Evaluating a Quantitative Flood Risk Assessment Tool in Manitoba and its Application to Policy

by

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Abstract

Manitoba's flooding is one of the principal sources of costs associated with flood disasters. Despite the tremendous financial investments in structural mitigation, flood cost, continue to rise. Currently at the national and provincial level, there exists no standardized operational framework and tool for flood risk assessment. The primary role of this research was two-fold. First, Hazus-MH a Quantitative Risk Assessment (QRA) tool was evaluated as a potential flood-loss estimation model in a Manitoba context. Secondly, to examine the application of a QRA tool in policy, a face-to-face questionnaire was completed with flood experts in municipal and provincial government and with consultants. The study results suggested that Hazus-MH has the potential to be applied as a standard QRA tool in Manitoba. This research found that developing a standard QRA tool in Manitoba, would empower communication between decision-makers, centralize data to support disaster planning, and reduce the cost of recovery.

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This study would not have been possible without the kind and generous assistance provided by many individuals. First I would like to thank Miroslav Nastev from Natural Resources Canada, for his financial support towards the Hazus pilot in Manitoba. My thesis advisor, Dr. David Walker. Through your academic guidance and direction I was able to discover a challenging research topic that was very intellectually rewarding. Thank you for having your door open and for taking the time to answer my numerous questions and provide thorough editorial comments. I would also like to acknowledge the members of my thesis committee for their guidance. Dr. Emdad Haque and Dr. Rick Baydak, thank you for your time, advice and support. I would also like to acknowledge, Ms. Angela Howell for her time and support in working with the Hazus-MH technology and assisting with data integration and flooding analysis. Your time and patience was appreciated. The steering committee of Emergency Measures organization (EMO); MIT formally known as Manitoba Water Stewardship and Sue Sutherland former CAO of the RM of St. Andrews for their support and opportunity to pilot the Hazus project in the Rural Municipality of St. Andrews. Without their trust in me as a graduate student the first stages of this thesis would not have been possible. Thank you to all the study participants who generously took the time to provide their input. I would like to extend thanks to my supervisor, Maj. Sean Ivanko for his continual support with my studies and for allowing me the flexibility at work to be able to complete my graduate studies. To my colleague Ms. Trish Buhler for her patience and support in the workplace, while I dedicated my time to my studies. A special thank you to my husband Robert Houlind to whom this research would not have been possible without his encouragement and support. Finally, I dedicate this study to my children and grandchildren: This is a legacy I leave behind to inspire each and every one of you.

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Abbreviations

CFS : Cubic Feet per Second

DEM : Digital Elevation Model

DFAA : Disaster Financial Assistance Agreements

EMO : Emergency Measures Organization

EPC : Emergency Preparedness Canada

FDRP : National Flood Damage Reduction Program

FEMA : Federal Emergency Management Agency

GIS : Geographic Information System

Hazus- MH : Multi-Hazard

MIT : Manitoba Infrastructure and Transportation

MMG : Manitoba Municipal Government

NRCan : Natural Resource Canada

RM : Rural Municipality

UNISDR : United Nations International Strategy for Disaster Reduction

USGS : United States Geological Survey

Chapter 1
Introduction and Literature Review

1.1 Introduction and Problem Overview

In Canada, extreme flood events are the single most frequent natural hazard responsible for the highest economic and social losses since the beginning of the twentieth century (Government of Canada, 2003). From the 287 major flood events inventoried between 1900 and 2012, 177 (or 62%), have occurred in four provinces: Ontario (53 events), New Brunswick (34), Quebec (34) and Manitoba (56). In 2011, Manitoba's Assiniboine flood proved to be the most costly in Provincial history, reaching over 1 billion dollars (Gerrard, 2012).

The primary goal of this study is to evaluate the role of a Quantitative Risk Assessment (QRA) tool in Manitoba and its application to policy. Currently at the national and provincial level, there exists no standardized operation framework tool for Quantitative Risk Assessment (QRA) by Emergency Measures Organization's (EMO's). The Hazus-MH (multi-Hazard) developed by the US Federal Emergency Management Agency (FEMA), represents an extensively applied and well documented GIS-based tool for quantifying natural hazards such as flooding in the United States (US). The objectives to this study are two-fold:

First this study will evaluate Hazus-MH as a QRA tool in Manitoba's Red River Basin to determine if a QRA tool can influence decision-makers to mitigate development in flood risk areas. Secondly, this study will define the application of a QRA tool in policy to reduce the cost of recovery. The first objective will be met by piloting the Hazus technology in the selected study area of the Rural Municipality (RM) of St. Andrews, Manitoba. To achieve the second objective the research method selected was quantitative and qualitative in nature. This research utilizes a face-to-face questionnaire with flood experts in municipal and provincial government, and with consultants. This survey will determine the land development processes; role of technology; public policy, in mitigating and responding to flood risk in Manitoba's Red River Basin. The Analysis involved two sets of questions, open (long questions) and Likert format ranked questions. This study will establish two-fold, if and how the Hazus tool can be applied in a Manitoba context as a standard QRA tool to inform decision-makers and secondly, examine the link between QRA tool and policy to empower land use regulations and reduce the cost of recovery.

Frequency of Global and National Disasters

Worldwide economic and insured losses from natural catastrophes such as earthquakes, hurricanes and floods have increased significantly in recent years. Given the massive economic losses from the March 2011 earthquakes and resulting tsunami in Japan, 2011 was the most costly year on record for disasters globally estimated at $370 billion (Re, 2011). Estimates were collected for the total costs of weather-related disaster events globally between 2000 and 2012 by year from the four main institutions engaging in this exercise: Swiss Re, Munich Re, CRED (EM-DAT), and Aon Benfield. The average annual cost worldwide for this time period ranges across the four sources from over $94 billion (EM-DAT) to over $130 billion (Aon Benfield) (Kousky, 2014). The recent global assessment report on natural disasters of the United Nations shows that the number of natural disasters, economic losses, and people affected are increasing at a rapid rate; faster than risk reduction can be achieved (ISDR, 2009). Although the UN's International Decade for Natural Disaster Reduction is an effort to promote better management of catastrophic risk, losses remain unacceptably high (Kovacs and Kunreuther, 2001).

In Canada, disastrous severe weather and geological hazards take place every single year. These phenomenon continuously shapes our landscape, and have profound effects on the economic wellbeing, safety and security of millions of people. The most significant natural disasters in Canada have resulted in considerable damage, displaced households, injuries and or fatalities. The extreme flood event is the single most frequent natural hazard responsible for the highest economic and social losses since the beginning of the twentieth century. Flooding in Canada has resulted directly and indirectly in the deaths of at least 198 people and several billion dollars of damage during the twentieth century. Although floods can occur any time, most floods occur in spring when several common flood mechanisms such as snowmelt runoff, storm rainfall and ice jams are likely to take place concurrently, thereby increasing the likelihood of high water flows (Government of Canada, 2003). Figure 1.1 identifies the number of flood events which have steadily increased in the twentieth century with about 80% occurring after 1970. In the 1990s, the Saguenay region in Quebec (1996) and Manitoba's Red River Valley (1997) were the two costliest natural disasters in Canadian history with direct economic losses of $800M and $150M respectively (Ashmore and Church, 2001). As stated by Ashmore and Church, the frequency of flooding disasters has increased in Canada over the years. More recently, the 2013 Bow River flood in Alberta caused damages to capital assets which reached over 3 billion dollars (Veysey, 2013). While Canada is exposed to a variety of natural hazards, risk assessment is central to risk reduction as well as to the emergency management planning process. Although Canada floods are the most destructive natural disaster in terms of cumulative property damages and losses, most risk and emergency managers presently lack the necessary tools to manage risk assessment (Nastev and Todorov, 2013).

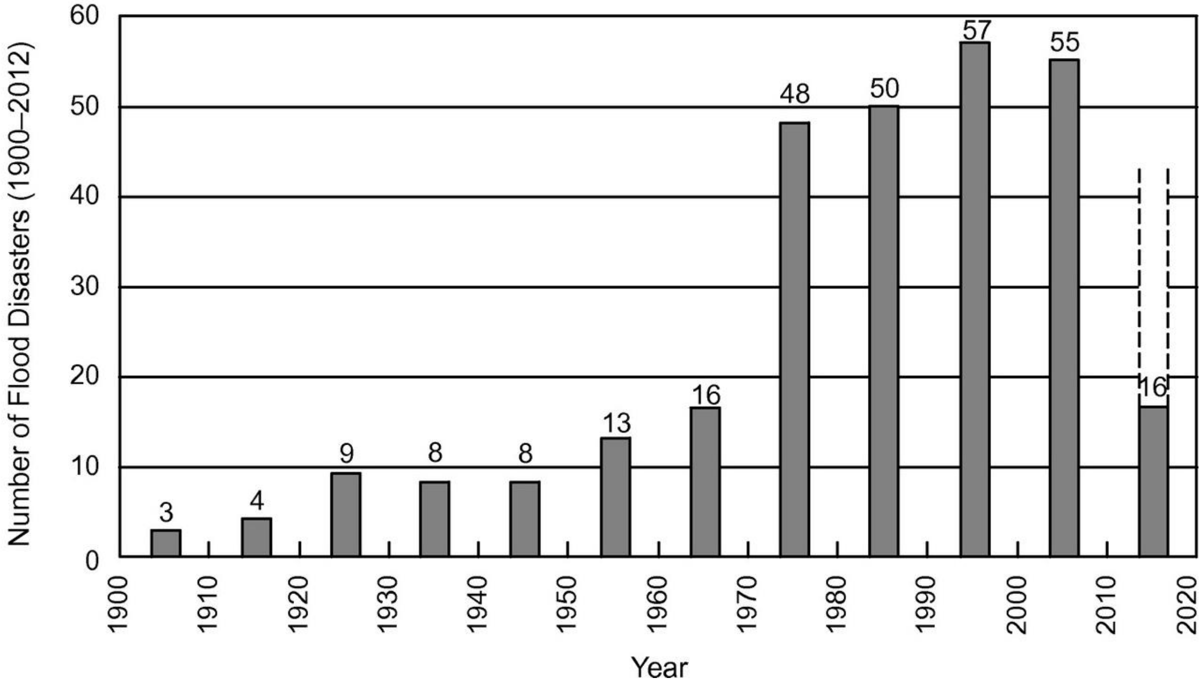

Figure 1.1 Natural disasters in Canada since 1900; (b) frequency of flood disasters (Public Safety Canada (PSC), 2010).

Flooding in the Red River Basin

The province of Manitoba's Red River basin has a flooding history that spans over 350 years (Rannie, 1999). The topography of southern Manitoba has been compared to a vast soup bowl with the comparatively flat basin of Lake Agassiz (Ledhowski, 2003). Figure 1.2 identifies the focal point of the valley in the Red River Basin, which forms in Wahpeton, North Dakota and flows northwards until it empties into Lake Winnipeg. The north-flowing Red River drains an area of 290,000 km^2 that traverses the flat and gently sloping clay plain of the Red River valley (Upham, 1895). The flatness of the basin is defined by the northward slope of the river, which is variable and averages less than one-half foot per mile. As a result, velocities are low and uncontrolled overbank flow often spreads over a wide area where it may flood for weeks. Over time the Red River basin has created an excellent environment for flooding as natural drainage is poor, gradient of the slope of the basin is low and the flows of the Red River, which carry excess water north, can be quite slow (Bumsted, 1987).

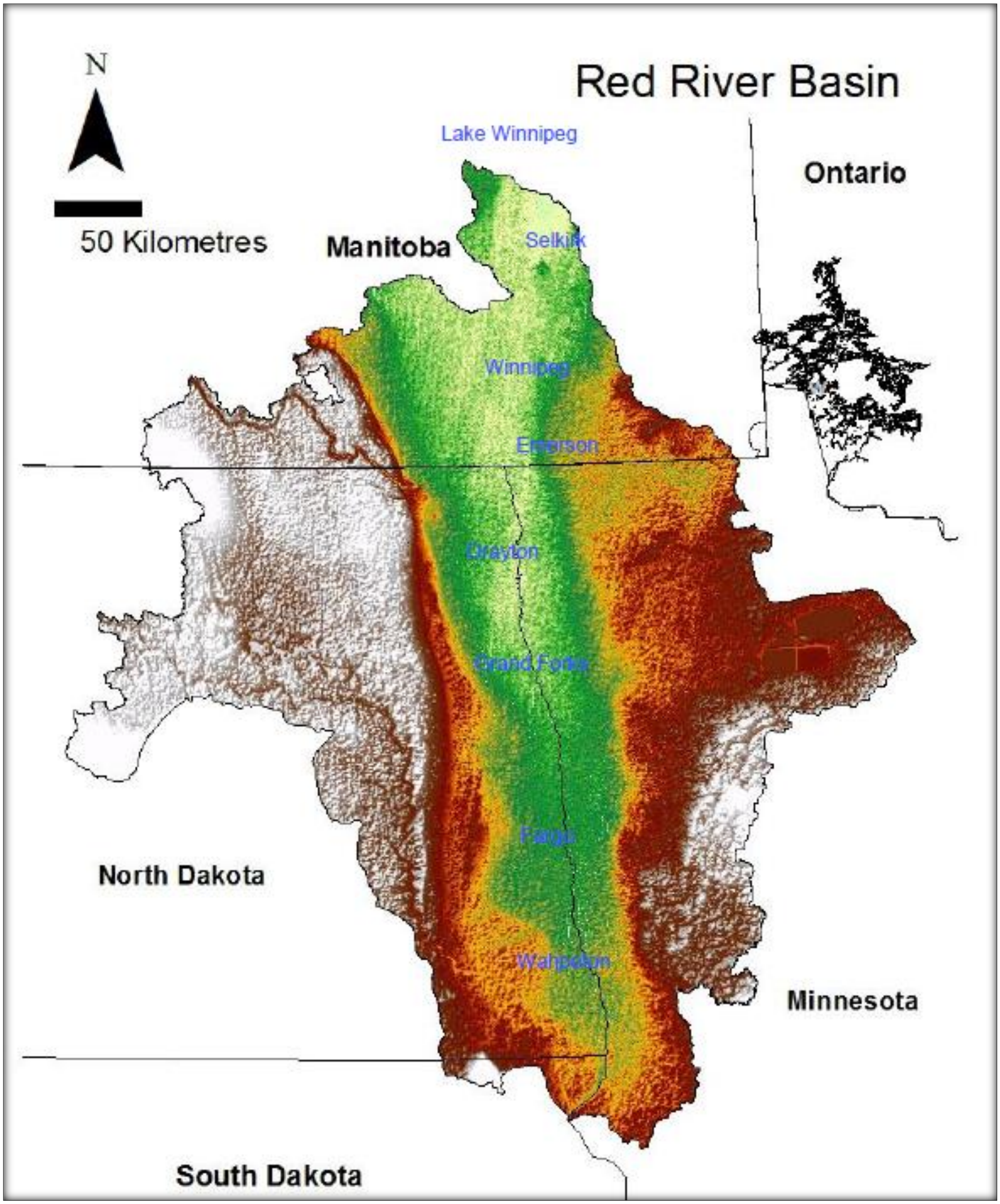

Figure 1.2 Map illustrating the focal point of the valley as the Red River Basin, between Wahpeton, North Dakota and Lake Winnipeg
Source: Adapted from Government of Manitoba (MLI) , 2015.

At Winnipeg, the drainage area of the Red River is increased from 48,000 to 111,000 square miles with the addition of its most significant tributary, the Assiniboine River. The Assiniboine River emerges from east central Saskatchewan and flows southward as it enters into Manitoba. The Assiniboine River intersects with the Red River at the heart of Winnipeg in an area known as the Forks. From a point near Portage la Prairie to Winnipeg, the Assiniboine River flows across the Lake Agassiz Plain where the low gradient creates a flood hazard similar to that of the Red River. The flooding of the Red River most often occurs in the spring when several common flood mechanisms such as snowmelt, large blizzards, heavy precipitation and ice jams are likely to take place concurrently (Government of Canada, 2003). In the 20th century, major floods occurred in 1950, 1966, 1979, 1996 and 1997 (Simonovic and Carson, 2003). The floodwaters of 1861 and 1950 covered the whole area of what is now the city of Winnipeg (Bumsted, 1987). The extents of 1997, 2009 and 2011 flooded areas are presented in Figure 1.3.

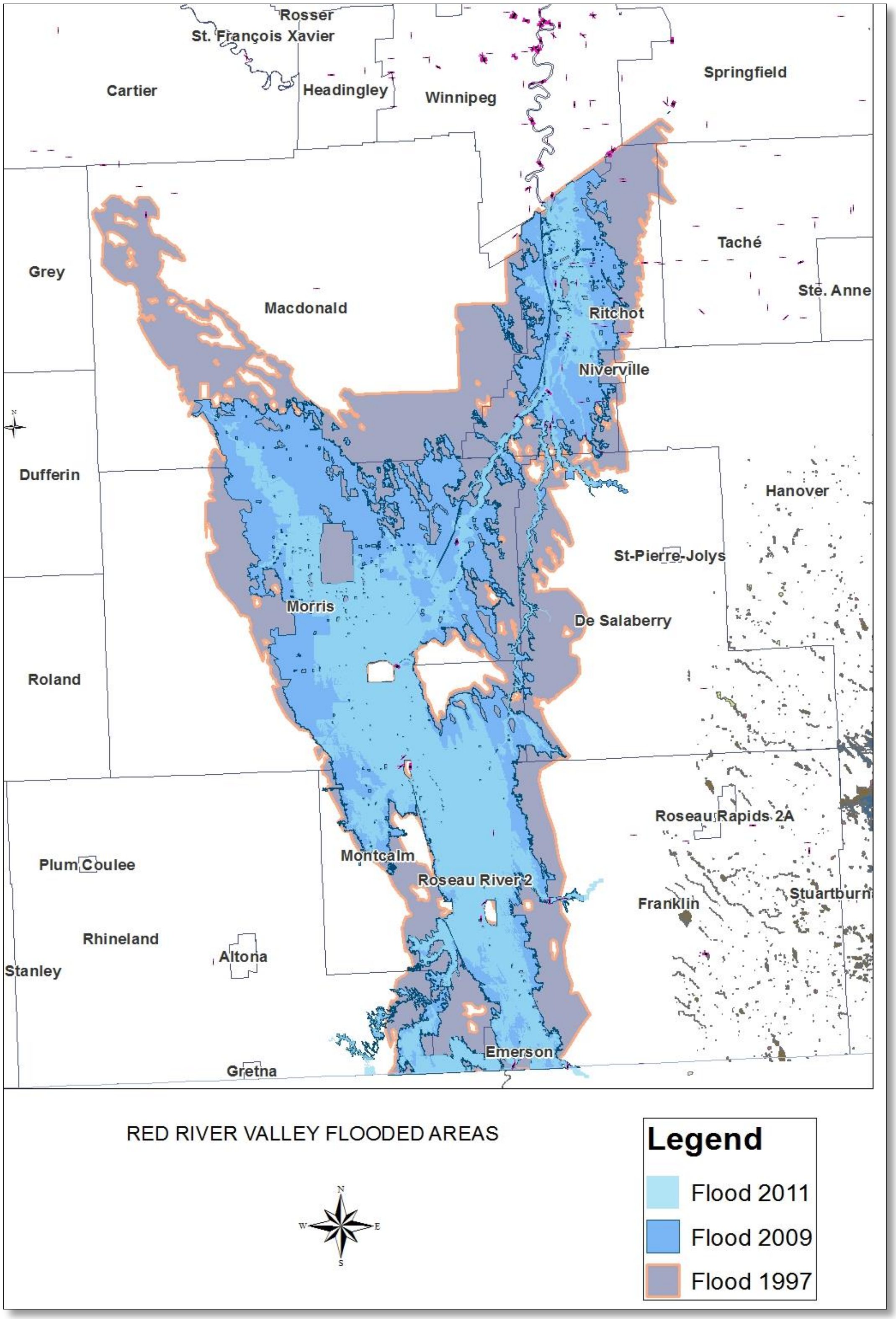

Figure 1.3 Physical extent of historical flooding of Red River Valley Flooded Areas
Source: Adapted from Government of Manitoba (MLI) , 2015.

Settlement History and Legislated Drainage Districts

Throughout Canada's settlement history, primarily in the 19th and early 20th centuries, many Canadians established residences and livelihoods along riverbanks, lakeshores and coastlines (De Loe, 2000). As stated by De Loe, "although flooding has existed for many centuries, it is considered a hazard only where human settlements and livelihoods occupy the floodplain, thereby placing property and lives at risk". The Province of Manitoba was formally created in 1870, and that decade saw rapid settlement within what were then its borders. A settlement grid was laid atop the Canadian West, including the wetter areas of southern Manitoba, and was used as the framework for land disposition, thus opening up to newcomers quarter sections of 160 acres (65 hectares) under the Federal Government's 1872 Dominion Lands Act. The settler's duties involved clearing the land and erecting buildings (Bower, 2007). In addition, drainage projects were undertaken after the installation of the Land Drainage Act in 1895. The Province of Manitoba legislated the creation of drainage districts as a solution for the flood problems, aimed at those areas in which surface water problems interfered with the private property landscape of the Dominion Land Survey. Drainage in Manitoba depended largely on the construction of surface ditches. Eventually districts were numbered in order of creation and identified by number. In total, twenty-four districts covering more than 2 million acres (809,375 hectares) were scattered across a significant portion of the more densely settled region of the province: from the eastern shore of Lake Winnipeg to near the Saskatchewan border, and from the American border to more than halfway up the northern basin of Lake Manitoba (Warkentin, 1999). Manitoba's soup-bowl topography was not taken into account in the caption of drainage districts. Overtime, the urbanization of these settlements grew into cities, communities and agricultural lands with primary development along flood prone lands (Blakie, 1994). As stated by Rannie (1998) “a complicated and controversial factor in any hydrological assessment is the change that has occurred in the land cover and drainage within the watersheds”. Over the years, the original native grassland and forest have been replaced by agricultural uses, most of which have left the land surface bare during the spring runoff. The drainage networks were developed to both increase the area of arable land and to remove surface water more rapidly during spring runoff. Many scholars including Rannie,(1998) have agreed that these factors compound hydrologic conditions and have raised questions on how to mitigate runoff impacts to minimize future floods.

Flooding Cost and Structural Mitigation

The city of Winnipeg, located in southern Manitoba, has suffered repeated physical, social and economic damage due to severe flooding. Based on (USGS, 1950) data, the Province of Manitoba, 1950 flood event became the largest flood since 1861 costing over $30 million (Rannie, 2015). Following the 1950 flood, a study was completed by the Royal Commission (1958) to determine flood mitigation and protection options. As a result, the first structure known as the Red River Floodway was constructed and completed in 1966, with the objective to divert portions of the Red River flood waters around the city of (Simonovic and Carson , 2003). Flood control structures completed by 1970 included: the Red River Floodway; Portage Diversion; Shellmouth Dam and Reservoir as well as the primary dike system within the city of Winnipeg and the community ring dike system around settlements in the valley. These flood control works identified in Figure 1.5 prevented widespread devastation from significant flood events in 1974, 1979 and 1996 (Olczyk, 2005). In 1997, “the flood of the century” forced the evacuation of over 28,000 people and was estimated to cost Manitoban’s over $500 million dollars. After the 1997 flood, the level of flood protection was raised another two feet (Haque, 2000). The original floodway cost approximately $63 million to build and is estimated to have saved more than $10 billion in damages on more than 20 occasions to protect the city of Winnipeg (Armstrong, 2008). More recently, the 2011 Assiniboine flood proved to be the most costly, reaching over 1 billion dollars (Gerrard, 2012). Over the years, federal, provincial and local governments, along with independent property owners, have spent millions of dollars to build structures in response to mitigating floods. Despite the tremendous financial investments in flood control works it is evident that over the years, spring flooding has presented the occupants of the Red River Valley in south-central Manitoba with one of the most costly environmental hazards in Canada (De Loe, 2000).

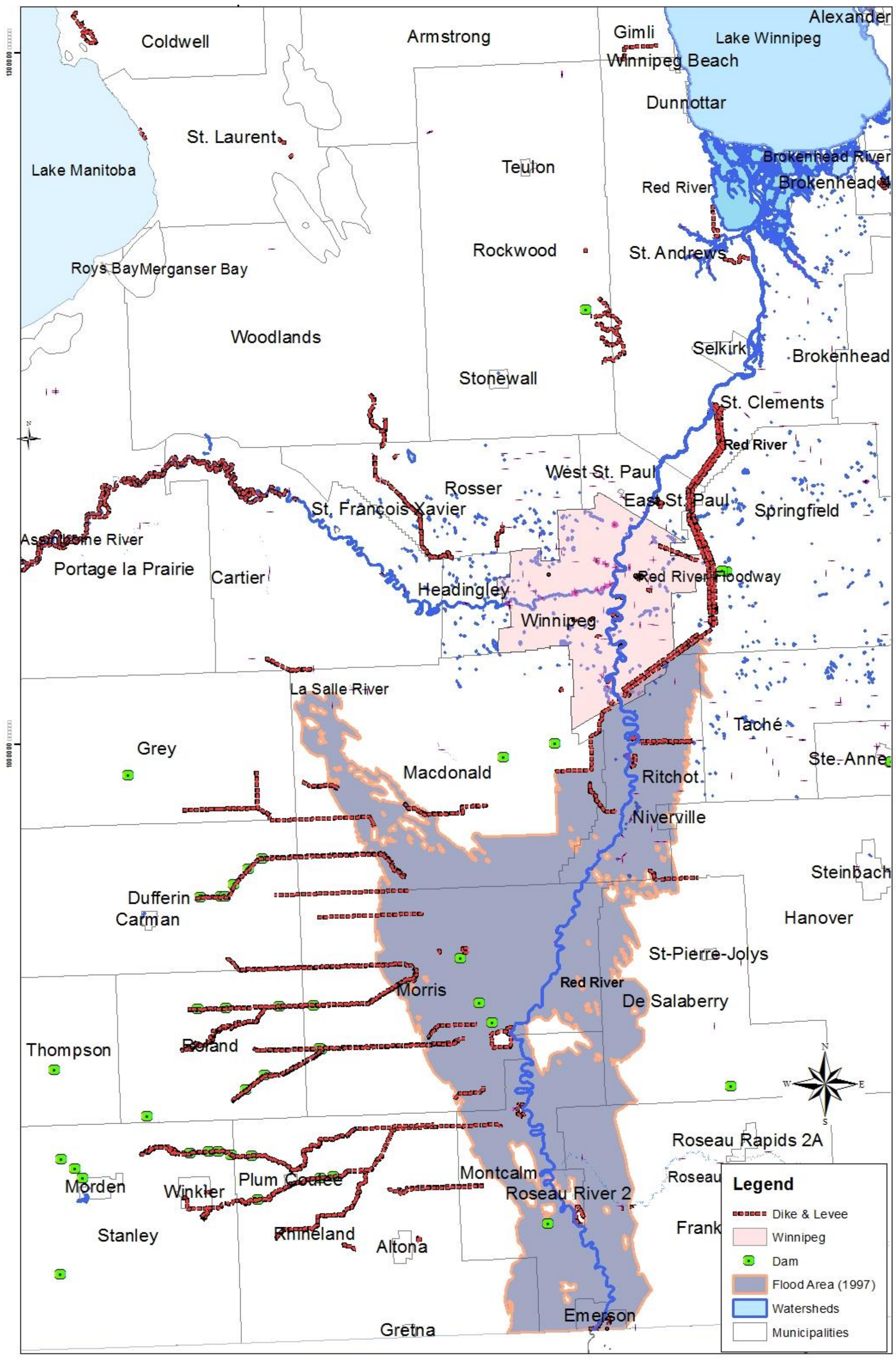

Figure 1.4 illustrates perimeter of 1997 flood and location of Flood Control Works.
Source: Adapted from Government of Manitoba (MLI) , 2015.

Disaster Financial Assistance Arrangements (DFAA)

When response and recovery costs exceed what individual provinces or territories can afford to fund, the Disaster Financial Assistance Arrangements (DFAA) provide the Government of Canada with a fair and equitable means of assisting Provincial and Territorial Governments. A province or territory may request Government of Canada disaster financial assistance when eligible expenditures exceed an established initial threshold (based on provincial or territorial population). As of January 31, 2015, the initial threshold is defined as $1 per capita of the provincial population (as estimated by Statistics Canada to exist on July 1st in the calendar year of the disaster). Once the threshold is exceeded, the federal share of eligible expenses is determined by the cost-sharing formula (Table 1.1). In addition, effective February 1, 2015, the initial threshold for all new events is defined as $3 per capita of the provincial population (as estimated by Statistics Canada to exist on July 1st in the calendar year of the disaster). Once the threshold is exceeded, the federal share of eligible expenses is determined by the formula detailed in Appendix A on the Government of Canada Website:
http://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/rcvr-dsstrs/dsstr-fnncl-ssstnc-rrngmnts/index-eng.aspx.

The authority to provide financial assistance rests with the Governor in Council who may, on the recommendation of the Minister, make an order as required under the Emergency Management Act declaring a provincial emergency to be of concern to the Government of Canada. The Minister is the final authority regarding eligibility of events and expenditures, and amounts of payments to be made through the DFAA. The provision of any federal financial assistance to provinces is at the discretion of the Government of Canada (Public Safety Canada (PSC), 2015). In response to the 2011 flood, the Minister of Public Safety, paid out an

Table 1.1. Disaster cost-sharing formula in Canada

Eligible provincial expense thresholds (per capita of population)		Government of Canada share (percentage)
Up to 31 January 2015	**From 1 February 2015**	
First $1	First $3	0
Next $2	Next $6	50
Next $2	Next $6	75
Remainder	Remainder	90

Source: Public Safety Canada, 2015.

additional $50 million in federal funding under the Disaster Financial Assistance Arrangements (DFAA) program for response and recovery costs incurred by the Province of Manitoba. This second payment brings the federal contribution for the 2011 spring flood to $100 million thus in Canada (Public Safety Canada (PSC), 2015). The initial $50 million payment was made in November 2011. "This second payment of $50 million to the Province of Manitoba underscores our Government's commitment to helping Canadians and their communities recover from natural disasters like the unprecedented flooding in the spring and summer of 2011," said Minister Vick Toews. "Manitobans are undertaking the largest flood recovery in decades and we are supporting families and the 141 affected municipal governments with unprecedented compensation and resources for rebuilding," said Manitoba's Infrastructure and Transportation Minister Steve Ashton. As stated by Public Safely Canada, 2012, "With the cost of the flood estimated at more than $1 billion, we look forward to continued collaboration with the Federal Government to help people get their lives back to normal." Severe flooding throughout the Province of Manitoba in 2011, caused by the spring break up, resulted in both public and private property damage and the evacuation of several thousand residents. Since its inception in 1970, the DFAA program has provided more than $2.1 billion in disaster financial assistance to the provinces and territories Canada (Public Safety Canada (PSC), 2012).

Government Cost-Sharing Arrangements

Provincial and Municipal Governments provide various forms of disaster relief. Since Manitoba's 1997 flood, Emergency Measures Organization (EMO) provides up to $100,000 compensation for eligible expenses, subject to a 20 percent deductible for approved costs (IJC, 1997). In general, cost-sharing arrangements place a heavier burden on senior governments for extreme losses. The DFAA generally defines eligible costs as those related to restoring public works to pre-disaster conditions, and replacing and repairing basic or essential personal property (EPC, 1999). The intent is to prevent recipients from financing home or building improvements through taxpayers' contributions. However, this coordination means that the future damage potential is maintained rather than reduced. Manitoba has followed this limited approach far too long. As defined by the UNISDR, prevention contributes to lasting improvement in safety and is essential to integrated disaster management (Henstra and McBean, 2005).

Flood Mitigation Perception

Structural measures alter the stream flow of rivers and channels, resulting in the reduction of the frequency and severity of floods. In Manitoba's Red River Basin and elsewhere, structural measures have often encouraged floodplain occupancy and produced a false sense of security, as people assume that the flood risk has been eliminated (Environment Canada, 1993). As stated by Hewitt, (1997) when people and buildings at risk are moved out of the flood-plains they are no longer subject to floods, including those that might occur if upstream dams fail. During the 2005 Hurricane Katrina catastrophe, New Orleans experienced breach of levees and as a result the risk impacts were greater where the water poured through the levees. Their experience justified that when floods exceed the design capacity of dams and levees, consequently vulnerability to damages can be greater than those which would have occurred had the structures not been built (Askew, 1991). A combination of structural and non-structural adjustments would be ideal. This theory has long been advocated as a requirement for effective floodplain management (White, 1945; Shrubsole et al., 1995).

Report on Manitoba's Future Flooding Disasters

At the request of the Federal Government of Canada and the United States, the International Joint Commission (IJC) established an International Red River Basin Task Force to investigate the causes and effects of the 1997 flood and make recommendations on measures to reduce the impacts of future floods. The Task Force made it clear in their post-flood report that the basin remains at undue risk from floods larger than 1997 (Olczyk, 2005). "A flood equal to the flood of record in 1826 could lead to the evacuation of at least 300,000 people and cause damages of as much as $5.8 billion "(IJC, 2000). For comparison, in 1997 "the peak calculated natural flow at the Forks was 63,000 cfs [and] the flow during the 1826 flood is estimated to have been 225,000 cfs" (IJC, 2000). Based on current hydrologic knowledge, a flood equivalent to the magnitude experienced in 1826 would overwhelm the reliable capacity of Winnipeg's flood control works as displayed in Table 1.2, and evacuate at least 300,000 residents with damages estimated at $5.8 billion (IJ C, 2000). "The current reliable capacity of the Winnipeg flood protection works has a 37 percent probability of being exceeded at least once in the next 50 years" (IJC, 2000).

Table 1.2 Demonstrates the capacities of Winnipeg's Flood Protection Systems.

Component	Design Capacity	1997	Reliable Capacity
Shellmouth Reservoir	7000 cfs	4000 cfs	7000 cfs
Portage Diversion	25,000 cfs	11,900 cfs	25,000 cfs
Red River Floodway	60,000 cfs	67,100 cfs	730,00 cfs
River Channel	77,000 cfs	80,000 cfs	71,000 cfs
Totals	169,000 cfs	163,000 cfs	Up to 176,000 cfs

Source: Compiled from IJC, 2000

The IJC report identified 57 ways in which Winnipeg would be vulnerable to inundation if a flood larger than 1997 were to occur (IJC, 2000). These were reduced into eight categories:

1. Overall Flood Protection System. These vulnerabilities include limitations on the overall capacity of the flood control system, inadequate detailed emergency preparedness and response plans, floodplain development that limits flexibility and may affect public safety, and flood monitoring concerns.

2. Red River Floodway Inlet Structure. If the embankments near the inlet structure erode or fail, floodwaters could bypass the inlet. The control system could fail in ways that would make it impossible to control gates - for example, fire in the inlet structure. Other issues include damage from ice, debris, or sabotage, and the need for clarity and understanding of the operating rules.

3. Red River Floodway Channel. Bridge failures could restrict the Floodway capacity. The embankments could fail. A failure of the Seine River Syphon could breach the West Embankment of the Floodway and allow an uncontrolled flow of up to 15,000 cfs (425 cms) to enter the city from the Seine River. Many services, such as water and electricity, are vulnerable under certain circumstances as they cross the Floodway channel, but that risk appears low.

4. West Floodway Embankment. If any portion of the first three miles (a.8 km) of the West Embankment (between the Floodway itself and the city) is breached, an uncontrolled flow of water would enter the south or east side of Winnipeg.

5. West Dike. Failure of the West Dike (the long dike extending from the Floodway Inlet Structure toward the town of Brunkild) through wind action, overtopping, or other causes would lead to uncontrolled flows into south Winnipeg by way of the La Salle River.

6. Flood Protection Infrastructure within Winnipeg. The city itself is subject to a number of internal vulnerabilities. These relate to the primary and secondary diking systems and to the flood-pumping stations and floodgate chambers. When river levels are high, floodwater can enter the city through the storm water or sanitary sewer system. There is no guarantee that the many temporary measures taken during the 1997 flood would be as successful again, even for a flood of the same magnitude.

7. Portage Diversion. The major threat is that the break-up of ice jams upstream of the diversion reservoir could cause a surge of ice and water and damage the system. Failure of the system for any reason could reduce the flow diverted to Lake Manitoba and hence increase flows toward Winnipeg.

8. Shellmouth Dam. The gates could fail, or the dam could breach or fail from erosion. While a Shellmouth dam failure would have severe consequences immediately downstream, the effect on flood protection levels in Winnipeg would be relatively minor.

Based on these significant vulnerabilities and associated risks the province is working with consultants on a feasibility flood protection study with options to raise the flood protection works for Winnipeg. IJC's report recommends that the design flood standards for flood protection works should be the highest that can be economically justified or at a minimum built to the 1826 flood levels (IJC, 2000). To meet this requirement, the most feasible solution would be the expansion of the Floodway which would provide protection up to a 1 in 700 year flood, well above the 1826 levels which is equivalent to a 1 in 300 year flood. Although IJC's solution to implementation of physical structural measures can assist us with flood mitigating, one of the problems with relying too heavily on structural measures is that they provide a false sense of security (Kumar et al., 2000). Many studies have advocated for the combination of both structural and non-structural approaches as a solution to mitigate flooding. Wright states, "as opposed to relying solely on structural mitigation we need to look at a combination of structural and non-structural approaches as practicable measures to minimize the detrimental impacts of floods" (Alexander, 2000).

Non-Structural Mitigation

By the late 1960's and early 1970's Canada's attention turned to non-structural mitigation measures. Initially, non-structural measures were seen as a more lucrative and environmentally nonthreatening approach to floodplain management as opposed to structural mitigation measures. The advantage of non-structural measures involves (e.g. floodplain management policies; warning systems; education; forecasting capabilities; zoning bylaws). These measures greatly expand the range of resources and adoptions available for adjusting human practices on the floodplain. Non-structural mitigation measures seek to identify the parts of a social system specific to reducing vulnerability including behaviors and perceptions (Pal, 2002). In Canada all levels of government share the responsibility to protect Canadians (Department of Justice

Canada, 2007). In 2007, the Canadian Parliament enacted the Emergency Management Act: a primary legislative umbrella which defines the roles and responsibilities for all federal departments across the full spectrum of emergency management. These include prevention/mitigation, preparedness, response and recovery, and critical infrastrcture (Department of Justice Canada, 2007). Each of the departments is directed by this Act to identify the risks from natural disasters related to their sphere of resonsiblitlty, and to devleop emergency mangement plans and supporting strategies. Public Safety Canada (PSC) and Defence Research Development Canada (DRDC)'s Center of Security Science support all Federal Government institutions in fulfilling their legislated responsiblitity (PSC, 2010). In response to this mandate, various federal departments are investigating the development and implementation of tools designed to produce Quantitative Risk Analysis (QRA).

Quantitative Risk Assessment

Proper pre-disaster planning and preparedness can not only save human lives but can also reduce the negative impacts of hazards in general. Natural hazard risk assessment is central to risk reduction as well as to the emergency management planning process. Quantifying Risk Assessment is the process of measuring impacts resulting from natural hazards in terms of likelihood and consequences (Slovic, 1987). It is estimated as a combination of hazard, exposure and respective vulnerability where hazard is a measure of the probability of a given intensity of a naturally occurring phenomenon that may pose a threat over a given geographic extent and time period; exposure (or inventory) refers to the elements at risk, i.e., built environment, population; and vulnerability introduces the concept of susceptibility to damage, loss and injuries. Note that sometimes the term "risk analysis" is instead used to indicate understanding of the hazard potential and associated negative impacts to people and the built environment (Public Safety Canada, 2010). Flood risk refers in particular to all probabilities and associated damage, and economic and social losses caused by flooding. The output of the risk assessment process is a standard understanding of consequences expressed as physical damage, economic and social losses, and the likelihood of their occurrence. In Manitoba there has been attempts to develop a virtual GIS database by the International Joint Committee (IJC) with the objective to quantify natural hazards. This geo-spatial database is known as the Red River Basin Disaster Information System (RRBDIN). The RRBDIN was designed with the objective to become a decision-making support tool for flood-related emergency management in the river basin, and to make data available to both Canada and the US decision-makers responsible for solving flooding problems. After the first phase of development in 2000, a number of challenges identified the lack of geo-spatial data and technological limitations for the implementation of internet-based tools (Simonovic and Akter, 2006). It was concluded that further improvements, resources and maintenances of the RRBDIN would be required **(**Bender et al.,2000).Hazus-Multi-Hazard (MH) technology has been applied as a QRA tool in the U.S and assisted decision makers with development in the flood plain zones. This has also assisted decision-makers with mitigating vulnerable structural development where a flood would incur economic loss to the county, state and at a national level. Unlike other GIS tools, Hazus-MH is design specifically for natural disasters quantify and produce lost estimates.

Hazus-Multi-Hazard (MH) – Quantitative Risk Assessment (QRA) Tool

Hazus is a quantitative loss estimation methodology and software tool developed by the US Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences (NIBS). It supports risk-based planning activities that promote national disaster mitigation policies in the United States (Mickey and Coats, 2013). Hazus is designed to produce loss estimates for use by federal, state, regional and local governments and private enterprises in planning for risk mitigation, emergency preparedness, response and recovery. Hazus-MH is a risk assessment tool for analyzing potential losses from floods, hurricane winds and earthquakes. Hazus-MH has been developed and maintained by FEMA for over 20 years and is designed to work specifically with US datasets. When applying the Hazus flood model the user can evaluate losses from a single flood event or for a range of flood events allowing for annualized estimate of damages. In the case of Minnewaukan, North Dakota the computer visualization of flood risk, provided by Hazus-MH through incremental inundation maps and damage elevation profiles, enables individuals and decision-makers to better understand both personal risk and community risk. In addition, by quantifying the risk in dollars, Hazus has stimulated local and state government to identify and pursue appropriate mitigation measures (Mickey, 2012). Although Hazus has been calibrated as a QRA tool within a US context, this study will evaluate the pretention of Hazus as a QRA tool within a Canadian context. Hazus adaptation for use in Canada started in 2011. Although the flooding model still remains in a BETA version, studies in Canada are currently evaluating the robustness of the Hazus technology to produce a Quantitative Risk Analyses (QRA) for flooding disasters. Finally, by applying the Hazus model in the study area of the Rural Municipality (RM) of St. Andrews, this study will evaluate the role of a QRA tool in the design of public policies and development processes in a flood risk area. The Hazus-MH QRA tool will be discussed further in chapter 3.

1.2 Research Purpose and Objectives

The research is a component of a larger project with the objective to provide a methodology to evaluate, "Hazus-MH" a Quantitative Risk Assessment tool in public policy to reduce the cost of recovery and regulate land development in the Red River Basin, Manitoba, Canada. The Hazus technology represents an extensively applied and well documented GIS-based framework for risk estimation of natural hazards in the US (FEMA, 2014). This study has been funded by Natural Resources Canada and involves various institutions working together in partnership to evaluate the potential of Hazus for fulfilling the requirements of Emergency Measures Organization (EMO) within a Canadian context in particular by focusing on flooding events in Manitoba. Hazus in a Quantitative Risk Assessment (QRA) tool and decision-support tool for natural hazard risk mitigation and emergency management (Nastev and Todorov, 2013). Hazus models physical damage and economic and social losses for natural hazards such as earthquakes, floods and hurricanes (FEMA, 2014). Currently, only the earthquake module is available in the Canadian version; the flood module is presently being adapted in collaboration with Public Safety Canada and Environment Canada (Nastev and Todorov, 2013). The primary goal of this research is to evaluate the role of a Quantitative Risk Assessment (QRA) tool in Manitoba and its application to policy. The specific study objectives are two-fold:

1) Evaluate Hazus-MH as a QRA tool in Manitoba's Red River Basin to determine if a QRA tool can influence decision-makers to mitigate development in flood risk areas.

2) Examine the application of a Quantitative Risk Assessment tool in policy to reduce the cost of recovery.

In order to attain the first objective the following were achieved: Knowledge of the Hazus-MH software; establishing a study area in the (RM) of St. Andrews, Manitoba to pilot the Hazus-MH; collecting and analyzing local data; piloting the Hazus tool with Manitoba data. The second objective utilizes a face-to-face questionnaire with flood experts in municipal and provincial government, and consultant organizations to determine: a) land development processes in flood plains b) role of technology c) public policy process, in mitigating and responding to flood risk in the Red River Basin. The questionnaire involved two sets of questions, open (long questions) and Likert format ranked questions. The first set of question (long questions) were open-ended discussion style questions and were analyzed using a qualitative approach while the second set of questions were structured as rank order Likert format and were analysed using quantitative approaches. Quantitative analysis of the ranking question responses was first performed using perceptual mapping to visualize independent responses and their relationship. Secondly, the ranking responses were thematically grouped by organizations, to calculated frequencies of responses. This study will establish two-fold, if and how the Hazus tool can be applied in a Manitoba context as a standard QRA tool to inform decision-makers and secondly examine the link between QRA tool and policy to empower land use regulations and reduce the cost of recovery.

Rational of Study

This type of research is necessary as Manitoban's living or developing along the Red River Basin remain at risk of flooding. As identified earlier a flood larger than 1997 could realistically occur in any given year (IJC, 2000). In Manitoba, poor enforcement of land regulations in flood risk areas has been an ongoing weakness (Shrubsole, 2000). In addition, legislated ministerial powers have not been used in instances of non-compliance (Hawkins-Bowman and Newbury, 1999). These deficiencies affect the capabilities and efficiency of policies designed to regulate land development in flood risk areas. As flood cost continues to increase decision-makers in municipalities and in various levels of government are facing a pressing need to implement methods for risk assessment in order to identify communities at risk of flooding. Case studies have proven that a standard Quantitative Risk Analysis (QRA) tool can inform decision-makers and empower policies to reduce the cost of recovery. Hazus-MH may represent a standardized methodology for estimating potential losses from natural hazards and could assist decision-makers in Manitoba with being more pro-active in preparedness and response procedures and reduce the cost of recovery.

Chapter 2
Study Area

2.1.1 Introduction

The study area selected for this research is the Rural Municipality (RM) of St. Andrews. The RM of St. Andrews presented in Figure 2.1 is located west of the lower Red River and extends north from the City of Winnipeg to the south end of Lake Winnipeg. The RM of St. Andrews contains the communities of Winnipeg Beach, Lockport, Clandeboye, Petersfield, including several smaller communities along the Lake Winnipeg shore (Land Resource Unit, 1999). The lower Red River runs through the municipality of St. Andrews and extends to the Assiniboine River confluence in Winnipeg (The Forks) to the Red River outlet at Lake Winnipeg. The lower reach of the Red River between Winnipeg and Lake Winnipeg specifically in the municipality of St. Andrews is prone to ice jam flooding. The most downstream portion of this river flows through a delta and marsh system that has almost no associated elevation gradient and empties to an outlet mouth on the lake that retains ice cover several days to weeks after the River thaws. The impact of ice jam flooding is exacerbated by low-lying adjacent topography and river banks allowing water to spread well beyond the channel boundary. The overall flat topography and large fetch on Lake Winnipeg also results in periodic seche events (wind driven flooding), providing an additional risk to properties adjacent to the delta marsh. The flood of 2009 proved to be one of the most challenging especially downstream of the city of Selkirk. This area underwent flooding of a magnitude that had not been experienced for a century and a half (Wazney and Clark, 2015). Recent years of severe ice jamming with flooding are 1996, 2004, 2007, 2009, 2010 and 2011 (Karl-Erich and Maurice, et al.,2012).

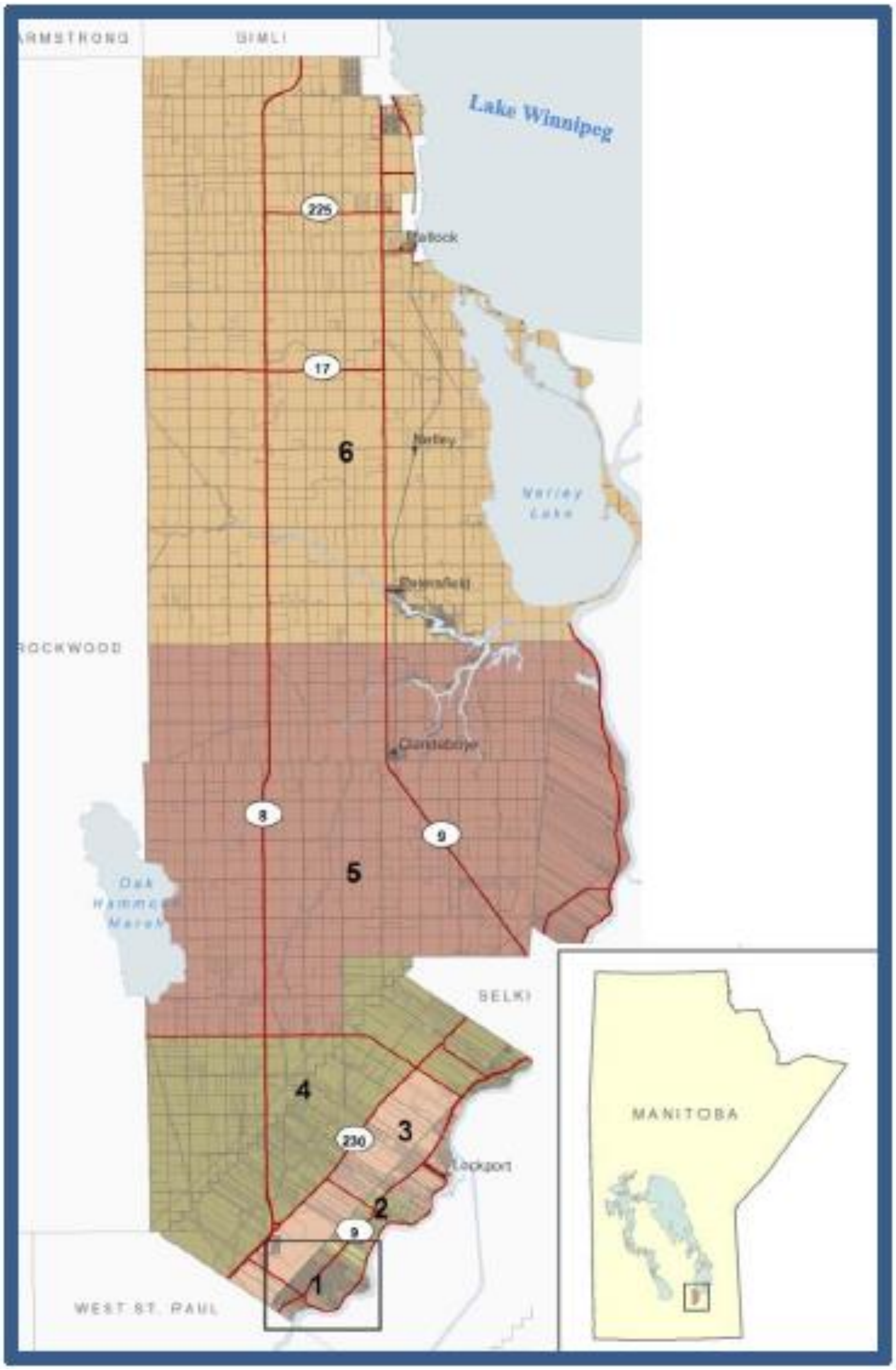

Figure 2.1 Rural Municipality (RM) of St Andrews, Manitoba
Source: Adapted from Government of Manitoba MLI , 2015

2.2 Physiography

The RM of St Andrews includes part of the Red River Valley and a portion of the Lake Winnipeg Terrace extending south from the west shore of Lake Winnipeg (Canada-Manitoba Soil Survey, 1980). Elevation of the land surface in the south slopes gradually from 228 m above sea level (asl) to 225 m near the Red River, and in the north from 240 m asl to 214 m asl on Lake Winnipeg. Local relief is generally under 3 metres and slopes are less than 2 percent. Surface gradients range from 0.4 to 0.6 m/km (2.2 to 3.3 ft/mi) in the south to 2 m/km (11 ft/mi) in the north. Surface drainage throughout the municipality is poorly developed with Netley, Wavey and Parks creeks draining to the Red River which flows north through Netley Marsh to Lake Winnipeg. Between Selkirk and Lake Winnipeg, the river flows through a delta system called the Netley-Libau Marsh. The marsh is flat and consists of many small bodies of water interconnected by a network of channels with the Red River. Due to backwater effects from Lake Winnipeg, the water level gradient along the most downstream portion of the river, between Lockport and Lake Winnipeg, is essentially almost flat (<0.00001 m/m). Much of the area is characterized by high groundwater levels with artesian waters surfacing along the west shore of Lake Winnipeg. Drainage for agricultural purposes has been improved by a network of man-made ditches (Land Resource Unit, 1999).

2.3 Geography

Land in the RM of St. Andrews is categorized in seven various classes identified in Figure 2.2. The agricultural land, make up the largest class covering 58 percent of the area. The grassland portion covers 15 percent and the tree class covers 8.5 percent. Together these two classes provide forage and grazing capacity as well as wildlife habitat. The wetlands and water class cover 12 percent of the area, primarily adjacent to Lake Winnipeg and provide waterfowl habitat and potential recreation activities. Various non-agricultural uses such as infrastructure for urban areas, transportation and recreation occupy about 5 percent of the municipality (Land Resource Unit, 1999).

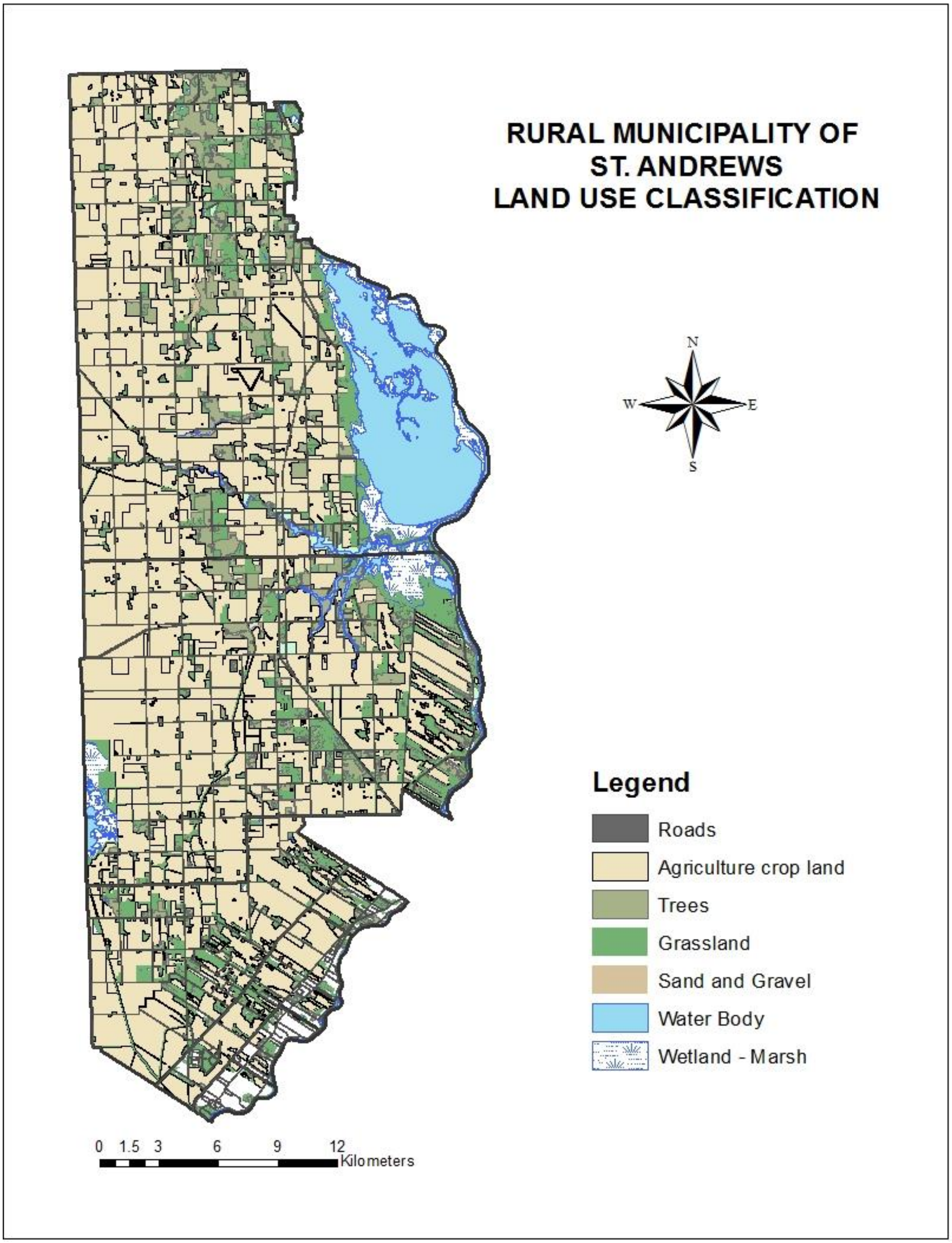

Figure 2.2 RM of St. Andrews Land classification map
Source: Adapted from Government of Manitoba MLI, 2015.

2.4 Soil

The majority of soils in the RM of St. Andrews have moderate to moderately severe limitations for arable agriculture. However, clay textured soils require management practices which maintain adequate surface drainage, soil structure and tilth. A major portion of the municipality has low relief and is primarily composed of poorly drained soils. These soils are frequently saturated and subject to surface ponding, particularly during spring runoff or following heavy rains. Consequently, improvement and maintenance of water management infrastructure on a regional basis is required to reduce surface ponding while maintaining adequate soil moisture for crop growth (Land Resource Unit, 1999).

2.5 Climate

Floods in the lower reaches of the Red River have always been associated with the spring snowmelt. Although snow only makes up about 17% of the total yearly precipitation, its accumulation in combination with other factors has been the main cause of general river overflows. The major factors which may contribute to flooding in the Red River valley are produced by a combination of circumstances. These circumstances are defined as follows: Abnormally wet conditions during the previous summer and autumn cause the ground to be saturated prior to freeze-up, and fill available natural water storage sites in the basin; Severe freezing before the first significant snowfall permits frost to penetrate deep and reduce infiltration during the subsequent spring runoff period; A cold winter with minimal thawing and heavy snow over the entire watershed produces a large snow pack at the beginning of spring; A late spring, which delays the release of meltwater, is followed by rapid warming that releases most of the stored water within a few weeks. Floods may be exacerbated by a south-to-north progression of melt, which maximizes local contributions as the flood crest moves downstream by abundant rainfall during the rising phase, and by southern winds which increase water elevation in the northern flood zone. Conditions prior to and during the 1826 flood satisfied these requirements in all respects (Rannie, 1998).

2.6 History of the Red River Basin

The Red River Basin occupies a large geographic area encompassing portions of North Dakota, north western Minnesota, southern Manitoba, and a small part of north eastern South Dakota (Olczyk, 2005). The basin covers approximately 45,000 square miles (116,500 square kilometres) of land, excluding the Assiniboine River Basin, and drains into Lake Winnipeg in Manitoba (IJC, 2000). Throughout most of its length, the river occupies the lowest portion of the Lake Agassiz Plain, a large expanse of proglacial lacustrine deposition laid down during the late stages of the Wisconsin Glaciation. The main component of the basin is the Red River Valley, "measuring 17,000-square miles [44,000 square kilometres]. This valley is as a remnant of glacial Lake Agassiz and is the flattest part of the basin. At its widest point the valley spans 60 miles (95 kilometres) across and extends for 315 miles (500 kilometres) in length (Krenz and Leitch,1993). The focal point of the valley is the Red River, which forms in 'Wahpeton, North Dakota with the convergence of the Bois de Sioux and Ottertail Rivers and flows northwards through a pattern of meanders until it empties into Lake Winnipeg. From the border the river continues northward for 250 kilometers to Lake Winnipeg.

In Manitoba, the Red River became established on the lake bed between 7800 and 8200 carbon (14) years B.P., as the lake waned and receded northward (Fenton et al., 1983; Teller et al., 1996). The river has since eroded a shallow valley into the clay plain, up to 15 m deep and 2500 m wide, that contains the genetic flood plain of the river. The flood plain and the contemporary river- banks are composed predominantly of silt alluvium; as a result, the river represents an example of a mud-dominated stream. The flatness of the basin is defined by the northward slope of the river, which is variable and averages less than one-half foot per mile. The gradient on this lake-bed is gentle, averaging two to three feet per mile for ten to fifteen miles on either side of the river and only about .05 feet per mile along the river channel (Clark, 1950). As a result, velocities are low and uncontrolled overbank flow often spreads over a wide area where it may flood for weeks. Over time the Red River basin has created an excellent environment for flooding as natural drainage is poor, gradient of the slope of the basin is low, and the flows of the Red and Assiniboine Rivers, which carry excess water north, can be quite slow (Bumsted, 1987).

2.7 Structural Mitigation Measures in Study Area

The total drainage area of the Red and Assiniboine river watersheds is approximately 287,500 km^2. A lock and dam is situated at Lockport, which was built in 1910 to allow navigation along the river between Winnipeg and Lake Winnipeg. The dam has steel curtains that dam the river for navigation and roll up to allow flood waters from the spring freshets to pass. The lock and dam was built to allow navigation over a series of five rapids including an approximate 4 m drop in elevation around Lister Rapids. Just downstream of Lockport is the outlet of the Floodway, a channel that diverts spring floodwaters from the Red River south of Winnipeg to protect the city of potentially high flooding. Between Selkirk and Lake Winnipeg, the river flows through a delta system called the Netley-Libau Marsh. The marsh is very flat and consists of many small bodies of water interconnected by a network of channels with the Red River. A

400 m long cut, Netley Cut, short-circuits water from the river into Netley Lake. Figure 2.3 identifies the flow of the lower Red including structural works from Lockport to Lake Winnipeg (Karl-Erich, et al., 2012).

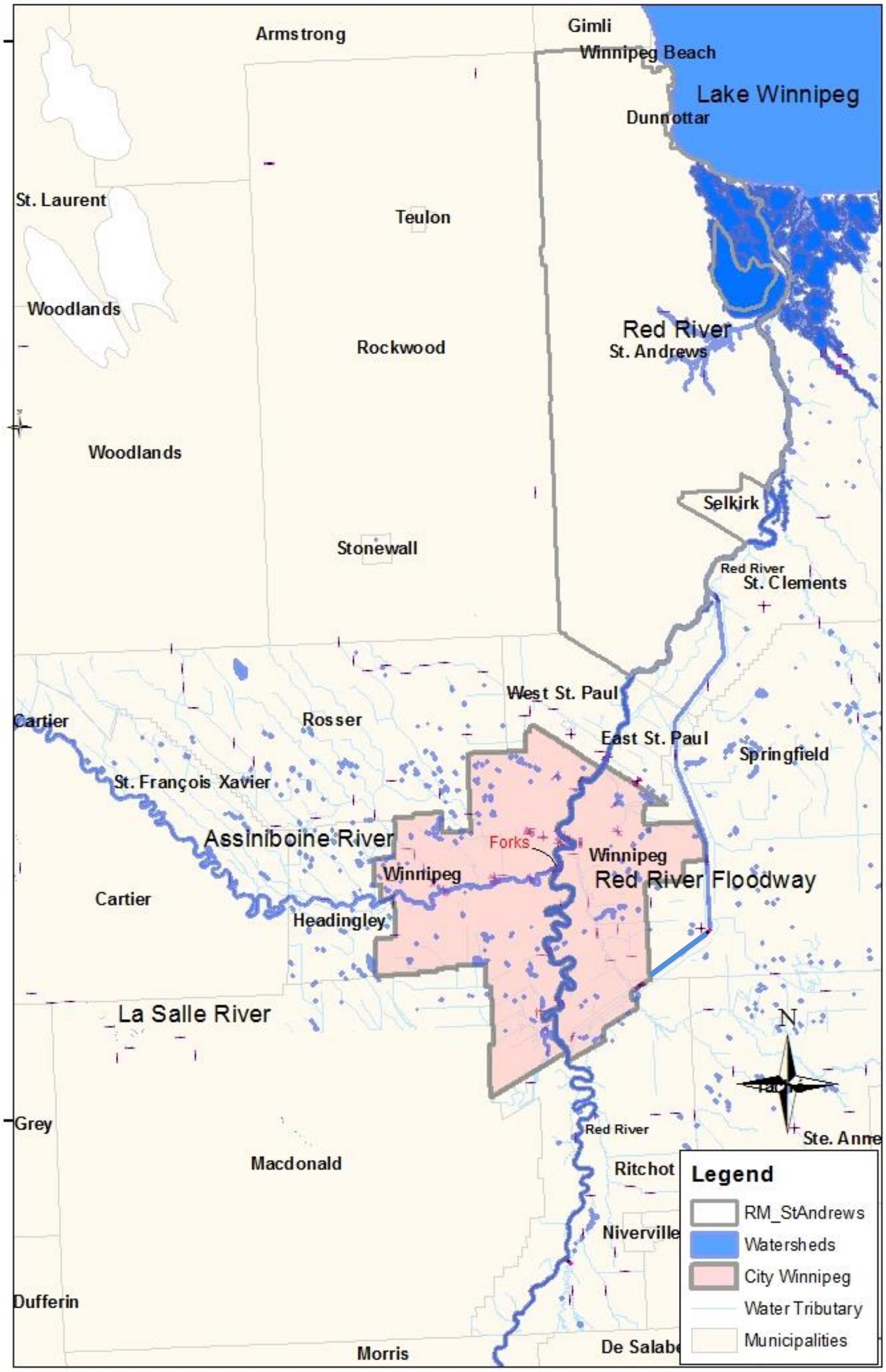

Figure 2.3. Lower Red River between the Forks in Winnipeg and Lake Winnipeg.
Source: Adapted from Government of Manitoba MLI , 2015.

2.8 History of Ice Jam Flooding

The ice cover season along the Lower Red River generally extends from November to April. Once the ice-cover is formed it measures 1m thick and usually remains in place throughout the winter season. Ice jams are a common occurrence during the onset of spring flooding along the Red River, especially at its most-downstream reach between Winnipeg and the river's confluence at Lake Winnipeg. As identified by Farlinger and Westdal, (2010), Ice jams have occurred in this area for all of recorded history and are a frequent problem in regards to local flooding. Trends show that the spring flood hydrographs begin earlier and rise steeper than in past decades. Historical newspaper articles indicate that serious ice jams occurred on the Red River near Selkirk as early as the mid to late 1800s. Typically, the ice cover initially opens at the North Perimeter Bridge and over the next few days ice moves in the reach between the North Perimeter Bridge and Selkirk. On occasion, ice jams along this stretch cause local flooding, as was the case along River Road (Ward 1) in the spring of 2009. The ice movement is often blocked at Selkirk and forms a jam. This usually causes flooding of the east approach to the Selkirk Bridge, thus requiring the bridge to be closed to traffic. The jam pushes past Sugar Island to the PTH 4 Bridge. Parallel to these events, the ice cover may break up north of PTH 4 Bridge and cause jamming at various points downstream to the Netley Creek confluence. Ice then moves further downstream as presented in Figure 2.5 and its initial surge is diverted into Netley Lake through Netley Cut. Jamming in this area very often is accompanied by water backup into Netley Creek causing local flooding. Recent years of severe ice jamming with flooding are 1996, 2004, 2007, 2009, 2010 and 2011 (Karl-Erich, et al., 2012).

Figure 2.4 Identifies of Ice jam at Netley Cut on 29 March 2010.
Source: Rural Municipality of St. Andrews, 2014.

2.9 Flood of 2009

The 2009 spring flood was the fourth highest on the Red River in Manitoba, since 1826. Flooding in the Red River watershed was worse due to unusual ice conditions which caused blocks in the drainage system and raised river levels beyond what would have occurred under normal conditions. River levels from St. Adolphe to Breezy Point were particularly affected by ice. River ice was generally of average thickness, based on an early March survey, but was unusually strong due to a cold winter and a two-week cold spell from late March to early April which kept river ice from deteriorating before spring run-off. Ice jams developed on the Red River when high flows resulting from the March snow-melt in the United States portion encountered strong, solid ice in the Manitoba portion (Government Manitoba, 2009). Ice jams in the Breezy Point and St. Peters Road areas raised the Red River about 2.74 metres (9 feet) overnight, at up to 0.6 metres (2 feet) an hour, to record levels. For the first time in history equipment known as the Amphibex machine had to be utilized to break the ice. When ice jams occur along the Red River in Winnipeg they can hinder the operation of the Floodway, which was evident in the flood years of 1997 and 2009. Large ice pans did move into the Floodway during both events causing ice accumulations at the first bridge, St. Mary's Road Bridge, crossing the diversion channel. The accumulation at the St Mary's bridge during the 2009 event required mechanical removal of the ice flows using 15 extended-reach excavators (Amphibex) for a continual period of three days before the ice cleared the channel (Lindenschmidt,et ,al., 2011). The greatest success of the 2009 flood was the protection provided by operation of major flood controls. Operation of the Red River Floodway, Portage Diversion and Shellmouth Reservoir reduced the crest in Winnipeg by 10 feet, preventing approximately $10 billion in damages. Overall, an estimated 250 homes were damaged (Government of Manitoba, 2009).

2.10 Government Funding

The RM of St. Andrews has also taken advantage of government funding programs to assist homeowners with flood structural mitigation measures. The Federal and Provincial Governments contributed 90% of the cost of the ring dikes with the local rural municipality paying the remaining 10%. Similarly, almost all rural individual homes and farmsteads upstream of the floodway inlet will be protected to the same level (1997 plus 2 ft.). Approximately 90% of the cost went towards either ring dikes or the raising of structures on earthen mounds in the areas affected by spring flooding of the Red River and tributaries (Farlinger and Westdal, 2010).

2.11 Property Buyouts and Future Land Use

In the RM St. Andrews, flooding occurs only in certain locations. As illustrated in Figure 2.6, the areas around the Netley Creek, Petersfield, Breezy Point, Little Britain, Lockport, St. Andrews, and Less Crossing flood regularly (Maness, 2015). After the 2009 flood, the Winnipeg Free Press (2009) reported on the mitigation measure taken by the Province of Manitoba to buyout homes in the flood prone area of Breezy Point in the RM of St. Andrews. Fourty-two cottages and homes in Breezy Point North, were heavily damaged during the 2009 spring flood when ice jams along the Red River caused flash flooding. Winnipeg Free Press, Kusch, (2010) reported that minister Stan Struthers stated “flood-prevention and protection measures in the area were not viable, and flooding would continue to pose a risk to the lives of both cottagers and rescue personnel as long as settlement remained in the area”. Due to these facts the Province of Manitoba initiated a buyout of these properties. All 42 homes were bulldozed and the land has returned to its natural state. This land will remain vacant, unoccupied Crown Land. Meanwhile, the RM of St. Andrews has bought out four flood-prone homeowners on private land just south of the Breezy Point Crown-held area. The deal was estimated to cost more than $1 million. (kusch, 2010).

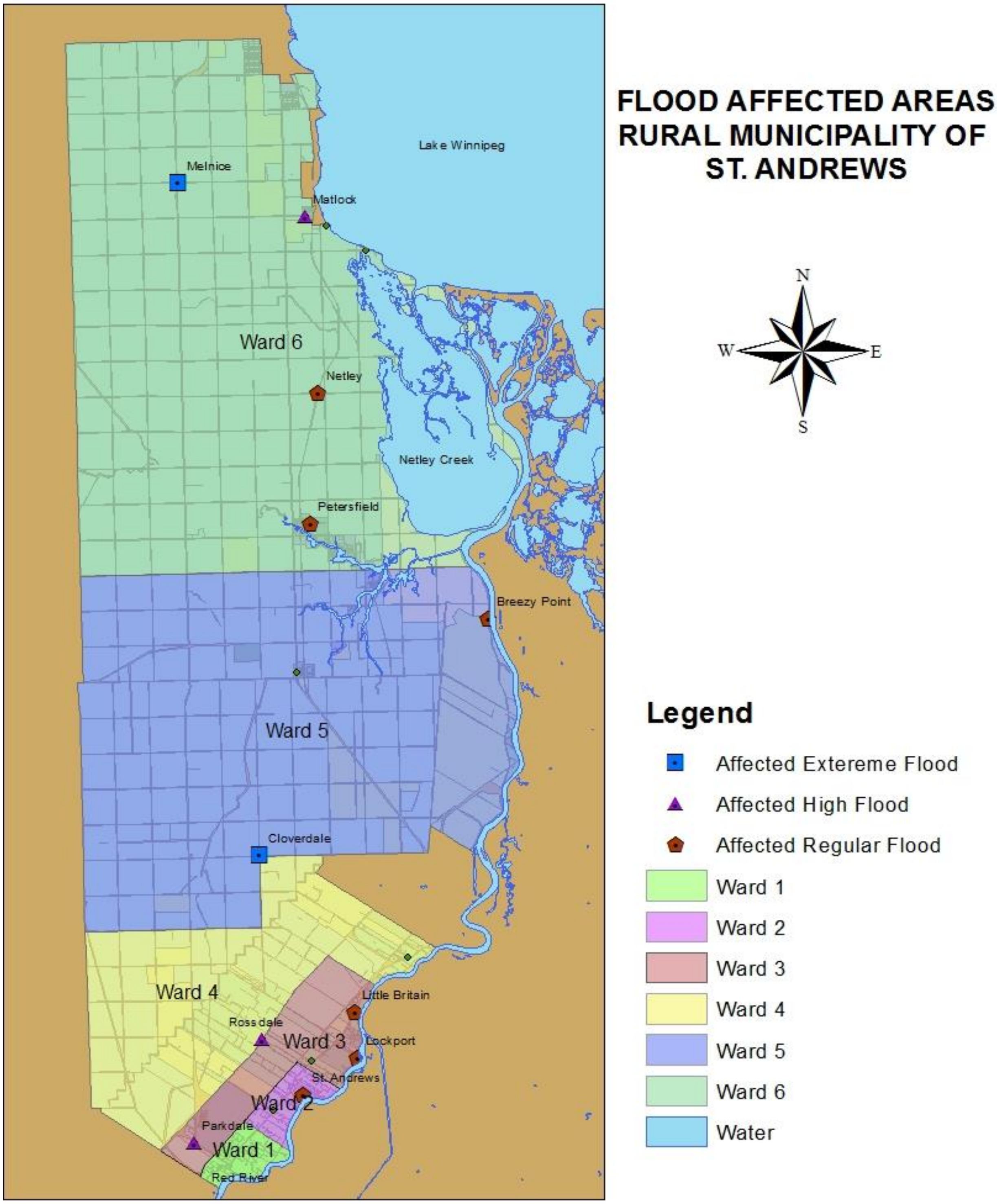

Figure 2.5 Identifies affected areas of flooding in the RM of St. Andrews.
Source: Adapted from Government of Manitoba MLI, 2015.

Chapter 3
Evaluating HAZUS-MH as a Quantitative Risk Assessment (QRA)Tool

3.1 Abstract

In the Province of Manitoba, the 2011 flood on the Assiniboine River was estimated to cost Manitoban's over 1 billion dollars (Gerrard, 2012). As flood cost continue to rise, planners and decision-makers are facing a pressing need to perform risk assessments in order to identify communities at risk of flooding. Currently at the national and provincial level, there exists no standardized operational framework and tool for flood risk assessment implemented by Emergency Measures Organization (EMO). The purpose of this study is to evaluate Hazus-MH as a QRA tool in Manitoba's Red River Basin. This research was completed by using Hazus-MH flood-loss estimation tools to quantify the potential flood damages to an array of buildings in Ward 1 of the Rural Municipality of St. Andrews. To determine which Manitoba dataset is most applicable in Hazus this study examined: a) default (aggregated) data, b) Local data (User Defined Facility) c) flood depth grid. The flood depth grid was developed using 1 in 100 year flood water marks and Digital Elevation Model (DEM). A User Defined Facility (UDF) file was created with a local inventory provided by the Municipality that was normalized and integrated into Hazus. A Flood Loss Analysis was run using the flood depth grid with first the aggregate data and secondly with UDF data. The results from the analysis of both datasets included flood maps illustrating the location and assessed value of inundated buildings, and flood damage profiles identifying the cumulative number of buildings inundated and their assessed value. The validation study results attained from flood-loss modeling tool using the UDF (local data) suggested a more realistic monetary loss than using aggregated default data. The results of UDF and flood-loss estimates could be improved by ensuring data (such as LiDar, building and

property information) are regularly updated and maintained. Although Hazus provides an important mapping tool to mitigating losses and to assist with relocation, a complete and current inventory is required to have a fully standardized QRA tool in Manitoba.

3.2 Introduction

The province of Manitoba's Red River basin has a flooding history that spans over 350 years (Rannie, 1999). Despite the financial investments in structural mitigation measures, flood damage costs have increased (De Loe, 2000). In 2011, Manitoba's Assiniboine River flood proved to be the most costly in Provincial history reaching over 1 billion dollars (Gerrard, 2012). As flood costs continue to increase decision-makers in municipalities and in various levels of government are facing a pressing need to implement methods for risk assessment and communication in order to identify communities at risk of flooding. Currently at the national and provincial level, there exists no standardized operational framework and tool for flood risk assessment implemented by Emergency Measures Organization (EMO). The Hazus-MH (Multi-Hazard), is a Quantitative Risk Assessment (QRA) tool developed by the US Federal Emergency Management Agency (FEMA). Hazus-MH represents a standardized methodology in the US for estimating potential losses from natural hazards including earthquakes, floods, and hurricanes and has recently been adopted for use in Canada. Hazus mapping capabilities promote the necessary communication and interaction among end-users during the planning process. The Hazus-MH flood loss estimation relies on the combination of flood level data, inventory of the built environment, and depth-damage function. Although Hazus-MH was originally designed for the US some of the parameters (occupancy and vulnerabilities), have similarities between Canadian provinces and states south of the border.

Overview of Hazus-MH

Hazus is a standardized methodology or program for assessment of potential losses from floods, earthquakes, and hurricanes. This tool was designed to assist local governments and agencies develop emergency management plans and mitigation strategies. Hazus is a quantitative loss estimation methodology and software tool developed by the US Federal Emergency Management Agency (FEMA) and the National Institute of Building Sciences (NIBS). It supports risk-based planning activities that promote national disaster mitigation policies in the United States. It encompasses an integrated suite of analytical models, spatial decision support tools, and procedural guidelines for quantitative risk assessment of floods, earthquakes, and hurricanes. The methods and tools are based on state-of-the art scientific and engineering knowledge and industry standards for quantitative risk assessment. They provide a robust and standardized approach to loss estimation that is being adopted by emergency management organizations worldwide (Mickey and Coats, 2013). The flood model analyzes riverine flood, coastal flood, and coastal surge hazards (Scawthorn, et al. 2006). The flood analysis portion of the model characterizes the spatial variation in flood depth in a given study area for riverine flooding conditions. The direct damage and loss portion of the flood model estimates structural damage to buildings and infrastructure through the use of depth-damage, or vulnerability, curves. Two primary approaches to apply the model are aggregated verses User Defined Facility (UDF). Aggregated data is a default program setting that provides the General Building Stock (GBS) at the census block level, where the percentage of each census block and specific flood depths is determined, and damage is calculated by proportion and exposure. If most of the built structures in aggregate are not in the flooded area, proportion and exposed structures will be overestimated. To assess flood losses, vulnerability, and risk for a community, flood hazard data and the built environment using individual structures (termed User Defined Facilities, UDF) based on local data can be collected and developed. This approach avoids the potential over and under-estimation that can occur with aggregated data and provides more accurate results (Neighbors et al., 2013; FEMA, 2009). When using aggregated data, Hazus Flood model performs an area-weighted assessment of damage and losses. By contrast, the damage for UDF, an essential facilities analysis, is determined by the depth of flooding at the location of the facility; thus, if the specific building's geographic coordinates lie within the inundated area, the proper flood depth at that location will be used by the damage function(s) to calculate damages and losses. For both aggregate and UDF, the depth-damage curve analysis results in quantitative estimates of the damage to buildings and infrastructure for a given depth. The economic costs are expressed as a percentage of the replacement cost of the structure(s) and converted into estimates of dollar loss. From these estimates, direct and indirect economic losses are computed and results are reported in figures, tables, and maps.(Gall et al., 2007; Ding et al., 2008; Merz et al., 2010). Figure 3.1 summarizes the possible losses included in the analysis output. For additional information on Hazus technology see: https://www.ce.udel.edu/UTC/Final-Working%20Paper-HAZUS-091028_rev.pdf

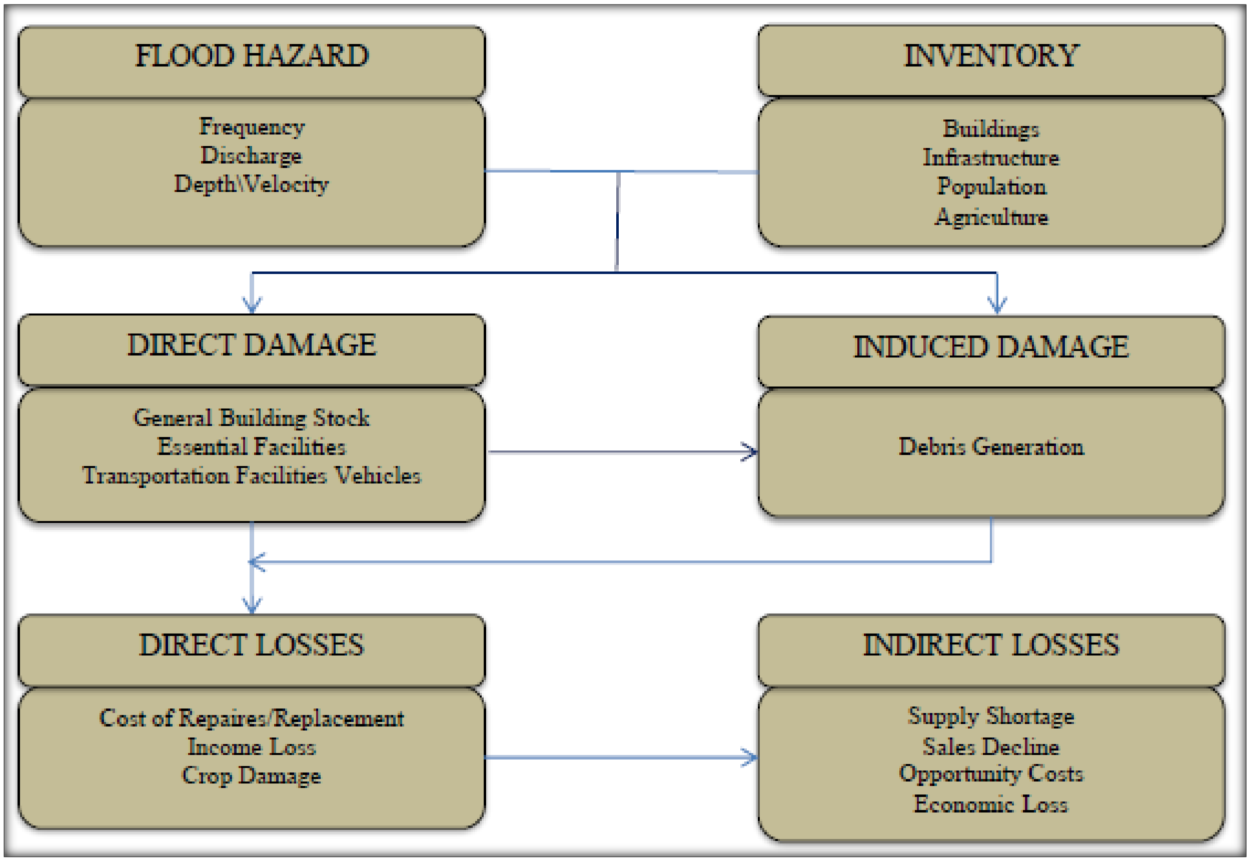

Figure 3.1. Summarizes the possible losses included in the flood analysis output.
Source: Compiled from Hazus-MH Application DVD Flood Manual, FEMA, 2007.

Need for a QRA tool in Manitoba

As flood costs continue to rise planners and decision-makers are facing a pressing need to perform risk assessments in order to identify communities at risk of flooding. Government officials, GIS specialists and emergency managers are all decision-makers which require tools to develop mitigation and recovery plans including preparedness and response procedures for natural disasters (Neighbors et al., 2013). In Manitoba there is a need for a QRA tool to assist decision-makers to quantify losses before they occur. Being proactive could assist in reducing the cost of flooding. Quantification of losses under existing conditions is valuable for understanding and communicating the relative importance of natural hazards risks and the various factors such as location, land use zoning, construction quality, etc. contributing to that risk. Similarly, analysis of the beneficial impacts of mitigation measures such as relocation, improved land use and planning, structural modifications, warning, etc., permits informed decision making and efficient allocation of scarce resources. (Scawthorn et al., 2006) The objective of this study is to evaluate the robustness of Hazus-MH as a standard Quantitative Risk Analysis (QRA) tool in Manitoba's Red River Basin to determine if a QRA tool can assist decision-makers to mitigate development in flood risk areas. In order to achieve this, the study will pilot Hazus-MH flood model in Ward 1 of the RM of St. Andrews, Manitoba.

3.3 Study Area

The Rural Municipality (RM) of St. Andrews, located north of Winnipeg along the lower reaches of the Red River, has been plagued with over 100 years of flooding. The Red River runs through the municipality of St. Andrews and extends itself from the Assiniboine River confluence in Winnipeg (The Forks) to the Red River outlet at Lake Winnipeg. The lower reach of the Red River between Winnipeg and Lake Winnipeg specifically in the municipality of St. Andrews is prone to ice jam flooding. The most downstream portion of this river stretch flows through a delta and marsh system which poses challenges with ice jams and flooding in an area of low-lying topography and river banks. Recent years of severe ice jamming with flooding are 1996, 2004, 2007, 2009, 2010 and 2011 (Karl-Erich, et al., 2012). The flood of 2009 proved to be one of the most challenging especially downstream of the city of Selkirk. This area experienced flooding of a magnitude that had not been experienced for a century and a half (Wazney and Clark, 2015). In response to the Hazus pilot in Manitoba, the RM of St. Andrews was selected due to its flooding challenges, municipal support, and data access. The following section will demonstrate the potential of Hazus in a Manitoba context. The Hazus-MH flood model was piloted in Ward 1 of the Rural Municipality of St. Andrews to explore its potential as a Quantitative Risk Analysis (QRA) tool in Manitoba.(See Chapter 2 for complete description of study area).

3.4 Methods

We used the Hazus-MH flood-loss estimation tools to examine the potential flood damages to an inventory of buildings in Ward 1 of the RM of St.Andrews. This study examined two Manitoba building datasets. In Method (1) we applied the Aggregate default inventory and in

Method (2) we applied the User Defined Facility local inventory, to determine which data is best applicable in Hazus-MH. To accomplish this, three types of data were considered in this study to develop the two flood loss models: (i) flood hazard data, (ii) default aggregated data (which comes with Hazus) and (iii) User Defined Facilities (UDF) composed of local data inventory. The flood depth grid was created by using Digital Elevation Model (DEM) and high water mark data. The high water marks were based on the 2009 flood (100 year flood). The flood depth grid was created using inverse distance weighted flood level, by subtracting the base DEM from the surface. By subtracting the base flood elevation surface from the terrain elevation, yield the flood depth grid, which was then imported into Hazus. The flood depth grid provided flood level in Ward 1 of the RM of St. Andrews and was applied in both Method (1) and Method (2).

Building Inventory and Database Development

In Method (1) the aggregated building inventory data which (comes with Hazus) was used for analysis. This inventory is derived from 2011 Canadian census data. The census data are used to determine impacts and effect such as the population at risk, shelter needs, and aggregated buildings including seven occupancies (residential, industrial, commercial, educational, government, agriculture and religious, McGrath, et al., 2014). Building replacement costs per square foot are based on values derived from the 2006 RSMeans values listed in tables 14.2 to 14.3 in US Hazus Flood Technical Manual. Manuals are available: http://www.fema.gov/media-library/assets/documents/24609 (FEMA, 2010).
These values are editable within the Hazus software, and it is expected that these values will need to be revised to reflect a Canadian context (McGrath, et al., 2014).

In Method (2) to complete a User Defined Facilities inventory with local data, a number of building data is required. First, the following fields are essential to calculate loss estimations:

(a) First floor height (b) Foundation

Secondly, to convert losses to monetary values the following fields are required: c) Point structure location d) Building value e) Contents value f) Occupancy type g) Number of stories. Through the data sharing agreement with the Province of Manitoba, data was retrieved from the municipality of St. Andrews, provincial departments and consultants as identified in Table 3.1. Assessment data was retrieved from the municipality of St. Andrews which provided up-to-date information on residential, commercial, and other buildings. The Assessment branch (Manitoba Municipal Government) provided 2015 assessed property values. A spatial polygon dataset for all buildings in Ward 1 was provided through a consultant contracted to the RM. Current databases in Manitoba do not contain all the required Hazus parameters therefore generic values were applied to the building inventory as specified in Hazus Level 2 Site Specific Flood Model Manual (FEMA, 2014). For this study, the foundation type was defined as basement for all residential structures. Hazus-MH estimates the first-floor elevation for structures with a basement to be 1.22 m (4 feet) above the ground (FEMA, 2009). Although there were a few buildings zoned under commercial and agriculture the majority of the buildings were defined as residential occupancy type. For the building content default value we followed the formula contents value of 50% of building replacement cost. The building category codes as used in the Province of Manitoba, did not match those in Hazus-MH. This meant reclassifying the building attribution codes to conform to Hazus. In addition, Hazus-MH does not have the occupancy classification for garages and sheds therefore these structures were deleted from the building file.

Table 3.1 Identifies the datasets and the departments or municipality which hosted the inventory.

HAZUS Inventory Data	Department/Municipality	Available Datasets
User Defined Facilities (UDF)	MB Conservation (MLI) Consultant RM of St. Andrews	Building FootPrints Point Structure Location Number of buildings by specific occupancy class Replacement cost per square foot by specific Property Assessment Depreciation Parameters
Hazus Inventory General Building Stock (GBS)	Hazus Software	Occupancy Class Foundation types First floor heights Content Value
Hazus Inventory Demographics (Census Canada 2011)	Aggregated Data (Default)	Population by age, race & income levels Day & night population Number of property owners & renters Rental & vacancy rates
Flood Hazard Data	Geogratis	Digital Elevation Data (DEM)
	Water Stewardship; Manitoba Infrastructure and Transportation (MIT)	High Water Marks (Based on 1-100 year flood (1997)

Table 3.2. Details generic values to building inventory specific to Hazus Manual. Source: Hazus Level 2 Site Specific Flood Model Manual, FEMA, 2014.

Data	Generic Value	Hazus Manual
Occupancy Type	Residential;Commercial;Agriculature	Table 3.2 (p.9)
Foundation Type	Basement	Table 3.11 (p. 8)
First Floor Height	4’	Table 3.11 (p. 8)
Number of Stories	2	Generic Value
Content Value	50% of Assessed value	Table 14.6 (p.12)

UDF Data Process

Once the local building inventory was gathered it was reviewed and normalized in an Excel spread sheet. A building shapefile containing the buildings in Ward 1, was inserted in the Hazus map. Using the ArcMap GIS tools the spatial building polygon was used to calculate the square area of each building. The building inventory polygon feature was then re-projected to geographic coordinates (Latitude and Longitude, NAD1983), a format required in Hazus. Following this process, the location of the buildings was calculated based on the polygon centroid. Next a relation join was activated between the building inventory in the excel spreadsheet and the building point feature. Once the building data was geographic the table was exported from the shapefile and saved to an Access geodatabase. In the final step the building geodatabase was imported as a user defined facility (UDF) table into Hazus-MH. The UDF table converted the MS Access columns into data that Hazus recognizes and uses to perform the flood analyses. Figure 3.2 represents the processes describe d to calculate, join and map building data into a User Defined Spreadsheet (UDS) file applicable in a Hazus format.

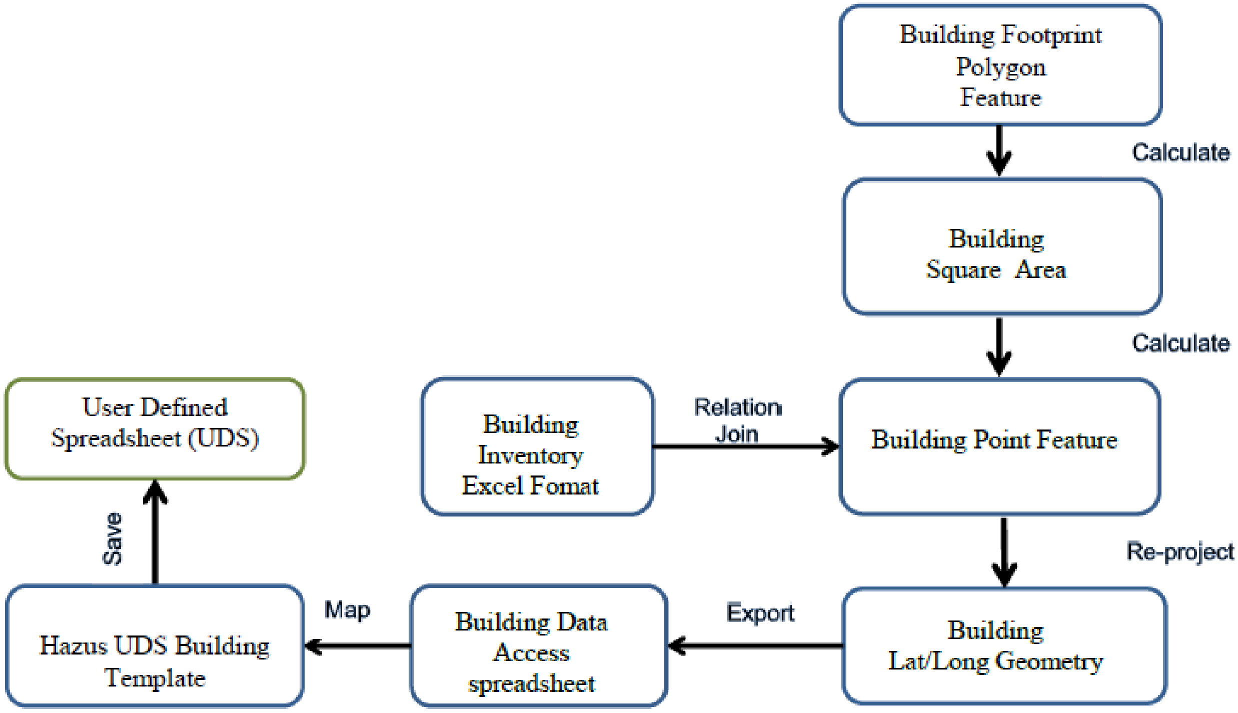

Figure 3.2 Illustrates, the processes to calculate local building inventory and merge into one file applicable in a Hazus UDS format.

Hazus MH Flood Model

Both Method (1) and Method (2) applied the same procedures in Hazus-MH to generate a flood analysis. The only difference is that with Method (2) before any flood analysis can be completed the User Defined Facility (UDF) must be loaded into the study area of Hazus. The flood analysis was completed in Hazus by using the" Flood Hazard Riverine" hazard type and tools. The flood depth grid was imported into Hazus and attached to the study region of Ward 1 in the RM of St. Andrews. With this data we simulated a riverine flood based on 1-100 year flood levels. Based on this flood level, a number of damaged buildings were mapped and replacement values were derived using Hazus-MH tools.

3.5 Results

The results developed flood maps illustrated in figure 3.3 and figure 3.4, and summarized the estimated buildings damaged and replacement values. In Method (1) Table 3.3 estimates that there are 899 buildings in Ward 1 which have an aggregate total replacement value of 164 million dollars. The flood analysis identified in Table 3.4, estimates that 12 buildings will be at least moderately damaged. Table 3.5 summarizes the replacement value of 63 million dollars for buildings moderately damaged by the 1-100 year flood in Ward 1.

Method (2), Table 3.6 estimates that there are 606 buildings in Ward 1 which based on local data have a replacement value of 168 million dollars. The flood analysis identified in Table 3.7 estimates that 27 will be moderately damaged. Table 3.8, summarizes the replacement value of 1.8 million dollars for buildings moderately damaged by the 1-100 year flooding Ward 1. When comparing the results from the two flood analysis the total building damaged and value of buildings were significantly different. In Method (1) the percentage of buildings damaged based on building count was 12 and in Method (2) was a count of 27. Although there were fewer destroyed buildings in Method (1), the cost is higher than that of Method (2) Table 3.9 summarizes the flood loss results for Method (1) and Method (2).

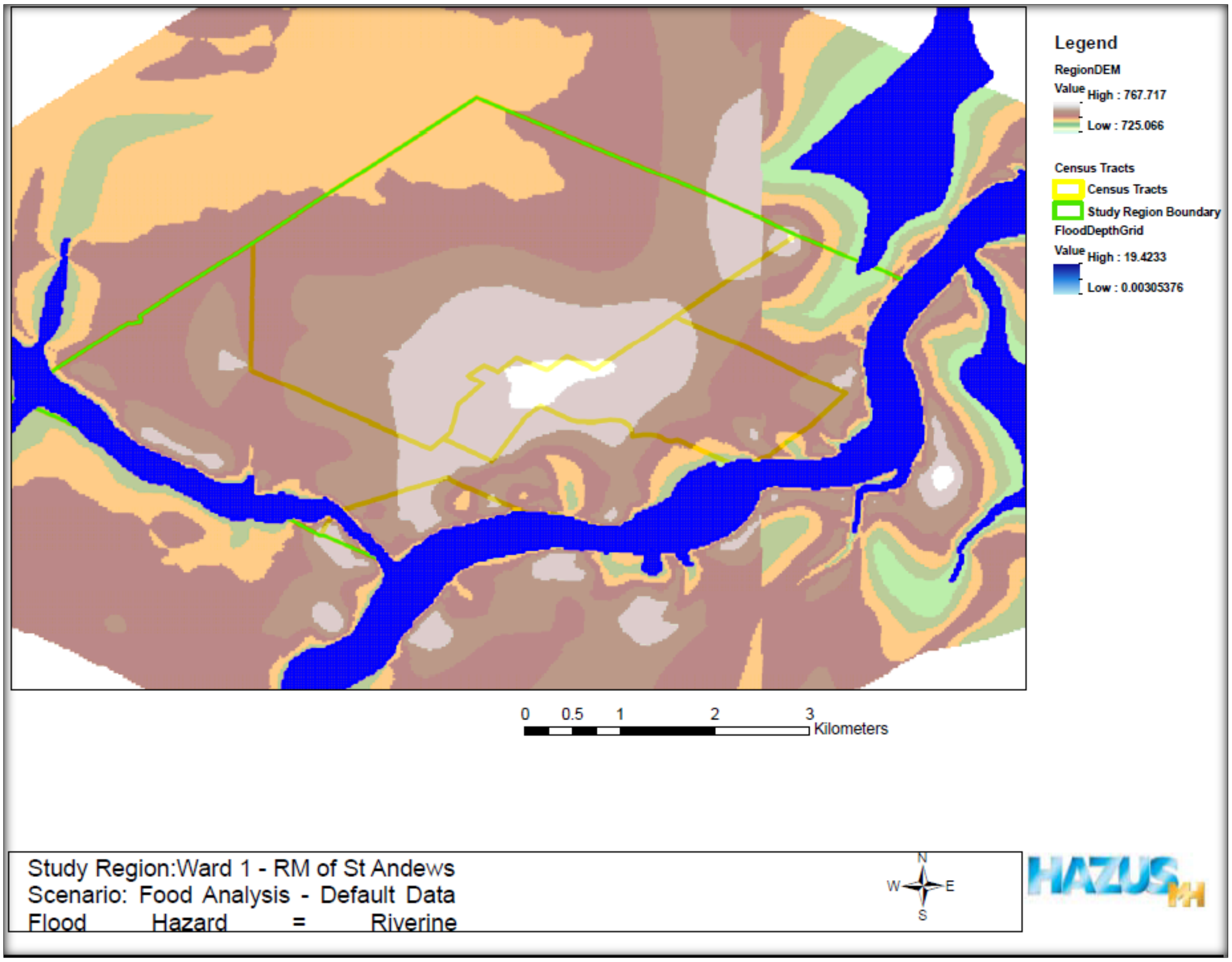

Figure 3.3. Flood Map for Method (1) identifies Potential inundated area in Ward 1, RM of St. Andrews for 1-100 year flood levels.

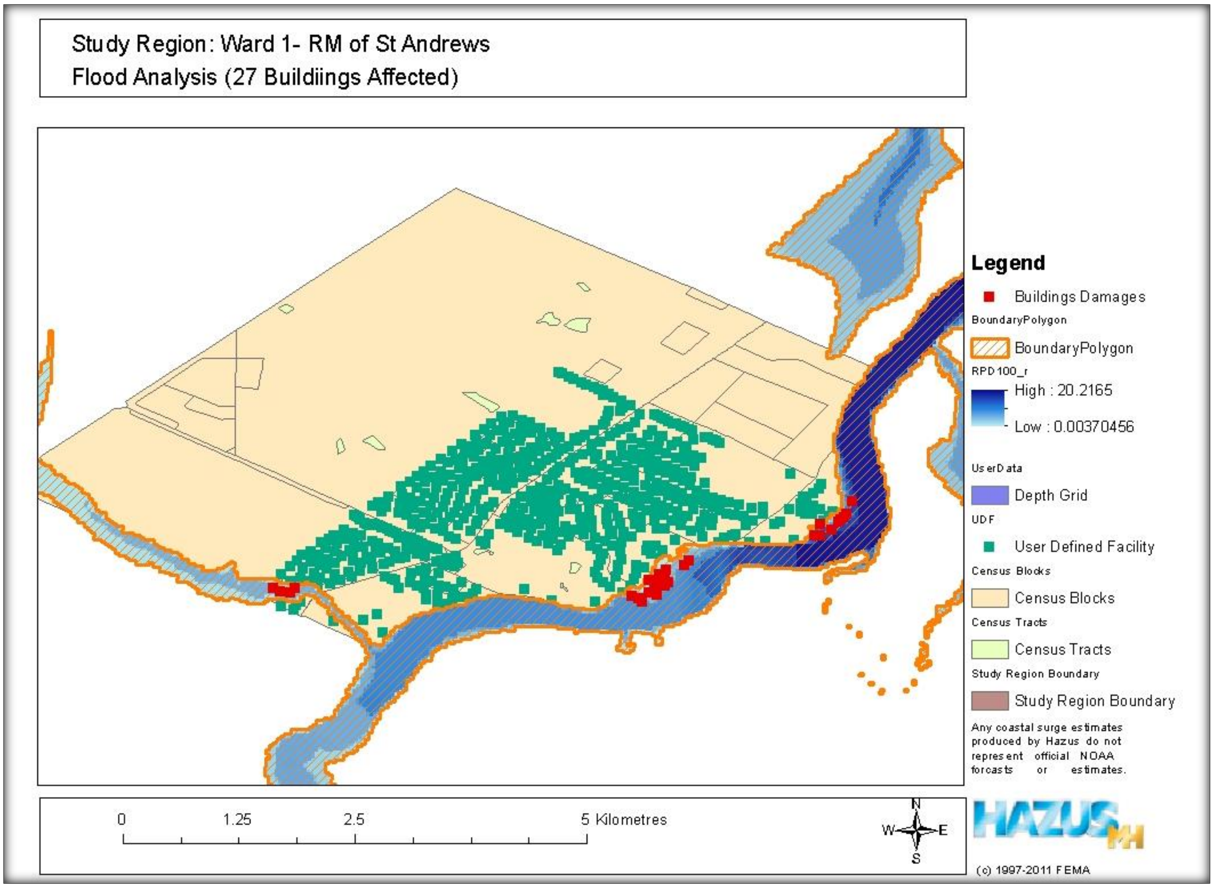

Figure 3.4. Flood Map for Method (2) identifies possible inundated area in Ward 1, RM of St. Andrews for 1-100 year flood levels.

Table 3.3. Estimates that there are 899 buildings in the study region of Ward 1 which have an aggregate total replacement value of 164 million dollars.

Building Inventory

General Building Stock

Hazus estimates that there are 899 buildings in the region which have an aggregate total replacement value of 164 million dollars. Table 1 and Table 2 present the relative distribution of the exposure values with respect to the general occupancies by Study Region and Scenario (the area affected by the flood event) respectively. Appendix B provides a general distribution of the building value by Province/Territory and Census Division.

Table 1
Building Exposure by Occupancy Type for the Study Region

Occupancy	Exposure ($1000)	Percent of Total
Residential	151,233	92.1%
Commercial	11,252	6.9%
Industrial	1,530	0.9%
Agricultural	0	0.0%
Religion	139	0.1%
Government	0	0.0%
Education	0	0.0%
Total	**164,154**	**100.00%**

Table 3.4. Hazus Flood Analysis identifies 12 buildings will be moderately damaged in Ward 1.

Building Damage

General Building Stock Damage

Hazus estimates that about 12 buildings will be at least moderately damaged. This is over 4% of the total number of buildings in the scenario. There are an estimated 2 buildings that will be completely destroyed. The definition of the 'damage states' is provided in Chapter 5 of the US Hazus-MH Flood Model Technical Manual. Table 3 below summarizes the expected damage by general occupancy for the buildings in the region. Table 4 summarizes the expected damage by general building type.

Table 3: Expected Building Damage by Occupancy

	1-10		11-20		21-30		31-40		41-50		>50	
Occupancy	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**	**Count**	**(%)**
Agriculture	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Commercial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Education	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Government	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Industrial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Religion	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Residential	0	0.00	0	0.00	1	8.33	3	25.00	6	50.00	2	16.67
Total	**0**		**0**		**1**		**3**		**6**		**2**	

Table 3.5. Identifies the total replacement value of $63 million dollars for (12) buildings affected by the 1-100 year flood in Ward 1.

Table 2
Building Exposure by Occupancy Type for the Scenario

Occupancy	Exposure ($1000)	Percent of Total
Residential	54,629	86.3%
Commercial	7,769	12.3%
Industrial	770	1.2%
Agricultural	0	0.0%
Religion	139	0.2%
Government	0	0.0%
Education	0	0.0%
Total	**63,307**	**100.00%**

Table 3.6. Estimates the total replacement value of (606) buildings at 168m in Ward 1 before the flooding.

Occupancy	Exposure	Percent of Total
Residential	$166,687,500.00	97%
Commercial	$2,047,600.00	2%
Industrial	n/a	
Agricultural	$148,700.00	1%
Religion	n/a	
Government	n/a	
Education	n/a	
Total	$168,883,800.00	100%

Table 3.7. Hazus Report identifies 27 out of 606 buildings damaged based on (Residential) occupancy in Ward 1

	1-10		11-20		21-30		31-40		41-50		>50	
Occupancy Count	Count	(%)	Count	%	Count	%	Count	%	Count	%	Count	%
Agriculture	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Commercial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Education	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Government	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Industrial	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Religion	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Residential	0	19.00	12	45.00	4	15.00	2	8.00	0	0.00	3	30.00
Total	**6**		**12**		**4**		**2**		**0**		**3**	

Table 3.8. Table 3.5. Identifies the total replacement value of $1.8 million dollars for (27) buildings affected by the 1-100 year flood in Ward 1.

Occupancy	Exposure	Percent of Total
Residential	$1,836,734.20	1%
Commercial	$0.00	
Industrial	0	
Agricultural	$0.00	
Religion	0	
Government	0	
Education	0	
Total	$1,836,734.20	100%

Table 3.9. Summarize the results of building loss of General Building Stock applied in Method(1) and Method(2)

Flood Analysis	**Aggregate Data Method (1)**	**Local Data (UDF) Method (2)**
Building Count	899	606
Total Building Replacement Value	164 million	168 million
Building Damaged	12	27
Replacement Value Damaged Buildings	63 million	1.8 million

3.6 Discussions

In the Province of Manitoba, flood costs continue to rise and planners and decision-makers are facing a pressing need to perform risk assessments in order to identify communities at risk of flooding. Currently at the national and provincial level, there exists no standardized operational framework and tool for flood risk assessment. This study evaluated Hazus-Multi-Hazard (MH) as a Quantitative Risk Assessment (QRA) tool in Manitoba's Red River Basin to reduce the cost of flooding. This research was completed by using Hazus-MH flood-loss estimation tools to examine the potential flood damages to an array of buildings in Ward 1 of the RM of St. Andrews. The results from the analysis of both datasets included flood maps illustrating the location and assessed value of inundated buildings, and flood damage profiles identifying the cumulative number of buildings inundated and their assessed replacement value. The flood-loss modeling tool using local data calculated a more realistic monetary loss than using aggregated default data. Local data was suggested as being more accurate in another Hazus study completed by Natev and Todorov. Given that local data are generally of much better quality, users can overcome eventual deficiencies and improve accuracy by providing more detailed data about their community: upgrading the inventory and flood depth data set, employing higher-resolution digital elevation models, and correcting the depth-damage curves (Natev and Todorov, 2013). Although both Manitoba datasets (default and local) worked in Hazus, there are limitations to running the Hazus software with current datasets, in particular assumptions regarding inputs such as first floor height and foundation type. We did find that the aggregate reporting tool does provide an inflated and incorrect RSMeans value (US building calculator, 2006) listed in tables 14.2 to 14.3 in US Hazus Flood Technical Manual. This error was confirmed by a study completed in New Brunswick. It is important to note that the estimates of social and economic impacts applicable to aggregated data are based on current scientific and engineering knowledge. Building replacement costs per square foot are based on values derived from the Hazus Manuals available: http://www.fema.gov/medialibrary/assets/documents/24609. These values are editable within the Hazus software, and it is expected that these values will need to be revised to reflect a Canadian context (McGrath, Stefanakis and Nastev, 2014). In addition, the aggregate building data are derived from 2011 Census Data, which estimated damage by proportion and exposure of census block. This exercise suggested that there are significant differences in calculations using Hazus aggregate data versus local data.

In Neighbors (2013) it was found that if most of the built structures in aggregate are not in the flooded area, proportion and exposed structures will be overestimated. To assess flood losses, vulnerability, and risk for a community, flood hazard data and the built environment using a local UDF, can be collected and developed. This approach avoids the potential over and under-estimation that can occur with aggregated data and provides more accurate results (Neighbors et al., 2013; FEMA, 2009). Although the results from Method (1) provided coarse results as opposed to Method (2), maps and custom reports are a great function of the Hazus flood analysis. The results of local data and flood-loss estimates could be improved by maintaining current data. With continued efforts and resources in government to build calculative default data and current local data, Hazus has the potential of becoming a standard QRA tool in a Manitoba context.

3.7 Conclusion

The objective of this study was to evaluate the role of Hazus-MH as a standard Quantitative Risk Analysis (QRA) tool in Manitoba, to assist decision-makers with being more pro-active to assessing flood risk and to lower the cost of flooding. The study determined that Hazus has the potential to be applied using both aggregated and local data. This tool could assist decision-makers in all levels of government with visual interpretation of various flood scenarios and estimate economic damage and loss to structures. Working with the province and municipal stakeholders will be crucial to having an operational standard QRA tool in Manitoba which host current data to assist decision-makers in assessing flood risk in Manitoba's floodplain area.

Chapter 4
The Application of a QRA tool in Policy

4.1 Abstract

In 2011, Manitoba's Assiniboine river flood proved to be the most costly in Provincial history reaching over 1 billion dollars (Gerrard, 2012). Despite the tremendous financial investments in structural mitigation measures flood damage costs have increased (De Loe, 2000). In Manitoba, poor enforcement of land regulations in flood risk areas has been an ongoing challenge in mitigating flood risk (Shrubsole, 2000). In addition, legislated ministerial powers have not been used in instances of non-compliance (Simonovic, 2000). These deficiencies affect the competence of policies designed to regulate land development in flood risk areas. It is time to review the benefits of non-structural mitigation measures to assist with reducing the cost of flood recovery in Manitoba. Case studies have proven that a standard Quantitative Risk Analysis (QRA) tool can inform decision-makers and empower policies to reduce the cost of recovery. This research utilizes a face-to-face questionnaire with flood experts in municipal and provincial government, and consultants to determine the land development processes; role of technology; public policy, in mitigating and responding to flood risk in Manitoba. Analysis involved two sets of questions, long questions and Likert format ranked questions. The Likert questionnaire used perceptual mapping and response frequencies. Analysis from the perceptual mapping revealed that within government perceptions can be very different between departments, while consultants and municipalities often shared opinion. Analysis of long questions retrieved the knowledge, need and expertise from each participant. Results reveal that knowledge on process and policies reside within some government organizations but not all. Consultants are often contracted by

government due to their expertise with methods/data and technology. There is no centralized database hosting flood data in Manitoba, leading flood experts in government and industry to manage independent datasets and silos/stove pipe systems. Finally, results suggest that the majority of the participants agreed that a standard QRA tool would inform all decision-makers and empower policies design to regulate land development in flood prone areas.

4.2 Introduction

Over the last fifty years, the province of Manitoba has developed structural disaster mitigation measures such as dams, levees, dikes and floodways and diversions. Despite the tremendous financial investments in structural mitigation measures it is evident that flood damage costs have increased (De Loe, 2000). Disaster response alone is not sufficient, as it yields only temporary results at a very high cost (Henstra and McBean, 2005). The 1997 Flood of the Century in the Red River Basin suggested a need for a new paradigm of sustainable flood management in which local stakeholders become more pro-active and develop the future they will live in rather than one that just happens (Myers, 1998). This can be achieved by empowering non-structural measures such as policies that mitigate development in flood risk areas and reduce the cost of recovery. The advantage of non-structural measures (e.g. floodplain management policies; warning systems; education; forecasting capabilities; zoning bylaws) as opposed to structural ones is that they greatly expand the range of resources and options available for adjusting human practices on the floodplain (Pal, 2002). Land use regulation as a means of flood damage reduction has been slow to be effectively adopted in Manitoba. Although land use regulations are in place, they are often breached. This has allowed for increasing residential development along the river south of the Floodway which is extremely vulnerable to flooding. Poor enforcement of regulations has been an ongoing weakness; legislated ministerial powers have not been used in instances of non-compliance (Simonovic, 2000). Case studies have demonstrated that Quantitative Risk Assessment (QRA) tools such as Hazus-Multiple Hazard (MH) have been applied globally for over a decade to assist decision makers to map flood risk areas and mitigate development to reduce the cost of recovery. The Hazus- MH mapping tool developed by FEMA represents an extensively applied and well documented GIS-based framework for risk estimation of natural hazards in the US (FEMA, 2009). Hazus-MH is a risk assessment tool for analyzing potential losses from floods, hurricane winds and earthquakes. Hazus-MH flood model has been piloted in New Brunswick and has proved it has potential as a standard QRA tool in the city of Fredericton (McGrath, 2015).

Disaster Management

Disaster management is a term that encompasses a range of policies and practices developed to prevent manage and reduce the impact of disasters. It can be conceptually divided into four elements; preparedness (policies and procedures designed to facilitate an effective response to a hazard event); response (actions taken immediately before, during and after a hazard event to protect people and property and to enhance recovery); recovery (actions taken after a hazard event to restore critical system and return a community to pre-disaster conditions; and mitigation (actions taken before or after a hazard event to reduce impacts on people and property (Godschalk 1991; Mileti 1999). As identified by (Henstra and McBean, 2005**)** historically, public policy in this area has been heavily concentrated on response, reflecting a belief that disaster are “acts of God” or acts of Nature, catastrophes beyond our control. Disaster response alone is not sufficient, as it yields only temporary results at a very high cost.

Flood Management

Canadian institutional arrangements include a hierarchal decision-making system to combat emergencies including floods. Four levels of decision-making are present in flood management: federal, provincial, local (city and rural municipalities). In Canada the Canadian Constitution defines the water law but it is the responsibility of all levels of government to protect Canadians (Department of Justice Canada, 2007). The federal government can involve itself in areas of provincial jurisdiction through its spending powers. It is within this framework that all levels of government participate in flood management. In general terms, the federal government often provides research and recommendations concerning aspects of hazard management such as building standards or acceptable levels of risk and provides training for local emergency officials (Doern and Conway, 1994). It is the responsibility of the province to govern and manage water and all other natural resources (Rubec and Hanson, 2009). The provinces' ability to legislate in the general area of water management is derived primarily from their exclusive authority to legislate over property and civil rights, over matters of a local and private nature, and over local works. Significant responsibilities are also associated with their ownership of water and other resources. Provinces can establish specific regulatory flood levels, set building standards, and advises municipal government in flood mitigation. As stated by Henstra and McBean, (2005) generally, provincial legislation delegates the responsibility for disaster management to local government. A case study completed by Rubec and Lynch-Stewart, (1998), identified local government and community planning acts control land use and development in the urbanized regions of the provinces and territories. Municipal planning, zoning, park and land acquisition, bylaws and environmentally sensitive areas statutes can all have a major impact on development protection in urbanized areas. The decision to development is left up to the discretion of the local government (Sutherland, S, 2015). This arrangement between the province and local government epitomized 'passing the buck' because all levels of government are involved but no one is truly accountable (Harrison, 1996).

Hazus case studies

Minnewaukan, North Dakota

Minnewaukan, ND has a population of over 200 people. It is located geographically 48.0667° N, 99.2500° W, on the west edge of Devils Lake. The Hazus flood model was applied in Minnewaukan to examine potential flood damages. For each flood stage (lake surface elevation) examined, the number of damaged buildings and potential economic losses were mapped and statistics were derived. For the community of Minnewaukan, the relocation of threatened properties to an elevation above the natural ordinary high water level will significantly reduce the threat of terminal lake flooding from the city's future (Tobin & Peacock, 1982). The computer visualization of flood risk developed by Hazus through incremental inundation maps and damage elevation profiles enabled individuals and decision-makers to better understand both personal risk and community risk (Battistini, et al., 2013). This information allowed the decision-makers to close the gap between perceived and objective risk. Using Hazus Quantitative Risk Analysis (QRA) capabilities to simulate future flood scenarios, assisted decision-makers to identify threshold water surface elevations where relocation becomes inevitable, and thus can help facilitate participatory planning projects. By seeing how rising lake levels will affect their community in both spatially-explicit and personally meaningful ways, the QRA in Hazus assisted local decision-makers to move their community forward toward a future free from the constant threat of flooding (Cummings, Todhunter & Rundquist, 2012).

City of Fredericton New Brunswick

The city of Fredericton is the capital of New Brunswick and is the third largest city in this province. Fredericton has a population of 94,000 (Census, 2011) and approximately 22,000 households (Lantz, et al., 2011). Flooding in New Brunswick has existed since 1700s and has cost over $133 million (PSC, 2014).Municipalities are therefore facing a pressing need to perform risk assessments in order to identify communities at risk of flooding. In addition, quantitative measures of potential structural damage and societal losses are necessary for these identified communities. Furthermore, tools which allow for analysis and processing of possible mitigation plans are needed. The objective of this case study was to establish a Data Warehouse (DW) to store relevant flood prediction data which may be accessed thru Hazus's QRA tool. Following the collection and integrating of datasets into Hazus the city of Fredericton now supports, historical flood visualizations through web maps, and mitigation tools thus making flood hazard information more accessible to decision makers such as emergency responders, planners, and residents. Although there is currently no real Fredericton Hazus there is a schema of DW, and some data including tools developed which facilitate mitigation. This project is on-going and currently remains in a preliminary stage. As data input continually improves, Hazus has the potential to become a standardized QRA tool within the province of New Brunswick. (McGrath , Stefanakis, and Nastev, 2014)

QRA Tool in Policy

In Manitoba, land regulations are too often breached and the lack of legislated ministerial powers have encouraged land development in flood risk areas. These deficiencies affect the process and competence of policies designed to regulate land development. There is a need to review non-structural mitigation measures specific to a QRA tool and policy. Non-structural flood mitigation measures have emerged as the preferred approach to reducing flood losses (Fraser and Doyle, and Young, 2006). These measures include those approaches that involve the adjustment of human activities to accommodate the flood hazard (Gruntfest, 2000). Case studies have proven that Hazus-MH can be applied as a QRA tool to reduce the cost of flooding and inform policies and decision-makers to regulated land development. The objective of this research is to examine the application of a Quantitative Risk Assessment tool in policy to reduce the cost of recovery. The results of the study will provide recommendations to empower policies and process designed to reduce land development in flood risk areas.

4.3 Study Area

The study area was in the RM of St. Andrews located west of the Red River and extends north from the City of Winnipeg to the south end of Lake Winnipeg. The lower reach of the Red River between Winnipeg and Lake Winnipeg specifically in the municipality of St. Andrews is prone to ice jam flooding. Recent years of severe ice jamming with flooding are 1996, 2004, 2007, 2009, 2010 and 2011 (Karl-Erich, Maurice and Robert, 2012).The Red River Planning District (RRPD) serves multiple municipalities including the Rural Municipality of St. Andrews and the City of Selkirk, as established by Order-in-Council. The Planning District objectives are to promote the optimum economic, social, environmental and physical condition of the area. Under the authority of The Planning Act, it is the responsibility of the RRPD to implement a Development Plan for the District. They seek to enhance and encourage development within these municipalities, in accordance with the appropriate Zoning By-law and the Planning District Development Plan. According to the Planning District Policies Development in areas subject to physical hazards shall generally be limited to agricultural uses or open space uses. Under special economic or social circumstances the Board or Council may permit more intensive development if the hazard is eliminated or protected against (Red River Planning District, 2011). For more detailed description of the study site see Chapter 2.

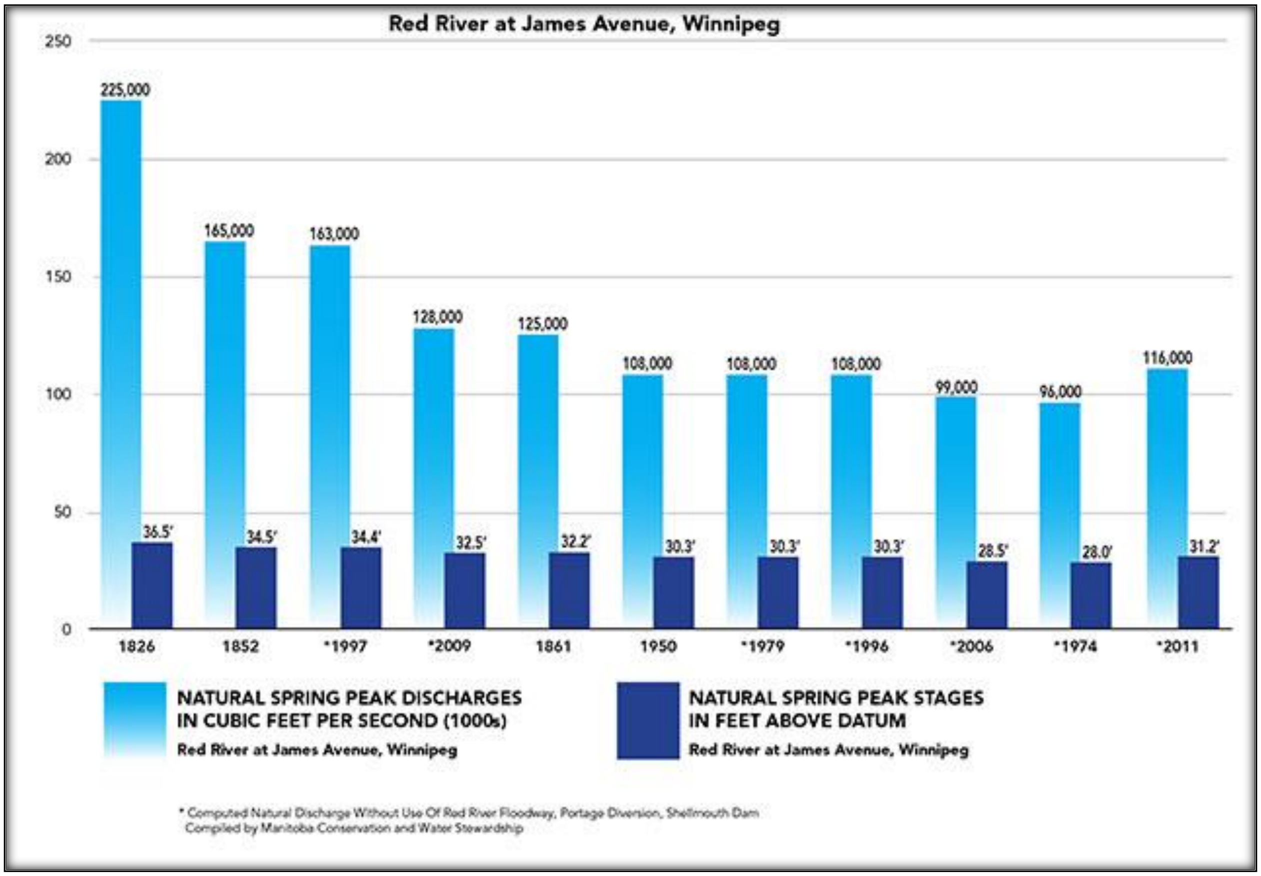

Figure 4.1 Major Manitoban floods since the early 1800s including the floods of 1950, 1997,2009 and 2011. Source: Government of Manitoba, 2014

4. 4 Methods

The methods used in this study consisted primarily of a survey questionnaire within a defined sample frame to elucidate the nature of a QRA tool designed to inform decision-makers and policy on factors affecting efficiency of policies designed to enforce land regulations in flood risk areas. Methods will also explore the role of partnership between all levels of government in support of policies and methods to mitigate flood risk associated with land development. Analysis for this study included, synthesis of responses, frequency analysis, and perceptual mapping.

Identification of Sampling Frame and Participants

The sampling frame was determined geographically with the primary region and scope of the study limited to Manitoba's Red River Basin. The study involved 11 Participant divided in three organizations, province, municipal government and consultants. The participants were selected based on their: expertise; knowledge on policies and process; technology; specific to mitigation flood risks associated with land development in Manitoba's Red River Basin. A long list of participants were identified through direct communication with organizations operating with and within the RM of St. Andrews and government agencies responsible for flood risk assessment, emergency response and municipal oversight. From this list of pertinent organizations and key informants a short list was identified. Organizations surveyed included, MIT formerly a branch of Water Stewardship, Manitoba's Emergency Measures Organization (EMO), and Red River Planning District. Municipal Government representatives were identified as CAO's located in a flood prone area and with experience with flood preparedness and recovery. Consultants were selected based on their years of experience and involvement with the RM of St Andrews or that had provided contract work for Provincial organizations applicable to flood mitigation measures.

Survey

To determine the current need of QRA in policy to regulate land development processes and assess the overall perception of risk, a survey was conducted using a questionnaire. Questions for the participants were developed through roundtable discussions with the advisory committee and by a pilot test with individuals on the long-list that were not included as part of the final sampled cohort. The final questionnaire was approved by the University of Manitoba's Ethics Committee as Protocol #J2015:139. The approved protocol form is presented in Annex I. Contact with key informants, and the distribution and administration of the questionnaire was done by phone. A Request for participation letter found in Annex II followed and was e-mailed to participants inviting them to take part in the survey and to setup an interview. With their approval, an introductory letter, identified in Annex III was then e-mailed to explain the purpose and methods of the research study. If a key informant was interested in participating, a face-to-face interview was then initiated with a consent letter defined in Annex IV and questionnaire completed by participant. The questionnaire consisted of two parts i) long questions, ii) Likert based rank-order questions. Participants selected were based on their decision-making involvement with past floods and associated experience with land development in flood risk areas. Questions were divided into themes. 1) policies/process 2) Government and funding 3) methods and data 4) mitigation measures 5) recovery. The final questionnaire is provided in Annex V and VI.

Step 1	**Telephone call invites potential interviewee and setup an interview. Call uses first paragraph of Appendix A as script.**	**CONTACT POTENTIAL PARTICIPANT**
Step 2	**In person face-to-face interview with questionnaire to be completed on site. Not recording written documentation with review. Described in Appendix A.**	**INTERVIEW**
Step 3	**Questionnaire responses thematically grouped, ranked questions entered into spreadsheet and assigned random identifier. Original documents destroyed.**	**ANONYMIZE AND DESTROY ORIGINALS**
Step 4	**Data analysis is by synthesis and summary of questions by themes and ranked answers using percentages, weighted averages and perceptual mapping.**	**DATA ANALYSIS**
Step 5	**Summary of results provided by e-mail by May 1, 2016.**	**SUMMARY OF RESULTS TO PARTICIPANTS**

Figure 4.2 Flow diagram of study methodology defining a direct sequence of activities.

Data Analysis

The methods chosen for data analysis were based on the structure of the questions being asked. The first set of question (long questions) were open-ended discussion style questions and were analyzed using a qualitative approach while the second set of questions which were structured as rank order Likert format were analysed using quantitative approaches. Qualitative responses were assessed using a content analysis of the direct quotations to synthesize trends in response characteristics (Krippendorff, 2004). Analysis of the accuracy and trends within the themes was broken down by key word and a count of frequency was determined. The analysis synthesized the participant's knowledge, need and expertise from the themes. In summarizing these in the results section, each response is associated with quotes to an answer but all respondents remain anonymous under a random ID. Participants were identified as follows: Province (P ###); Municipalities (MUN###) and Consultants (CSLT###). Quantitative analysis of the Likert rank question responses within this study was performed using perceptual mapping and thematically grouped response frequencies. Perceptual mapping is a psychometric methodology based on Correspondence Analysis (Higgs, 1991; Legendre and Legendre, 1998). Correspondence analysis uses a chi-squared metric to maximize the relationship between respondents and their responses in questionnaires, with one of the earliest applications to marketing research (Hoffman and Franke, 1986). This method can be easily adapted to the analysis of risk perception (Frewer et al., 1998). Results of this analysis are presented as a Joint Plot that 'maps' respondents and questions as coordinates within a perceptual space (Hoffman and Franke, 1986). Respondents that share perceptions are 'closer', and are located near the questions in which they share a positive concordance. Respondents that are far apart from each other typically have opposite perceptions of the questions, and questions that are plotted far from respondents indicate a shared negative concordance with respect to same. To examine individual questions, response frequencies were averaged and plotted as bar charts by grouping the cohorts thematically by province, municipality and consultant.

4.5 Results

Qualitative (Long Questions)

Results were identified by their themes (Policies and Process; Methods and Data; Recovery). . The analysis retrieved the participant's knowledge, experience, and needs from the themes. Most common responses are associated with quotes to an answer but all respondents remain anonymous under a random ID. Participant's responses were summarized and identified in: Annex VII (Policies and Process), Annex VIII (Methods & Data) and Appendix IX (Recovery)

Policies and Process (theme)

Results reveal that knowledge on policies and process are identified through circulation of the development application, but the provincial reports identifying flood risk or vulnerabilities are not necessarily enforced by the applicant's municipality or planning district. All provincial organizations surveyed, provided a similar response "Policies are considered during the permit process when an application is circulated through various provincial departments to identify flood risk to the applicant and local government." Although there are many government departments involved in the application circulation process, it is often the municipality who makes the final decision on whether an applicant can develop or not. As identified by the majority of the municipalities "We rely on the province for guidance. Council reviews the provinces report and will then make their decision (Engineering design, structural, riverbank stability). At the end of the application process, it is often the municipality who decides if an applicant can develop or not."

Methods and Data (theme)

All participants agreed that in Manitoba, there is no centralized database hosting flood data (maps, historical data, LiDar) leaving flood experts in government and industry to manage independent datasets. A consultant summarized the majority of responses by stating: "In Manitoba we do not have a centralized database. The data is scattered. Some of the data is with the municipality and some with the province and some have both." The knowledge of GIS technology and centralization of data appears to exist with consultants, leading many government departments to recruit them to assist with their data collection and GIS mapping. As identified by a provincial department, key and up to date datasets such as LiDar and flood buffers are often provided by contracts to consultants. "LiDar data resides in a (GIS) platform. In this tool we have flood buffer for the floods of 1997, 2009. We have Aerial photos (20cm) of all municipalities which fall under this planning district. At this time our data layers and parcel mapping data are georeferenced and correct." Not all municipalities have GIS capabilities or resources to manage flood data. During a flood emergency, some municipalities are highly dependent on MIT formerly (Water Stewardship) for maps, data and reports. As stated by a municipality, "All three levels of government would benefit from a centralized database. If it is made available we would use it."

Recovery (theme)

Results revealed that the majority of resources and expenditure related to flooding are currently allocated to flood response. It is the provinces experience that recovery is high but still a fraction of what they are spending if structural mitigation was not in place. As stated by a provincial department, “Recovery cost are high but it is still a fraction of what we are investing. All structural mitigation measures are an investment. There are future investments which will be directed to structural mitigation measures to reduce recovery from Disaster Flood Areas (DFA) and mitigation cost.” Ten of the eleven participants agreed that there is a need for non-structural mitigation measures such as a standard Quantitative Risk Assessment (QRA) tool in government to localize data; inform policy and assist with mitigating development in flood risk areas. As summarized by the province, “Yes a complete standardized tool would assist to influence policy and decision makers. This tool would have to prove its accuracy before it would become a standard tool in Manitoba.”

Quantitative (Likert Format)

Perceptual Mapping

Perceptual mapping, plotted Participants score to each question. The concentration of questions and participants are placed on the map based on the summary of the results displayed in Annex X. Each participant’s perception is mapped based on major trends. Participants who’s responses were different than that of all the other participants are placed towards the outside or edge of map identified in Figure 4.3. The strongest trend in these data are on Axis 1 is influenced primarily by participants P102A, P102 and P101, P108 which are two separate Provincial Departments. The individual positions of the participants from these Departments completely overlap and a line superimposed on the graph indicates the respondents with identical answers. In both cases the overlapping points are from within single Departments. On the second axis MUN103 and CSLT101 are the most distant and are outliers on that axis. Many of the Consultants and Municipal representatives interviewed had similar overall responses and plotted in close proximity near the origin of the graph. In looking at questions by theme, Mitigation measures (Q16-19) and Government/Funding (Q4-8) were answered with the most discordance. Methods and Data (Q9-15) were generally positive on the First axis and Recovery (Q20-23) generally negative. On the second axis Policy/Process (Q1-3) is positive and Government/Funding scored negatively. Outliers questions on the first axis include Q7 and Q18, while outliers on the second are Q2 and Q9 (for the full text of each question see Annex VI).

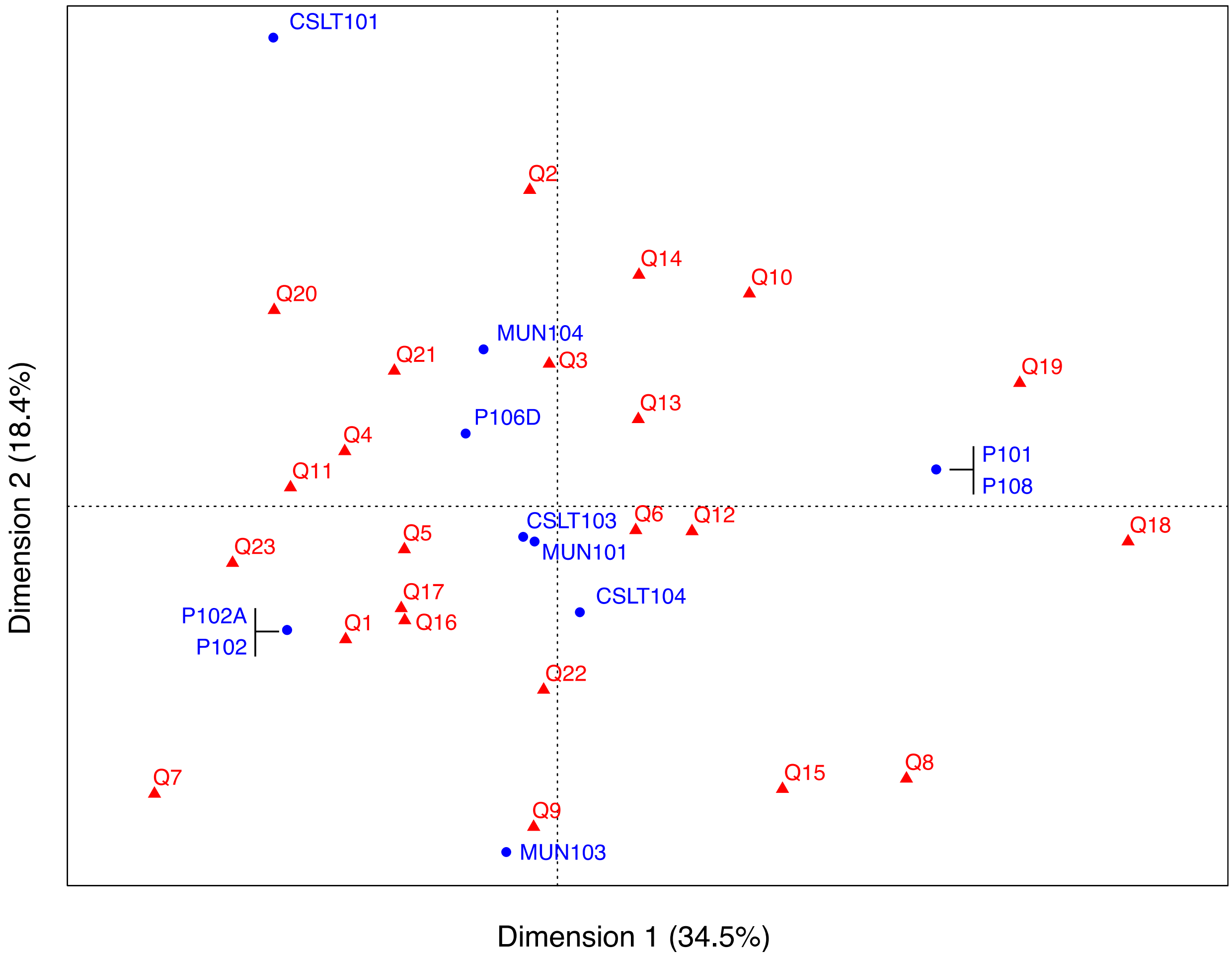

Figure 4.3 Joint Plot perceptual map based on the 11 participants perception of responses to 23 Likert questions.

Frequency Analysis

Results from the Quantitative analysis are summarized in Annex X. The mean Likert score was calculated for each of the three organzations (provincial, municipal, consultants) to summarize their responses to questions identified in Annex VI. The results from the summary are identified in figure (4.3, 4.4, 4.5, 4.6).

Policies and Process (theme)

Results identified in Figure 4.4, suggest that the participants from municipalities and consultants agree that it is the local government's responsibility to look after development. The province strongly disagreed to the fact that flood mitigation policies are implemented by Municipal Government. These results suggest deviating opinions on the organization which implements flood mitigation policies.

Method and Data (theme)

Results illustrated in Figure 4.4, suggest that all participants agree that mapping resources in government are insufficient and Manitoba's data is not centralized. There are currently no Quantitative Risk Assessment (QRA) tools being used in government. These results suggest that methods and data are stored independently and not all information is shared within government or outside organizations.

Mitigation Measures (theme)

Results identifies in Figure 4.5, indicate that all participants agree that Manitoba should continue to mitigate with structural measures as well as fund non-structural measures to include policies ,process and technology to restrict development in flood risk areas. These results suggest that the province, municipality and consultants see value in both structural and non-structural mitigation measures.

Recovery

Results identified in Figure 4.6, suggest that all participants agreed that the recovery of property should happen more than once. There were deviating answers on removal of structures in areas subject to repeated flooding. Overall participant's alluded that more needs to be done to protect flood victims and the tax payer for the cost of flood and recovery. Participant's responses suggest the need for a change in mitigation measures which would assist with the cost of recovery.

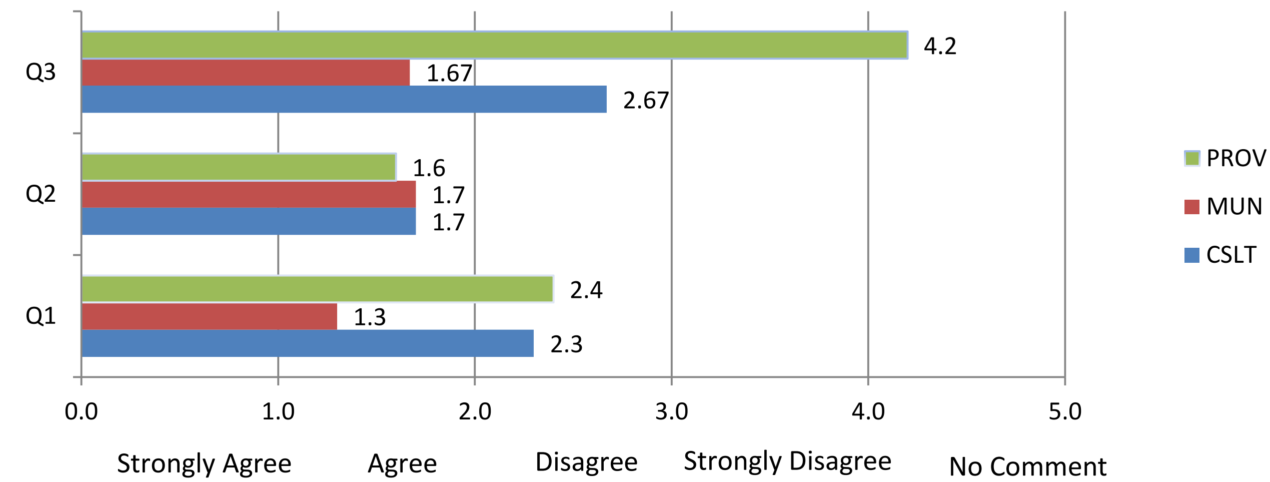

Figure 4.4. Identifies quantitative responses on policies and process. Questions address: government levels and roll in flood mitigation policies to development and disaster mitigation.

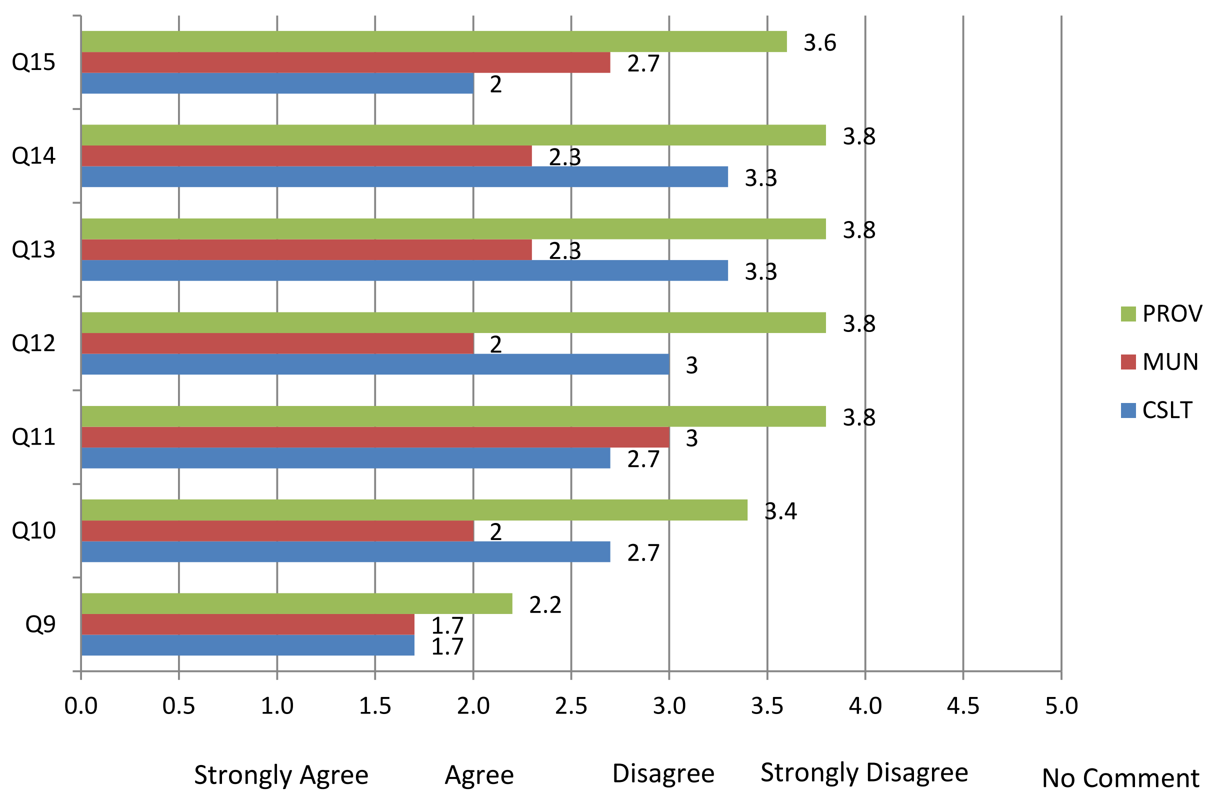

Figure 4.5. Identifies responses on methods and Data. Questions address: Methods and data applied in government and consultants to assist decision makers during flood event.

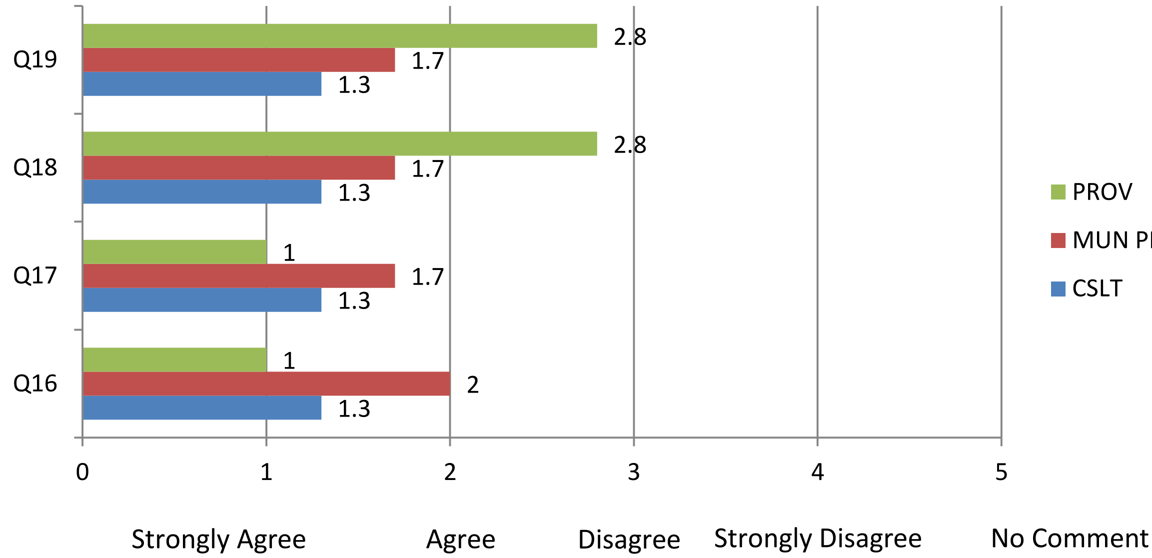

Figure 4.6. Identifies responses on Mitigation Measures. Questions address: Mitigation measures applied and financially supported as well as technology, and social perception on flood protection.

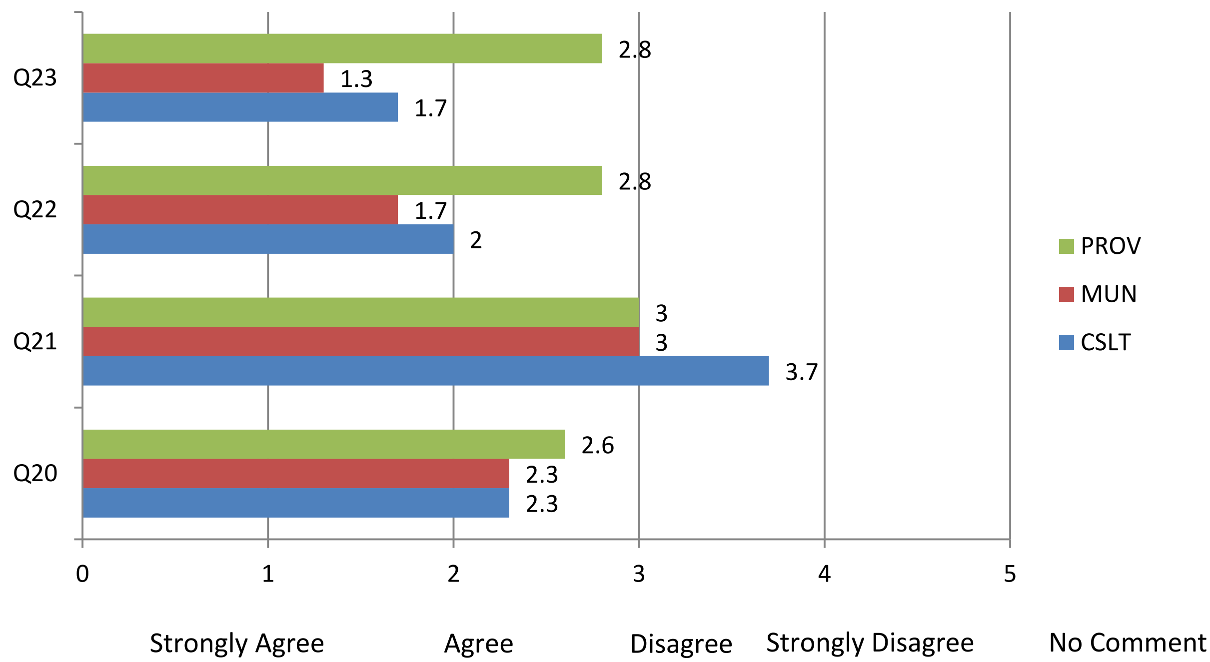

Figure 4.7. Identifies responses on Recovery. Questions address: Recovery of property and victims and cost to tax payer.

4.6 Discussion

In Manitoba, the breach of land regulation and the lack of legislated ministerial powers have encouraged land development in flood risk areas. These deficiencies have affect the process and competence of policies designed to regulate land development. This is a different outcome from that of Pal (2002) who found that floodplain policies can be effective through deterring new development. While policies in Manitoba may be similar, in the Ontario case studies in Pal (2002) a regulatory flood line defines a boundary where there is moratorium on new development. He did note that new residential homes have crept to edge of this boundary without implementing flood-proofing.

Synthesis of the long answer questions with flood experts found that all participants see value in non-structural mitigation specific to a QRA tool to enforce communication in policies on land regulations and lower the cost of recovery. Although participants positively supported this view, Myer, Priest and Kuhlicke (2011) found that non-structural methods do not necessarily reduce cost, but does improve efficiency in reducing risk. Their findings from qualitative to quantitative interviews showed that decision makers evaluate transaction costs to be high especially for non-structural measures which are associated with land-use changes, like resettlements but also dike relocations. If we assume that decision makers implicitly include transaction costs in their evaluation of alternative measures (which is supported by the interviews), this could explain why measures with perceived low transaction costs, like dike heightening but also warning systems, are often preferred (Meyer, et al., 2012).

Perceptual mapping elucidated trends amongst individual participants and their responses. The strongest trend was defined by Provincial participants and overlap was observed because individuals in the Departments insisted on collaborating on their answers. This strategy to complete the survey through collaboration seemed to be independently chosen in each Department. The perceptions within these Departments and answers to most questions were opposite indicating discordant views on key issues related to Funding and No-Comment on Mitigation. This may indicate the need to for better communication between organizations and the need liaison between Departments. Participant outliers and their influence on the second axis (MUN103 and CSLT101) were characterized by at least one No-Comment response in each thematic group. For CSLT101 a No-Comment on Q8 "Consultants are the mapping experts in government" was likely answered in that way to avoid personal perception and to remain unbiased. This consultant confirmed in the long questions, that they provide a consulting and mapping service in government. Similar, overall responses for Municipal and Consultant stakeholders, is likely because of closer working relationship between these individuals. Methods and Data (Q9-15) were generally positive on the First axis with exception of Q11which states "Total damage cost […] typically is estimated before such a disaster" this had No-Comment from one Provincial Department and Disagree from another. However that latter Department answered No-Comment for all other questions in the Methods and Data theme while the former selected "Agree or Disagree". There appears to be very strong sensitivities within Provincial Departments on questions related to Methods and Data. However, participants agreed that mapping resources in government are insufficient and data are not centralized. Policy on centralization of a standard QRA tool would eliminate the independent datasets. In the case of Minnewaukan North Dakota (Cummings, et at., 2012), the computer visualization of flood risk provided by Hazus-MH through incremental inundation maps and damage elevation profiles, enables individuals and decision-makers to better understand both personal risk and community risk. In addition, by quantifying the risk in dollars, the Hazus flood model stimulated local and state government to identify and pursue appropriate mitigation measures (Mickey, 2012).

Participants agreed that when it came to recovery there is a need for a QRA tool to influence policy to eliminate the cost of recovery in instances where people have been recovered more than one. Public Safety Canada (PSC) and Defence Research Development Canada (DRDC)'s Center of Security Science support all Federal Government institutions in fulfilling their legislated responsiblitity (PSC, 2010). In response to this mandate, various federal departments are investigating the development and implementation of tools designed to produce Quantitative Risk Analysis (QRA). A study completed by Pal, 2002, identified that non-structural measures seek to identify the parts of a social system specific to reducing vulnerability including behaviors and perceptions (Pal, 2002). Results from this study suggested that the majority of the participants agreed a standard QRA tool would inform decision-makers and quantify results to empower policies design to regulate land development and reduce cost recovery.

4.7 Conclusion

The objective of this research was to define the application of a Quantitative Risk Assessment tool in policy to reduce the cost of recovery. Results from the survey suggest that the majority of the participants agreed that a standard QRA tool would inform all decision-makers and policies design to regulate land development in flood prone areas and reduce the cost of flooding. If government decision-makers have a standard QRA tool they would ideally all be viewing and communicating the same information and managing one warehouse of data. In order for a standard QRA tool to be realized as a proactive mitigation measure in a Manitoba support will be required by federal, provincial and municipal government.

Chapter 5
Conclusion and Recommendations

5.1 Overview

The primary goal of this study was to evaluate the role of a Quantitative Risk Assessment (QRA) tool in Manitoba and its application to policy. In Chapter 3 we evaluate Hazus-MH as a Quantitative Risk Assessment (QRA)Tool and found that Hazus-MH has potential in a Manitoba context. The results of the flood analysis provided reports and summaries on structural damages and losses including maps quantifying the damage. This tool can inform decision-makers within government on potential flood risk loss to structures and their monetary value. Hazus capabilities to simulate a flood event and view the damages before they occur can inform decision-makers on land development in flood risk areas and has the potential to reduce the cost of flood recovery in Manitoba. Chapter 3 details the study and results on “Hazus-MH as a Quantitative Risk Assessment (QRA) Tool”. Chapter 4 defined the application of a QRA tool in Policy to reduce the cost of recovery. . The results summarized from a survey suggested that the majority of the participants agreed that a standard QRA tool would inform all decision-makers and empower policies design to regulate land development in flood prone areas. Analysis from the perceptual mapping revealed that within government perceptions can be very different between departments, while consultants and municipalities often shared opinion. Analysis of long questions retrieved the knowledge, need and expertise from each participant. Chapter 4 details the study and results on “the application of a QRA tool in Policy”.

5.2 Major Findings

This research found that all areas along the Red River in the RM of St. Andrews are at risk of flooding during a 100 year flood event. Areas such as Netley Creek, Breezy Point, Petersfield, Little Britain, which were highly exposed to the 2009 flood have now been protected or removed through provincial and municipal funds. However, floods are unpredictable in the RM of St. Andrews due to ice-jams and structural mitigation in some areas requires additional sandbagging. A discharge of high volume water from the Red River Floodway could increase the flood risk and create a much worse scenario than expected. Although large amounts of money have been spent on structural mitigation in the Red River Basin flooding cost continue to increase. In Manitoba's Red River Basin and elsewhere, structural measures have often encourage floodplain occupancy and produce a false sense of security, as people assume that the flood risk has been eliminated (Environment Canada, 1993). Historically, public policy has been heavily concentrated on response, reflecting a belief that disaster are "acts of God" or acts of Nature, catastrophes beyond our control. Secondly, the use of land use regulation as a means of flood damage reduction has been slow to be effectively adopted in Manitoba. As identified by (Simonovic, 2000) inconsistencies abound in use of Designated Flood Area (DFA) maps because it is at the discretion of the municipalities. The breach of land regulations has been an ongoing concern; legislated ministerial powers have not been used in instances of non-compliance. The inconsistency of regulations, are now costing Manitoban's billions of dollars. Although the municipalities may permit the development in flood designated areas, it is the province who recovers the flood victims (Sutherland S, 2014). The primary goal of this study was to evaluate the role of a Quantitative Risk Assessment (QRA) tool in Manitoba and its application to policy. The specific study objectives first evaluated Hazus-MH as a (QRA) tool in Ward 1 of the Rural

Municipality (RM) of St. Andrews, Manitoba and determine that Hazus-MH can be applied to influence decision-makers to regulate land development in flood risk areas. Through studies completed in chapter (3) identified that Hazus flood model has the capability to quantify loss and damage to Manitoba properties at risk of flooding. This tool has the potential to assist decision-makers in all levels of government with visual interpretation of various flood scenarios and estimate economic damage and loss to structures.

The second objective utilizes a face-to-face questionnaire with flood experts in municipal and provincial government, and consultants to determine the land development processes in flood plains and the role of technology and public policy process in mitigating and responding to flood risk in the Red River Basin. Analysis involved two sets of questions, open (long questions) and Likert format ranked questions. A sample of 11 participants was divided into three separate groups, provincial, municipal and consultant leaders with expertise in flood risk management. Through studies completed in chapter (4) results revealed that knowledge on process and policies reside within some government organizations but not all. Consultants are often contracted by government due to their expertise with methods/data and technology. There is no centralized database hosting flood data in Manitoba, leading flood experts in government and industry to manage independent datasets and silos/stove pipe systems. Finally, results suggest that the majority of the participants agreed that a standard QRA tool would inform all decision-makers and empower policies design to regulate land development in flood prone areas.

5.3. Recommendations

Based on the findings the following recommendations are suggested:

- Current LiDar data are inconsistently available. It is recommended that data coverage be expanded and regularly updated.

- To run Hazus flood model, updated DEM data is required. Provincial departments would need to create current up-to-date-flood surface data for southern Manitoba.

- Hazus requires local data to implement the current building attributes and values. Manitoba Municipal Government (MMG) host the assessment data in MAVAS but it needs to be made spatially aware.

- Building footprints and first floor elevation are inconsistently incorporated into databases, we recommend adding these to the assessment database.

- Hazus should be built on top of the Provincial and City assessment databases, which are well maintained and updated on a daily basis.

- It may be necessary to tie future flood compensation from the Federal Government to having Provinces adopt national standards and quantitative risk assessment tools.

- If a standard QRA tool is implemented in Manitoba, a policy will need to be developed to enforce the use of this standard QRA application.

- To increase the communication between decision-makers, it is recommended that Manitoba flood data be centralized and accessible to all levels of government and consultants.

- It is recommended that the cost of data redundancy in government be calculated against the cost benefits of developing a standard QRA tool design to centralize data.

5.4 Concluding

Historically, Manitoba has developed structural mitigation measures to protect Manitoban's in the floodplain. As flood costs continue to rise, Manitoba needs to evaluate non-structural measures specific to a QRA tool and policy. Currently, there is no standard centralized database in Manitoba, leading flood experts in government and consultants to manage independent datasets. These are expensive methods of managing and maintaining data. There is a cost to redundancy of data within government but there is also a cost to creating a centralized database. A standard database in government would reduce the redundancy of data and over time prove its efficiency and cost benefits. Although Hazus has the potential of being a standard QRA tool in Manitoba to centralize and quantify data it comes with its challenges. Hazus analyses depends on a large input of data which is critical to quantifying risk assessments and helping decision-making to support disaster planning activities. Using the Hazus default inventory database aggregated on the census block level is not an option in Manitoba. We must collect and use local data. Improving the quality of the local data in Hazus and generating new hazard-related knowledge is primary, as it will also increase the accessibility to users in government and industry (McGrath, 2014). The second challenge is the collecting, updating and maintaining the input inventory and hazard data. In the long term, all the Hazus-related work should be coordinated by a provincial organization. Finally, in order for a standard QRA tool to be realized as a proactive mitigation measure in Manitoba, financial support and resources will be required from all levels of government.

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APPROVAL CERTIFICATE

December 16, 2015

NR Can
42465

TO: **Suzanne Houlind** **(Supervisor: David Walker)**
Principal Investigator

FROM: **Lorna Guse, Chair**
Joint-Faculty Research Ethics Board (JFREB)

Re: **Protocol #J2015:139**
"Development and refinement of the HAZUS flood mapping tool for Canada: Date integration and database development in a municipal pilot project"

Please be advised that your above-referenced protocol has received human ethics approval by the **Joint-Faculty Research Ethics Board**, which is organized and operates according to the Tri-Council Policy Statement (2). **This approval is valid for one year only**.

Any significant changes of the protocol and/or informed consent form should be reported to the Human Ethics Secretariat in advance of implementation of such changes.

Please note:

- **If you have funds pending human ethics approval, please mail/e-mail/fax (261-0325) a copy of this Approval (identifying the related UM Project Number) to the Research Grants Officer in ORS in order to initiate fund setup. (How to find your UM Project Number: http://umanitoba.ca/research/ors/mrt-faq.html#pr0)**

- **if you have received multi-year funding for this research, responsibility lies with you to apply for and obtain Renewal Approval at the expiry of the initial one-year approval; otherwise the account will be locked.**

The Research Quality Management Office may request to review research documentation from this project to demonstrate compliance with this approved protocol and the University of Manitoba *Ethics of Research Involving Humans*.

The Research Ethics Board requests a final report for your study (available at: http://umanitoba.ca/research/orec/ethics/human_ethics_REB_forms_guidelines.html) **in order to be in compliance with Tri-Council Guidelines.**

umanitoba.ca/research

Annex II: Request for Participation Letter

UNIVERSITY OF MANITOBA | Dept of Environment and Geography

220 Sinnot Building, 70a Dysart RD
University of Manitoba, Winnipeg
Manitoba, Canada R3T 2N2
Phone (204) 474-9667
Fax (204) 474-7699

ANNEX - II

To: Participants,
November 3, 2015

I am a graduate student researching a project entitled "Applying technology in policy to Quantify Risk Assessment" that is promoting government stakeholders and consultant's participation in Sustainable Floodplain Management in the Red River Basin. This project is part of my master's thesis under the advisory of Dr. David Walker, Professor Department of Environment and Geography (204-474-6581). The primary purpose of this research is to enhance our understanding of development processes in the flood plain and the role of technology and public policy processes in mitigating and responding to flood risk in Manitoba.

We plan to survey Planning districts officials, local and provincial government leaders including consultants who have experience with floodplain development. With your generous assistance, this research will gain valuable insights of floodplain development procedures, from a government and Industry perspective. Your participation is voluntary and greatly appreciated.

Our research will involve one personal (face-to-face) interview with a questionnaire to be completed on-site. The approximate time commitment will consist of one hour for the face-to-face interview and a maximum of 1 hour to complete a questionnaire. The questionnaire answers will be documented during the face-to-face interview with participant review. All information that you provide will be kept in strict confidence and only aggregate (grouped) data will be utilized. Your name will remain confidential and only myself as the principal investigator will have access to personal data. Your answers to the questions will be viewed by myself the principal investigator and my advisor Prof Walker. Once your answers are summarized in thesis they will be destroyed.

The research is a component of a larger project with the objective to provide a methodology for estimating flood-loss using a technology known as "HAZUS-MH" and assist mitigation measures. The HAZUS technology represents an applied GIS-based framework for risk estimation of natural hazards in the United States (US). This study has been funded by Natural Resources Canada and involves various institutions working together in partnership to evaluate the potential of HAZUS for its application to the context of flooding events in Manitoba.

If you are interested and would be willing to participate in our study, we would appreciate that you respond to umhoulis@myumanitoba.ca by January, 2016. This would assist us in arranging interview dates in a timely manner.

This research has been approved by the Joint-Faculty Research Ethics Board and that any complaints or concerns can be addressed to you or the Human Ethics Coordinator at 204-474-7122 and email: humanethics@umanitoba.ca
Thank you for taking the time to consider our request; I look forward to hearing from you.

Sincerely,
Suzanne Houlind
Graduate Student in Geography
Dept of Environment and Geography
University of Manitoba

environment_geography@umanitoba.ca

Annex III Letter of Introduction

UNIVERSITY OF MANITOBA | Dept of Environment and Geography

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ANNEX III

INTRODUCTORY STATEMENT

My name is Suzanne Houlind I am a student in the Environment and Geography Department, University of Manitoba. The purpose of this research is to enhance our understanding of development processes in the flood plain and the role of technology and public policy processes in mitigating and responding to flood risk in Manitoba. We want to explore these issues through interviews with Planning districts officials, local and provincial government leaders including consultants. The objectives of the study are to:

1) Assess development processes at local and provincial levels.
2) Assess the methods and technology applied by decision-makers to assess flood risk.
3) Determine the nature of risk communication strategies among the decision-makers, and the factors affecting communication on floodplain management issues.
4) Explore the role of partnership between all levels of government in support of policies to mitigate risk associated with floodplain development.

Participant in this study were selected based on their role and knowledge on policies procedures and/or technology specific to mitigation risks associated with floodplain development in Manitoba's Red River Basin.
Individuals were selected considering their level of knowledge and past flood experience.

Each participant will be asked to complete a one-hour interview where they will verbally respond to a series of questions and fill out a short questionnaire consisting of 20 ranking questions. The questionnaire answers will be documented during the face-to-face interview with participant review. The research will explore issues relating to your experience, perception, knowledge, and decision-making involvement with past floods and associated floodplain development. The content will cover topics including floodplain development policies processes, methods, and technologies applied to mitigate flood risk, government responsibilities, and future flood preparation and response.

You are under no obligation to participate in the interviews. If you choose to participate, please feel free to discuss your opinions openly and freely. You can, at any time, end the interview or refuse to answer individual questions. In the event that you do not wish to answer a specific question, simply respond "no comment". Your responses will be held in strict confidence and the results of the study will be aggregated (grouped) with no reference to specific participants. Upon completion of this study, you will receive a summary of my findings.

The research is a component of a larger project with the objective to provide a methodology for estimating flood-loss using a technology known as "HAZUS-MH" and assist mitigation measures. The HAZUS technology represents an applied GIS-based framework for risk estimation of natural hazards in the United States (US). This study has been funded by Natural Resources Canada and involves various institutions working together in partnership to evaluate the potential of HAZUS for its application to the context of flooding events in Manitoba.

environment_geography@umanitoba.ca

Annex IV: Informed Consent Form

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ANNEX IV

INFORMED CONSENT TO PARTICIPATE IN THE STUDY

This consent form, a copy of which will be left with you for your records and reference , is only part of the process to be congruent with this document. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not include here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.
The purpose of this research is to enhance our understanding of development processes in the flood plain and the role of technology and public policy processes in mitigating and responding to flood risk in Manitoba. We want to explore these issues through interviews with local and provincial government officials; provincial planning district personnel and consultants. The objectives of the study are to:
1) Assess development processes at local and provincial levels.
2) Assess the methods and technology applied to assess flood risk.
3) Determine the nature of risk communication strategies among decision-makers and the factors affecting communication on floodplain management issues.
4) Explore the role of partnership between all levels of government in support of policies to mitigate floodplain development.
The research is a component of a larger project with the objective to provide a methodology for estimating flood-loss using a technology known as "HAZUS-MH" and assist mitigation measures. The HAZUS technology represents a GIS-based framework for risk estimation of natural hazards in the United States (US). This study has been funded by Natural Resources Canada and involves various institutions working together in partnership to evaluate the potential of HAZUS for its application specific to flooding events in Manitoba.
Each participant will be asked to complete a one-hour interview where respondents will verbally respond to questions and fill out a short questionnaire. The questionnaire answers will be documented during the face-to-face interview with participant review. The research will explore issues relating to your experience, perception, knowledge, and decision-making involvement with past floods and associated floodplain development. The content will cover topics including floodplain development policy processes methods and technologies applied to mitigate flood risk, government responsibilities, and preparation and response strategies for dealing with future floods.
You are under no obligation to participate in the interview. If you choose to participate please feel free to discuss your opinions openly and freely. You can at any time, end the interview or refuse to answer individual questions or withdraw from the study by telling Suzanne Houlind in-person, by email or telephone. If you withdraw from the study your data will be destroyed and not used in the study. In the event that you do not wish to answer a specific question, simply respond "no comment". Your responses will be held in strict confidence and the results of the study will be aggregated (grouped) with no reference made to specific participants. Once the results have been summarized in my thesis your questionnaire will be destroyed. My research may be published in a scholarly journal and will be presented at academic meetings. Upon completion of this study, you will receive a summary of my findings by May 1, 2016. In addition, I will send an e-mail when my thesis has been published and available at the U of M library.
There is no risk to the participants as I will be interviewing you on your knowledge of technology and flood plain management based on your job as public individuals. Your benefits will be the results of the study, which will demonstrate if new technology can assist decision-makers with mitigating flood loss. There will be no monetary or career benefits.

environment_geography@umanitoba.ca

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ANNEX IV

INFORMED CONSENT TO PARTICIPATE IN THE STUDY

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions form their legal and professional responsibilities. You are free to withdraw from the study at any time, and/or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

Suzanne Houlind, Graduate Researcher, Department of Environment and Geography: umhoulis@myumanitoba.ca or Dr. David Walker, Professor Department of Environment and Geography: David.Walker@umanitoba.ca.

This research has been approved by the Joint-|Faculty Research Ethics Board (JFREB) o the University of Manitoba. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator humanethics@umanitoba.ca. A copy of this consent form has been given to you to keep for your records and reference.

Signature of the Respondent ________________________ Date __________

Signature of the Interviewer ________________________ Date ___________

I would like to receive a summary of findings:
___yes   or ___no
Send it to the following address: ____

environment_geography@umanitoba.ca

Annex V: Face-to-Face Interview (Long Questions) Instrument for Participants

QUESTIONNAIRE
Survey (1)

Policies/Process

1) How is flood risk considered in the development application process?

2) What specific aspects of flood risk and tasks does an applicant need to consider prior to applying for a development permit?

3) Explain how policies legislated by the province to mitigate flood risk are considered in the application process?

4) How are developmental needs and risk reduction considered in the decision-making process?

Government/Funding

5) Which level or levels of government (local, provincial, federal) are responsible to permit (commercial, residential, agricultural) development in the floodplain areas?

6) The National Disaster Mitigation Program (NDMP) provides funds for disaster mitigation. Eligible projects would include actions such as the replacement of storm culverts, technology upgrades, and projects that improve flood. How has this program improved flood mitigation measures in your area?

Methods/Data

7) What data and mapping methods are currently being applied to inform decision-makers with any type of vulnerable development (commercial, residential, agricultural) in the flood risk areas?

8) Is there a centralized database to inform decision-makers with data such as: census data; assessment data; tax roll data; local maps and elevation or LiDar data?

9) If a GIS tool was to be installed in government to mitigate structural losses before they happen, which level of government do you see most likely to benefit from using this application?

10) In what way would the permitting process need to be changed so that building outlines and elevations could be included in electronic/GIS databases? Could MAVIS be made spatially-aware?

Recovery

11) Are the majority of resources and expenditures related to flooding currently allocated to flooding responses or mitigation strategies?

12) Can a quantitative GIS tool assist in reducing the cost of recovery by influencing decision-makers to mitigate development in flood risk areas?

13) Can a quantitative GIS tool be applied to inform policy and reduce the cost of recovery?

Annex VI: (Questionnaire) Likert Questions

Survey (2)

Please rank the following questions in compliance as you feel fit on a scale of 1- 5

1) Strongly Agree 2) Agree 3)Disagree 4) Strongly Disagree 5) No Comment

Policies/Process

	Strongly Agree	Agree	Disagree	Strongly Disagree	No Comment
1. It is the responsibility of the local government to look after development and flood risk**.**	☐	☐	☐	☐	☐
2. Canada is generally reactive rather than proactive to disaster mitigation and risk reduction.	☐	☐	☐	☐	☐
3. Provincial flood mitigation policies are fully and consistently implement by municipal government.	☐	☐	☐	☐	☐

Government/Funding

	Strongly Agree	Agree	Disagree	Strongly Disagree	No Comment
4. A flood equal or greater in magnitude than the 1997 flood will occur in your lifetime.	☐	☐	☐	☐	☐
5. The majority of floodplain residents understand that a 1 in100 year flood means it has a 1 % chance of occurring in any given year.	☐	☐	☐	☐	☐
6. Local governments should determine the disaster mitigation activities necessary in their respective jurisdictions, with the support of Provincial Government.	☐	☐	☐	☐	☐
7. Flood disasters maintain a high priority in public perceptions and on political agendas.	☐	☐	☐	☐	☐
8. The Federal government's National Disaster Mitigation Program (NDMP) financially assists provinces with prevention measures in flood mitigation projects.	☐	☐	☐	☐	☐

Methods/Data

	Strongly Agree	Agree	Disagree	Strongly Disagree	No Comment
9. Historical data on flood loss and recovery are being used to assist decision-makers.	☐	☐	☐	☐	☐
10. During flood events maps predicting the exact location and extent of floods are provided to assist in emergency response.	☐	☐	☐	☐	☐
11. Total damage cost from any particular flood is typically estimated before such a disaster takes place and used to direct emergency response resources and post-disaster compensation.	☐	☐	☐	☐	☐
12. Manitoba has centralized their assessment data making it accessible to all levels of government.	☐	☐	☐	☐	☐
13. Mapping resources in government are sufficient to assist decision-makers to mitigate risk for floodplain development.	☐	☐	☐	☐	☐
14. Quantitative Risk Assessment (QRA) tools are used in government to mitigate loss of structures before a flood occurs are sufficient.	☐	☐	☐	☐	☐
15. Consultants are the mapping experts in government.	☐	☐	☐	☐	☐

Mitigation Measures

	Strongly Agree	Agree	Disagree	Strongly Disagree	No Comment
16. Manitoba should continue to enforce mitigation measures such as floodway expansion, levees and dikes to protect Manitoban's living in the flood risk area.	☐	☐	☐	☐	☐
17. Funds should be put towards policies/process and technology to restrict development in flood risk area.	☐	☐	☐	☐	☐
18. GIS technology is applied in your office to mitigate risk for development in the flood prone areas.	☐	☐	☐	☐	☐
19. Many people believe that flood protection measures, such as buildings constructed above the base flood elevation, give them adequate or even complete protection.	☐	☐	☐	☐	☐

Recovery

	Strongly Agree	Agree	Disagree	Strongly Disagree	No Comment
20. Regardless of the recovery cost to repeated flood victims, they should be recovered more than once.	☐	☐	☐	☐	☐
21. Current levels of government are doing all they can to protect the tax payer from the cost of flood recovery.	☐	☐	☐	☐	☐
22. Recovery of property and structures in the floodplain should only happen once.	☐	☐	☐	☐	☐
23. Disaster financial assistance and procedures should be available to allow the permanent removal of structures in areas subject to repeated flooding.	☐	☐	☐	☐	☐

The survey is now finished.

Annex V11 Summarizes responses from participants on policies and process

Annex V11 Summarizes responses from participants on policies and process

Q.1 How is flood risk considered in the development application process?

Participant ID	Response
P106D	“There are two areas to consider: Subdivision and building development. a)The first step to a subdivision is applying for a permit where it then gets circulated to various provincial departments. If there are any flood risks to the development, it is identified in a report. b) For all structural building development applicants are required to build to flood protection levels and to provide a municipal drainage plan of the property in question.”

Q. 3 Explain how policies legislated by the province to mitigate flood risk are considered in the application process?

Participant ID	Response
P106D	“Policies are considered during the permit process when an application is circulated through various provincial departments to identify flood risk to the applicant and local government.”
P102	“There are two DFA governed by legislation under the Water Resources Administration Act, Red River Valley Designated Flood Area south of the floodway and the Lower Red River Designated Flood area north of the city. These are the only two areas where flood protection is legislated. Consequences are in section 17 of the act. “

Q.4 How are development needs and risk reduction considered in the decision-making process?

Participant ID	Response
P102	“We use flood risk maps and identify the flood area. We do object to development based on flood level, LiDar/available topographic data and historical imagery. It would be up to the local planning authority to approve or disapprove. MIT will inform the requestor on the natural hazard. These decision-makers may include planning districts and municipalities.”
MUN103	“We rely on provincial for guidance. Council reviews that info and will then make their decision (Engineering design, structural, riverbank stability). At the end of the application process it is the municipality which decides if an applicant can develop or not.”

Annex VIII - Identifies responses from participants on Methods and Data

Annex VIII - Identifies responses from participants on Methods and Data

Q.7 What data and mapping methods are currently being applied to inform decision-makers with any type of vulnerable development (commercial, residential, agricultural) in the flood risk areas?

Participant ID	Response
P106D	"LiDar data resides in Map Info a (GIS) platform. In this tool they have flood buffer for the floods of 1997, 2009. We have Aerial photos (20cm) of all municipalities which fall under this planning district. At this time our data layers and parcel mapping data are georeferenced and correct."
P102	"Flood Risk maps from 1980's (Hard copies and scanned pdfs which can be emailed). They are georeferenced in digitized polygons. Historical flood level (high water marks) and LiDar historical flood images."

Q.8 Is there a centralized database to inform decision-makers with locating data such as: census data; assessment data; tax roll data; local maps and elevation or LiDar data?

Participant ID	Response
P102A	"The only centralized database is the Manitoba Land Initiative (MLI). Looking forward to the new SDI being developed by Manitoba Conservation."
P106D	"No, not for all that data. Some of it yes Manitoba Assessments (MMG) will have some this data."
MUN103	"No not a one stop but data is accessible in various areas."
CSLT101	"In Manitoba we do not have a centralized database. The data is scattered. Some of the data is with the municipality and some with the province and some have both."

Q.9 "If a GIS tool was to be installed in Government to mitigate structural losses before they happen, which level of government do you see most likely to benefit from using this application?

Participant ID	Response
MUN103	"All three levels of government would benefit from this tool. If it is made available we would use it."

Annex IX - Identifies responses from participants on Recovery

Annex IX - Identifies responses from participants on Recovery

Q.11 Are the majority of resources and expenditures related to flooding currently allocated to flooding responses or mitigation strategies?

Participant ID	Response
P108	"Recovery cost are high but it is still a fraction of what we are investing. All structural mitigation measures are an investment. There are future investments which will be directed to structural mitigation measures to reduce recovery from Disaster Flood Areas (DFA) and mitigation cost."
MUN103	"Flood response. We are mostly reactive rather than proactive."

Q.12 Can a quantitative GIS tool assist in reducing the cost of recovery by influencing decision-makers to mitigate development in flood risk areas?

Participant ID	Response
P106D	"Yes it can. It can help by giving decision-makers the right information to either require proper flood mitigation measures and to avoid those flood risk areas."
P101	"Yes and it would be considered a massive investment. In addition it would go a long way to inform decision makers. "
P102A	"Yes, it could be applied by all levels of gov't. Also if there was a public viewer it would assist many with maps and questions during a flood event."

Q.13 Can a quantitative GIS tool be applied to inform policy and reduce the cost of recovery?

Participant ID	Response
P106D	"Yes it can. In my past experience the province of BC applied GIS to record historical data. As a result, this data was applied when it came to decisions on development specific to building structures and re-construction of building structures. Council was able to pass a policy stating that you were no longer able to build in flood risk areas."
P108	"Yes a complete standardized tool would assist to influence policy and decision makers. This tool would have to prove its accuracy before it would become a standard tool in Manitoba. "
CSLT103	"Yes, if you have current data this can change policies. This type of system would also lead to better decision making."

Annex X Table displays Quantitative results from all participants (Based on Questionnaire Annex V)

Formulation Frequency Answers)

Stongly Agree (1) Agree (2) Disagree (3) Strongly Disagree (4) No Comment (5)

	Policies/Process			Gov't Funding					Methods/Data							Mitigation				Recovery			
Participant_ID	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q22	Q23
CSLT101	2	2	4	2	2	1	1	5	5	3	3	2	3	3	5	1	1	5	2	3	4	1	2
CSLT103	2	2	2	2	4	2	1	2	3	3	3	4	4	4	4	2	2	2	1	3	4	2	2
CSLT104	3	1	2	2	3	2	1	2	2	2	2	3	3	3	2	1	1	2	1	1	3	3	1
MUN101	1	1	1	1	3	3	2	2	2	3	3	2	2	3	3	2	1	2	2	3	4	1	2
MUN103	2	1	2	2	1	1	2	2	2	1	2	2	2	5	3	2	2	1	2	1	2	2	1
MUN104	1	3	2	2	2	1	1	2	1	2	4	2	3	4	2	2	2	2	1	3	3	2	1
P101	2	2	5	1	3	2	1	4	2	5	3	5	5	5	5	1	1	5	5	2	3	3	2
p108	2	2	5	1	3	2	1	4	2	5	3	5	5	5	5	1	1	5	5	2	3	3	2
P102	3	1	4	1	4	1	3	2	2	2	5	3	3	3	3	1	1	1	1	3	3	3	4
P102A	3	1	4	1	4	1	3	2	2	2	5	3	3	3	3	1	1	1	1	3	3	3	4
P106D	2	2	3	1	3	2	2	5	3	3	3	3	3	3	2	1	1	2	2	3	3	2	2