shelter.

23. **Uncontrolled agriculture:** Indicate the potential impact of changing agricultural activities, and regulations in increasing flood impact. Other concepts under this theme described other negative consequences of agriculture besides flooding such as runoff derived from agricultural lands (e.g. 'pollution runoff') that can have a significant effect on environmental and human health.

24. **Wetlands and lakes:** Show the presence and role of wetlands and lakes, and wetland processes (e.g. ‘wetland fill and spill’) in local flooding. While the concepts in this theme described how the rise in water level in the wetlands might lead to overland flooding, some participants also saw the role of wetlands and lakes to store excess water and increase the property value. In that sense, wetlands and lakes had both positive and negative value in the community.

25. **Wildlife and natural resources:** describe the presence of local wildlife and natural resources in the community. The concepts under this theme demonstrated participants' concerns for the safety and well-being of the local natural resources such as ‘wildlife safety’ and ‘animals habitat’.

APPENDIX D

Table D.1 Qualitative condensation and concepts in Individual original FCM

SN	Condensed Variable	Concepts in Individual Maps	Exemplar quotes
1	Accessibility considerations	Roads to access parts of community Lands accessibility Accessibility to all members Availability of boats to access dryland Limited access Flooding between access ways	*"some of these houses only have, like this one down here, there's a road that sometimes gets flooded there and that's the only way in or out"*
2	Awareness and Understanding	Mistawasis data Being aware and knowledgeable of floods Being informed and updated Awareness on water table drainage Unwillingness to flood people downstream Knowing what to do How does it (emergency planning) work	*"if we had more data you could be able to figure out where the water is actually flowing and where it's coming from"* *"like you see it on TV and you just take it [flood] for granted 'oh it's not gonna happen to us' you know in our community and yeah it was all different today and just more awareness"*
3	Beaver Control Measures	Use of dynamite Not enough trappers More effective ways to deal with beavers Control beaver population	*"…we're trying to protect our assets but then beavers are also trying to protect their assets so how do we work together in that aspect?"*
4	Climate change impacts	Climate change Extreme weather Impact of weather conditions on creek level rise	*"I think we're starting to know or realize that these major events; the last one was 50 years ago in 56', but that time period may become shorter and shorter. So, we may have more flooding in 10-15 years. Worst flooding!"*
5	Communications	Communication (radio, telephone) Cell phone battery for communication Make use of radio as communication Communication Communication plan	*"Maybe in preparedness plans or for insurance purposes, like this communication, the radio, is seen as an asset in times of emergencies. So just the fact that we have it would help our argument for additional financial support to keep this running for these emergencies"*

6	Cooperation and coordination	Relationship between SENS and Mistawasis Check with neighbors Coordination with the RMs Community support Partnerships and alliances Support from other communities Check on neighbors Help for vulnerable people Who is in charge	*"And I know again what has happened off the reserve has impacted us. So part of our concern while we don't want to do that to others; we prefer to work with others for that"* *"I know when we had the power outage… people from that particular village that just went to check on the elders but we need to formalize that…there might be one or two people that might be emergency captains or whatever just to check on everyone"*
7	Emergency planning	Emergency plan Finding ways to deal with flooding Family escape plan Preparedness for future events Safety response plan Emergency preparedness Escape plan Multi hazard plan needed	*"..it kind of opens my eyes to the importance of planning and being prepared and realizing that we really aren't prepared-as prepared as we thought we were"*
8	Evacuation procedures	Transportation First Response Need for boats Gather family Need more boats Evacuation during flooding	*"There might be a need for equipment or large vehicles to rescue people"* *"The water was pooling up here and here and these houses here…it came to a point where we almost had to evacuate some people here because the water was pooling."*
9	Feeling of safety	Safety of people, animals, buildings, homes Where do we go Safe place Safety check to make sure everyone is out Muster points Safety of family Muster stations Poor indoor quality Normalized muster points	*"Kind of gets me scared there is no plan in place"* *"…it'd be good to find out where you would be safe say in the event of a flood or the event of wildfire. Where are some areas that you could go to be safe from these hazards. I think that is something we should look into"*

10	Flood protection from control structures	Culverts size and placement Proper drainage on roadways Culverts Natural drainage Controls for water level Local drainage projects Clearing snow (to prevent basement flooding)	*"So, Indian Affairs…spent just about $100,000 just to put those culverts in right here and then they had to open- they had to fix this culvert. They put another one in here"*
11	Flooding and related hazards	Erosion Lakes and creek flooding Rivers and creek level Flooded roads Flooded houses Fire Drought	*"As we do see flooding along the shoreline, we do see a lot of dead vegetation. Especially in our creek right now there's a lot of dead cattails and trees and all that poses a fire hazard cause they're very dry and in the spring and the fall that could pose a problem"*
12	Health concerns	Health Lung infection Illness Anxiety for future flooding Stress Health problems Quantity and quality of employees and employers Community anxiety Community health	*"Oh, it was stressful!"* *"I know being evacuated to the cities quite often sometimes families are broken up and separated and go to different places"*
13	Housing damages	Mold Housing Housing conditions (mold) Mold from home flooding Home damage Mold	*"This part is the Watson village. So there was a house right along the edge here, it was flooded and we had to get-it's fixed up now but at the time it was condemned because of that flooding."*
14	Impact on shoreline	Trees dying Flooded trees	*"You can see every single lake, every single shoreline has dead trees all around-all the shorelines"*
15	Land-use activities in flood prone areas	Where homes are or were built Building houses in risk areas Infrastructure Changing human activities on reserve Farming Property (dead trees and debris)	*"It's a combination of things; the water plus the straight roads. Our ancestors didn't travel the straight roads they followed the contours of the land. But, now we all have straight roads and of course we've done more damage or harm than the beavers with those straight roads"*

16	Need for beaver dam management	Beaver dams Keeping beavers dams open RMs to keep beaver dams open Getting rid of beaver dams	*"That road also behind my house, it's all beaver dams there and that road is out, gone now"*
17	Off-reserve impacts (dams and drainage)	Off-reserve activities Opening the dam Upstream drainage Controlled flooding from upstream	*"Yeah like off-reserve there are control dykes and that's what happened one year when the water was released from off the reserve it impacted us so we got additional flows"*
18	Rain and snow	Precipitation High precipitation	*"I'm wondering does the model support, like if you were to put something in the ends of like a flash flood, you get like a crazy amount of precipitation over like a few hours, kind of like how the other places did"*
19	Road damages	Roads integrity Roads damage Road conditions from washouts Potholes and ruts in roads	*"when that [2011] flooding happened we lost our road when it flooded over by Neil's over that way"* *"And it's still under water, this road here"*
20	Runoff and streamflow	Streamflow Mistawasis creek Rain/snow runoff Overland flow	*"I used to walk from the lake village to work each day , so I was aware of how the creek was changing with more and more water and also when the water went down then you could see the creek up on time it just looked like a big swamp"*
21	Recovery actions	Machineries for road maintenance Restoration projects Emergency planning never tested	*"It's part of that shoreline recovery. They're doing that all along. They did the whole bay area already, cutting down all the dead trees and getting rid of them and then taking more sand in to replace. Starting to look like a lake again"*
22	Survival needs	Access to clean water Water contamination Drinking/cooking/cleaning water Emergency food and water Backup generator	*"Also during the summer when it's extremely hot, we've had the power outage, like the one in 2012 for 4-5 days. So where do people go to cool off? And, with no power how do you*

		Flashlight Drinking water quality Accessibility to drinking water Concerns about drinking water	*cook? Where do you get your water?"*
23	Uncontrolled agriculture	Pollution runoff Low commodity prices for agriculture Increasingly high cost of AG production	*"you can really see where the shoreline has been affected as well as all the nutrients that have been leaching"*
24	Wetlands and lakes	Wetlands and lakes Lakes Wetland fill and spill Local water storage	*"the water was coming just because this lake had flooded over here"*
25	Wildlife and natural resources	Fish quality Animals habitat Birds migration Land Wildlife safety Beavers	*"all the nutrients that have been leaching in from the lakes, I don't know what kind of damages that's gonna have to marine life or the vegetation surrounding it but I'm pretty sure it's not too good"*

APPENDIX E

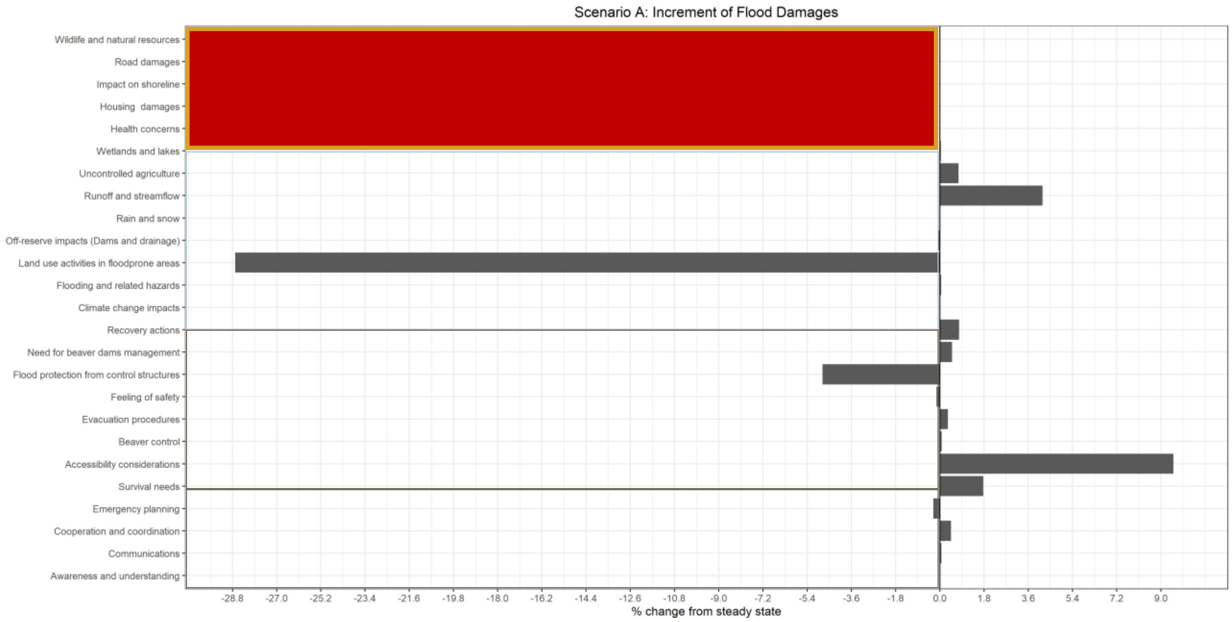

Figure E.1 Consequences of Scenario A (Increment in flood damages)

APPENDIX F

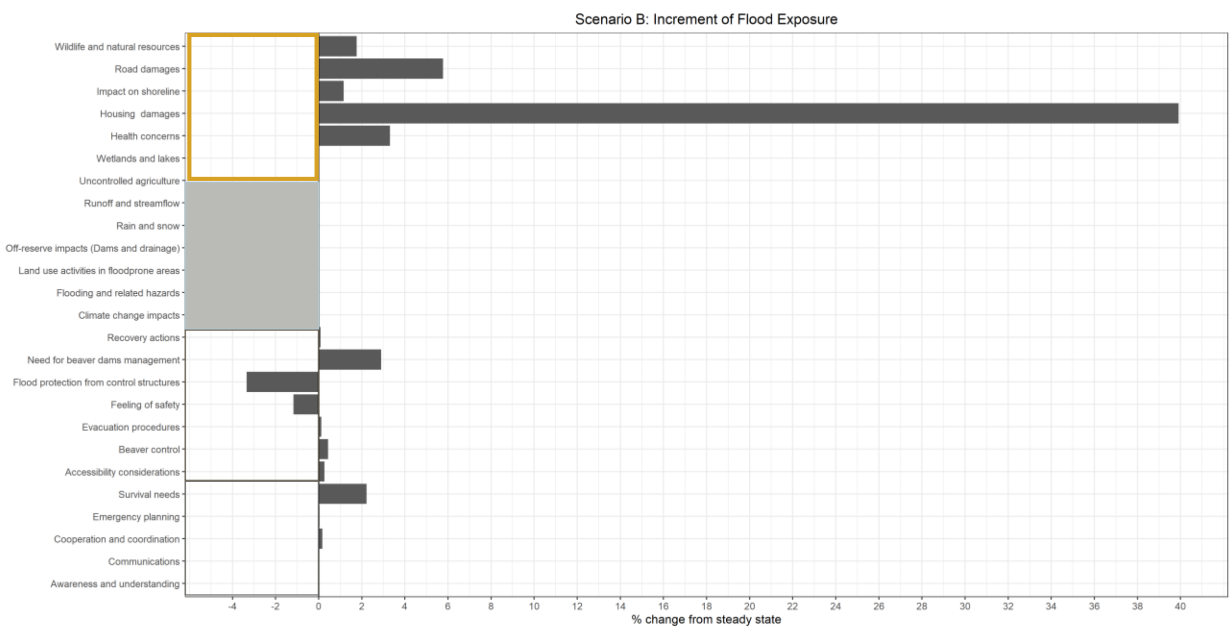

Figure F.1 Consequences of Scenario B (Increment in flood exposure

APPENDIX G

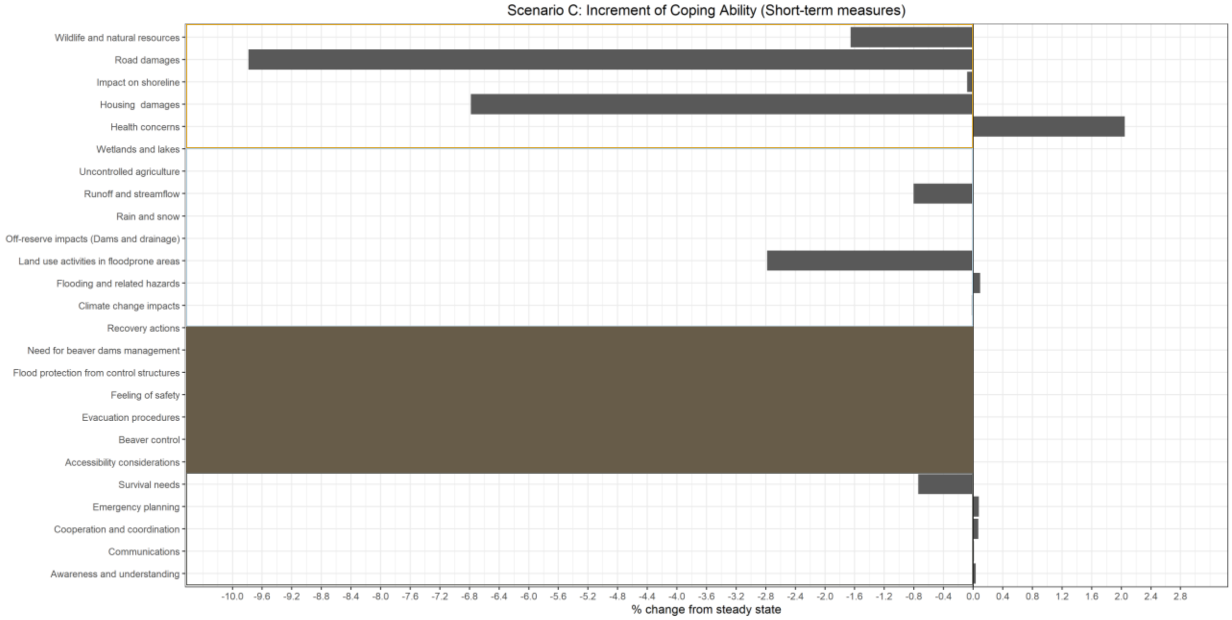

Figure G.1 Consequences of Scenario C (Increment in short-term coping abilities)

APPENDIX H

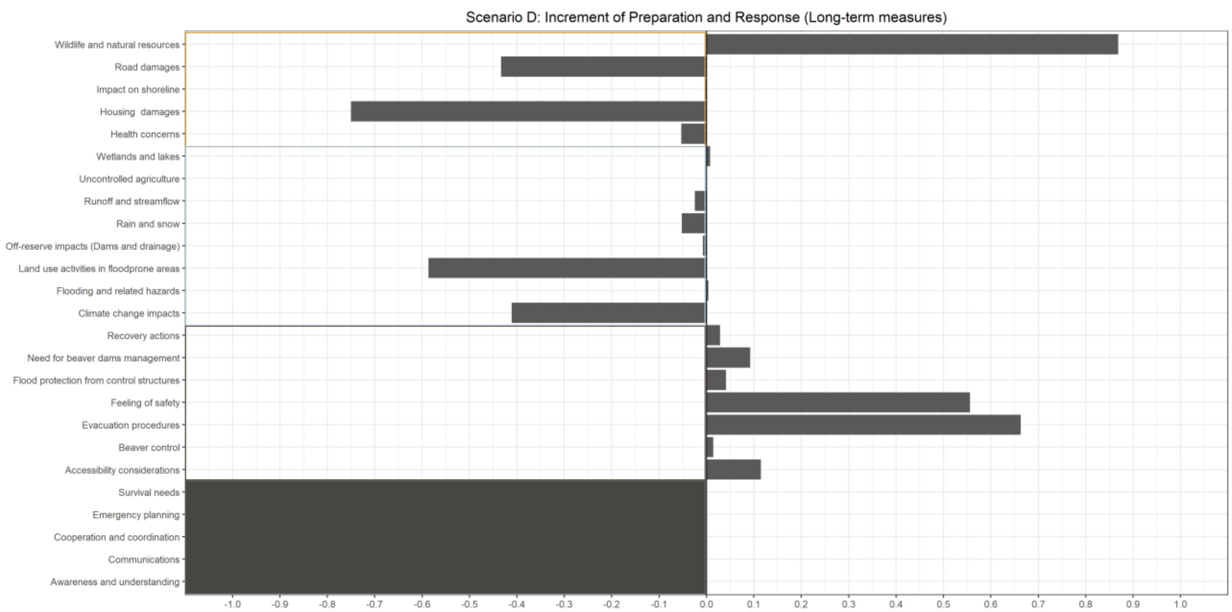

Figure H.1 Consequences of Scenario D (Increment in long-term preparedness requirements)