Analyzing the Geographical Impact of Water Control Structures and the 2011 “Super Flood” of Manitoba on Lake St. Martin First Nation using Historical Aerial Photos, Light Detection and Ranging Data, and Geographical Information System

by

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Abstract

To protect the City of Winnipeg from a devastating flood in 2011, provincial government officials diverted the water to Lake Manitoba and then to Lake St. Martin, which is 225 kilometers northwest of Winnipeg. This artificial, anthropomorphic diversion of water forced Lake St. Martin First Nation (LSMFN), a community of 2606 people to undergo emergency evacuation from their home community and caused many people from other First Nations on Lake St. Martin to relocate. More than six years after displacement, the LSMFN community is still displaced without a permanent land base. An historic water level data analysis of Lake Manitoba was conducted to find key contributors of the constant artificial flooding over the years at LSMFN. Light detection and ranging (LIDAR) data, satellite imagery, and geographic information system (GIS) tools were used to estimate the submerged land mass before and after the 2011 super flood. GIS raster analyses estimated that approximately 1200 acres of land was lost in LSMFN from the time of inception of the Fairford River Water Control Structure (FRWCS) in 1961 and the Portage Diversion in 1970. Diverting water through these structures over many years caused repeated artificial flooding of Lake St. Martin. First Nation communities should be involved in determining government's water management policies and decisions that impact them and gain compensation for loss of land and livelihoods.

Acknowledgements

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Dedication

To my dear parents

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CHAPTER ONE: INTRODUCTION

The Manitoba flood of 2011, nicknamed the "Super Flood", is considered to be one of the biggest floods in the history of Manitoba. The extensive period and the large geographical area of the flood created great hardships for many Manitobans, particularly for First Nation people (Thompson, 2015). The flood was so devastating and unusual that its reoccurrence interval for Assiniboine River is one in only 330 years (Lindenschmidt, Sydor, & Carson, 2012). Lake St. Martin First Nation (LSMFN) is one of the worst hit communities flooded by this Super Flood, with this community being completely displaced. Since 2011, thousands of community members have been waiting to relocate to a new area of higher elevation and must rebuild their entire community from scratch. In 2017, the LSMFN community people are still living in temporary housing in Winnipeg or in towns throughout the Interlake region. Since 2011, community members have been waiting for a permanent community and see this as an artificial flood caused by government.

1.1 Introduction

Lake St. Martin First Nation (LSMFN) is an Indigenous community of 2,606 (Aboriginal Affairs and Northern Development Canada, 2015), that is a short distance of 225 km northwest of Winnipeg in Manitoba. This community is located on LSM, which is connected to Lake Manitoba by the Fairford River, downstream from the Fairford River Water Control Structure (FRWCS) (see Figure 1.1) and upstream from Lake Winnipeg. Since the operation of FRWCS, the LSMFN has been repeatedly flooded (Ballard, 2012).

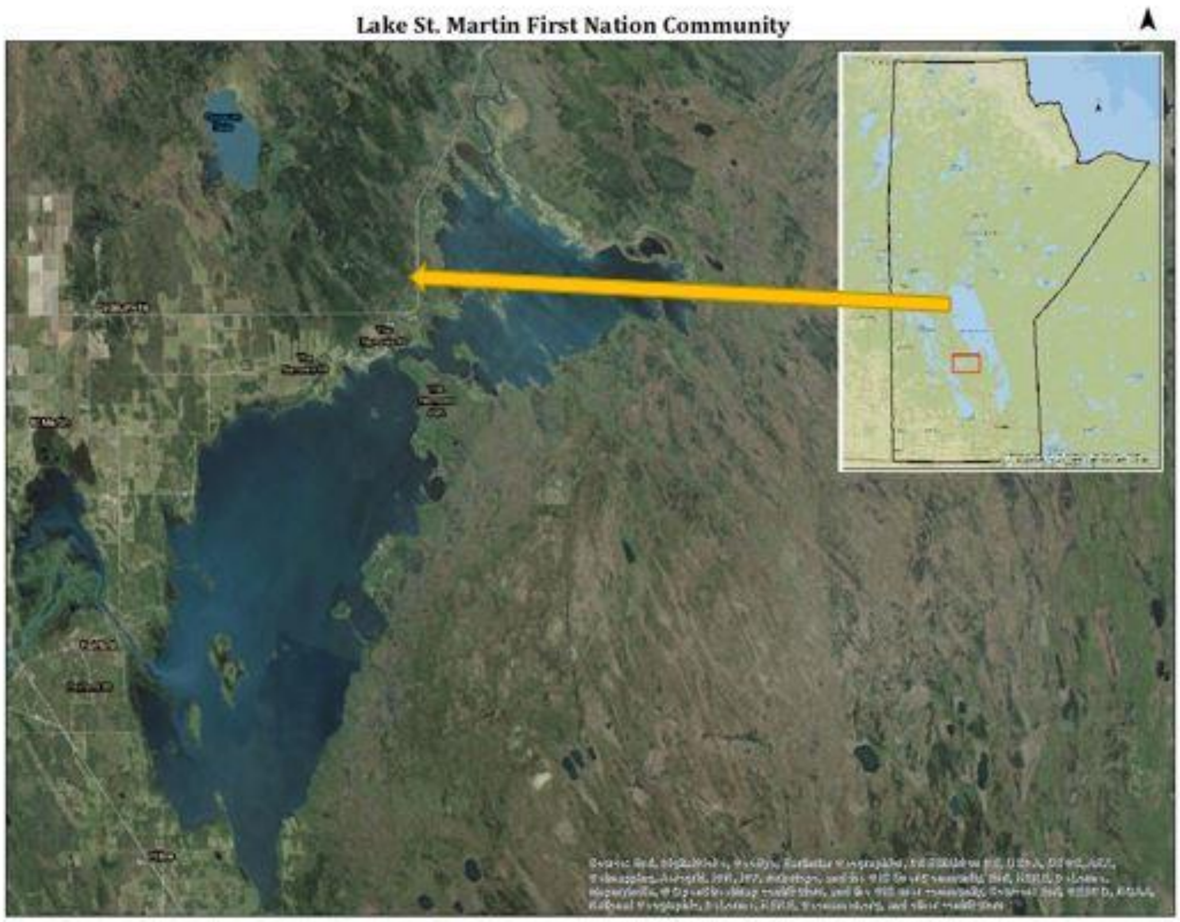


Figure 1.1: Lake St. Martin First Nation location on Lake St. Martin and in Manitoba
Map source: Adapted from ArcMap 10.2.2, 2016

1.2 Problem Statement

Over the years, Manitoba provincial government officials diverted floodwaters from the Assiniboine River to Lake Manitoba and then to LSM to protect the City of Winnipeg from floods. This diversion often resulted in continuous artificial floods to communities living around LSM. When a massive flood occurred in 2011, the unprecedented high water levels of LSM forced the LSMFN community members to undertake emergency evacuation of their reserve within 24 hours. The prolonged flood made the reserve land inhabitable and the LSMFN community members were permanently displaced. The community wants to understand the genesis of the flooding problem and analyze its impact on the land.

1.3 Hypothesis

The creation and operation of Fairford River Water Control Structures (FRWCS) and Portage Diversion (PD) result in adverse impacts on LSMFN.

1.4 Objectives

The specific objectives of this research are:

1. To study the water level history of FRWCS and PD and to analyze their impact on the water levels of LSM.
2. To examine historical raster data of LSM and estimate the change in land mass due to constant flooding from 1948 to 2011.
3. To compare the 2011 and 2013 Light Detection and Ranging (LIDAR) data of LSM and analyze it using a Data Elevation Model (DEM) to determine what areas are under water due to the 2011 super flood.

1.5 Research Significance

Even six years after the 2011 super flood of Manitoba, LSMFN community members could not return to their reserve. With the higher levels of LSM after the flood, the reserve remains inhabitable. The results of this study are expected to explore the history of flooding and its impacts on LSM and LSMFN.

1.6 Methods

The 2011 "Super Flood' of Manitoba had a devastating effect on community members of LSM First Nation (LSMFN). This is the background of the thesis but the focus of the thesis is on the changing geography of the land due to water flows. For this I explore the data from water gauges in LSMFN, along with various water gauge stations such as PD Control Structure, Steep Rock Water Station (SRS), FRWCS, and Hilbre Water Station (HS). These water gauge stations were constructed on the Assiniboine River, Lake Manitoba, Fairford River and LSM respectively. The study of historic water level data at these stations is important in understanding the amount of water diverted from Assiniboine River to LSM from the time of operations of FRWCS and PD. To understand the relationship between Assiniboine River, Lake Manitoba, Fairford River, and LSM water levels, it is important to study the changing water levels provided by Canadian water gauge stations. In general, water gauge stations are used to monitor the water levels at the waterways (Zheng, Zong, Zhuan & Wang, 2010).

The table below shows the research methods and the data applied for reach objective.

Objectives	**Research Methods**	**Data**
1: To study the water level history of FRWCS and PD and to analyze their impact on the water levels of LSM.	Microsoft Excel, Line Charts, Comparison analyses.	Historic hydrometric water level data, Environment and Natural Resources, Government of Canada.
2: To examine historical raster data of LSM and estimate the change in land mass due to constant flooding from 1948 to	ArcGIS 10.2.2 tools: Geo referencing, Editor, Spatial Analyst, 3D Analyst, Time-slider.	Historical aerial photographs of LSM, Department of Manitoba Conservation, Government of

2011.		Manitoba.
3: To compare the 2011 and 2013 Light Detection and Ranging (LIDAR) data of LSM and analyze it using Data Elevation Model (DEM) to determine what areas are under water due to 2011 super flood.	ArcGIS 10.2.2 LIDAR tools: LAS Dataset. 3D Analyst, Image Analysis, Spatial Analyst. Global Mapper LIDAR software.	Light Detection and Ranging Data (LIDAR) data for the year 2011, and 2013, Elizabeth Dafoe Library, University of Manitoba

Table 1.1: Research methods and data for each thesis objective

1.7 Limitations

This study focuses mainly on the artificial flooding of LSM caused by the diverted floodwaters through water control structures constructed by the government without any consultation with the First Nations' people. The researcher was limited to looking at flows from PD and Lake Manitoba and did not consider other factors such as prolonged rains or excessive snowfall in a season which can trigger a natural flood.

1.8 Organization of the thesis

The thesis is organized into five chapters. Following this introduction, chapter two provides the literature review of related studies. Chapter three describes the research methods used to achieve the specific objectives. Chapter four provides detailed results for each objective. Conclusions are provided in chapter five.

CHAPTER TWO: LITERATURE REVIEW

This chapter starts with a brief description of how relevant studies and journals were located. Then, a review of literature provides a brief history of Manitoba flooding, their impacts, and flooding policies in Manitoba. Then more technical literature related to my methods are overviewed with an introduction to the Geographical Information System (GIS), as well as a description of the concepts of raster data analyses and Light Detection and Ranging (LIDAR).

2.1 An overview of literature review

This literature review considers the following key areas related to my study:

(1) Historical water level data for four time intervals (a) Pre-1960 (FRWCS), (b) Post FRWCS & Pre-PD (1961-1970), (c) Post-PD (1971-2010), and (d) the Super Flood (2011).

(2) Understanding the connection between the water levels of PD, Lake Manitoba, FRWCS, & LSM.

(3) Uses of Aerial Photographs in GIS analyses and the visualizing the changes of raster data in time-slider tool.

(4) The process of capturing LIDAR data and the use of Digital Elevation Models (DEM) to analyze captured data.

(5) Relevant case studies, which used the LIDAR data for GIS analyses.

I used the Google Scholar web search engine and the Science Direct website to find relevant peer-reviewed journal articles. The literature review process for the first objective included the following key words: "LSM, floods, prairies flood, FRWCS, PD, Manitoba flood report, 2011 flood Manitoba, water regulations Manitoba, Water Survey of Canada, historic data."

When searching with the above key words, I was able to retrieve relevant journal articles. In addition, I received suggestions from Google Scholar and Science Direct about other key words I may use. For example, when I was searching with the key word "Manitoba Flood 2011", I received a suggestion from google scholar to search for "Prairie Flood". After following the suggestion, I located 9 peer-reviewed articles. Similarly, for the second and third objectives the following key words were searched: "Airborne Imaging, Raster data, Aerial photographs, LIDAR DEM Floods, ArcGIS Floods, Global Mapper" and 12 relevant articles were retrieved and analyzed.

I focused my literature search to answer the following questions:

1. What was the history of water and flood management for Lake Manitoba and LSM prior to 1960?
2. Did the construction of the FRWCS in 1961 and the PD in 1970 enable the Manitoba government to achieve their water management target?
3. What were the actual expectations of the PD and FRWCS and the end results?

2.2 Lake Manitoba

Lake Manitoba is a very large freshwater lake, one of the largest in the world. Its size is 225 kilometers long, with a surface area of about 4,700 square kilometers (Lake Manitoba Regulation Review Advisory Committee, 2003) but has only one outlet of Fairford River, which flows into Lake Winnipeg. Lake Manitoba drains through the Fairford River, where Pinaymootang First Nation is located, and then at its south shore through Pinemuta Lake into LSM (Lake Manitoba Regulation Review Advisory Committee, 2003). Lake Manitoba is part of the Dauphin River Drainage Basin.

2.3 Manitoba Water Level Management Prior to 1960

The water levels of Lake Manitoba prior to 1960 fluctuated a lot. In the late 1890's, there was lots of flooding of Lake Manitoba and to maintain the water levels of Lake Manitoba, work was carried out at Fairford outlet. In the 1930's, following a period of low water conditions, the same Fairford outlet was used to restrict the outflow from Lake Manitoba, which served to lower levels in LSM while increasing levels to more normal levels on Lake Manitoba. In contrast to this drought, after several years of heavy water inflow of Lake Manitoba in the early 1960's, FRWCS was put into operation in 1961.

The FRWCS adjusts the outflow of water from Lake Manitoba at the Fairford River (Lake Manitoba Regulation Review Advisory Committee, 2003).

The FRWCS was constructed in response to a recommendation of the 1958 Lakes Winnipeg and Manitoba Study Board, which examined the high-water level period during the late 1960's on Lake Manitoba. During that high-water level period, Lake Manitoba water level reached 816.25 feet above sea level at Steep Rock. Hence, they recommended constructing FRWCS to maintain the water levels in between 811 feet and 813 feet above sea level. There was no environmental impact study conducted prior to the construction of the FRWCS (Lake Manitoba Regulation Review Advisory Committee, 2003).

2.4 The Portage Diversion

The PD connects the Assiniboine River to Lake Manitoba at the west of the City of Portage la Prairie. High water levels on the Assiniboine River pose a high risk of flood to the City of Winnipeg and Brandon. The construction of this diversion was completed in 1970 and since then, this control structure has been the major contributor of water to Lake Manitoba. The highest impact of the diversion on Lake Manitoba happened in 1976 when approximately 1.75×10^{9} cubic metres of flow or 1,420,000 acre-feet was diverted from Assiniboine River into Lake Manitoba (Figure 2.1).

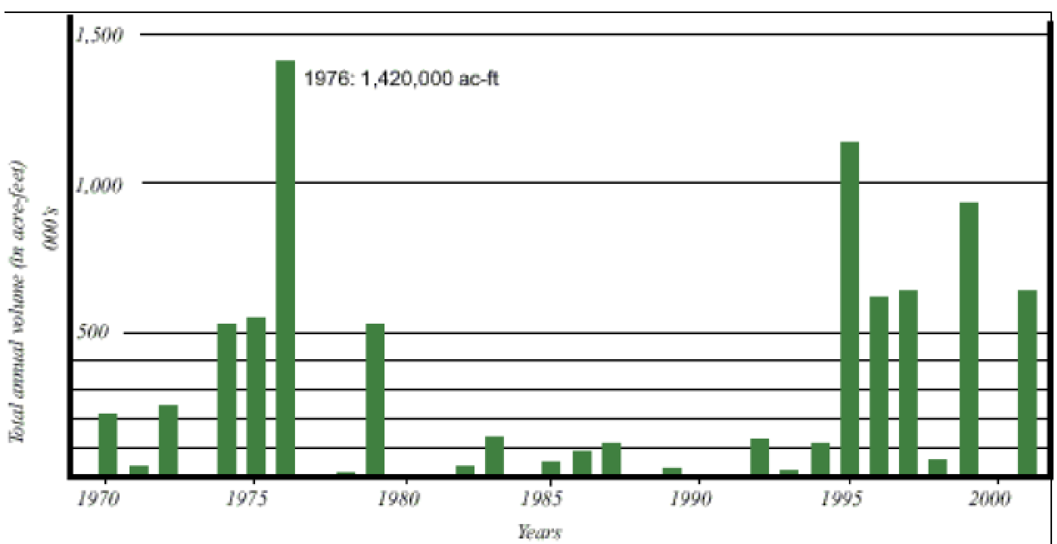


Figure 2.1: Water Flows at Portage Diversion between 1970-2001
Source: (Lake Manitoba Regulation Review Advisory Committee, 2003)

The impact of the PD was enormous, according to the Water Survey of Canada: "*The impact was so huge that it would have corresponded to a 1.22 ft. increase in the water level on Lake Manitoba if all of the water had been retained in the lake"* (Lake Manitoba Regulation Review Advisory Committee, 2003). The diversion of water to Lake Manitoba was estimated to add about 0.25 m of net impact to the lake level. This increase of water level not only impacted Lake Manitoba but also LSM as the outflow from FRWCS was released into LSM. *"The average annual volume of water directed into Lake Manitoba through the Diversion since 1970 is 246,774 acre-feet"* (Lake Manitoba Regulation Review Advisory Committee, 2003). This 2.47×10^4 acre feet of water is 3×10^9 cubic metres water annually can raise Lake Manitoba water levels to about 0.06 m higher than normal. The annual increase of water levels from 1970 at Lake Manitoba increased the water levels at LSM and resulted in continuous flooding at LSMFN since then (Lake Manitoba Regulation Review Advisory Committee, 2003).

2.5 Super Flood of 2011

The Super Flood that occurred in Manitoba in 2011 was so devastating that the Assiniboine River has a recurrence of this scale of a flood only once in every 330 years (Lindenschmidt, Sydor, & Carson, 2012). Lake St. Martin First Nation is one of the communities impacted by the Super Flood, which had the entire population displaced and living in temporary housing in Winnipeg or in towns of the Interlake Region of Manitoba to this day. Since 2011, the community members have been waiting for a permanent location to move in, at this point in 2017.

There are various causes that increased the severity of the flood situation in 2011. From May 2010 until the autumn of that same year, a lot of precipitation occurred, including a once in a 100 year storm, which added a significant amount of water to the region. Southern Manitoba averaged approximately 75 mm of precipitation due to the storm. This created the perfect storm to cause a flood: "*Combined with above normal summer precipitation, the storm caused high antecedent soil moisture conditions throughout* *southern Manitoba at freeze-up"* (Lindenschmidt et al., 2012) Also, large parts of the Assiniboine catchment area was covered in deep snow pack of snow–water equivalents ranging 100–120 mm in both western Manitoba and south-eastern Saskatchewan. The average long term normal at these regions is close to 75 mm. In May 2011, the spring precipitation doubled the long-term normal for the Assiniboine River (Lindenschmidt et al., 2012).

At Portage la Prairie, the Assiniboine River recorded a flow of 1500 m^3/s during the super flood. Approximately two-thirds of that flow, amounting to 1000 m^3/s of water, was channeled to Lake Manitoba through PD. As a result PD greatly exceeded its design capacity by 300 m^3/s, its 700 m^3/s design capacity (Lindenschmidt et al., 2012). The high flow as well as the more than five months of continuous operation greatly increased Lake Manitoba's water levels. Additionally, a big storm causing high winds and much precipitation at the end of May of 2011 caused shorelines to be battered by high waves. The likelihood of combining this windstorm with such high water levels was one in 2000 years according to estimates made from recorded history.

Flood damage to properties and shorelines in Lake St. Martin as well as Lake Manitoba could not be prevented during the May 2011 storm. To make the flood damage worse, another storm poured down in mid-June 2011 on southern Saskatchewan and Manitoba exceeding normal monthly precipitation records by two to three times. These storms together caused extensive flooding on the Assiniboine River with much of the additional floodwater channeled through PD to Lake Manitoba (Lindenschmidt et al., 2012).

2.6 Flooding Impacts on LSM First Nation

Floods are natural disasters outside of human control (Thompson, 2015). Although a flood is unstoppable, it is possible to divert floodwaters to another course (Thompson, 2015).

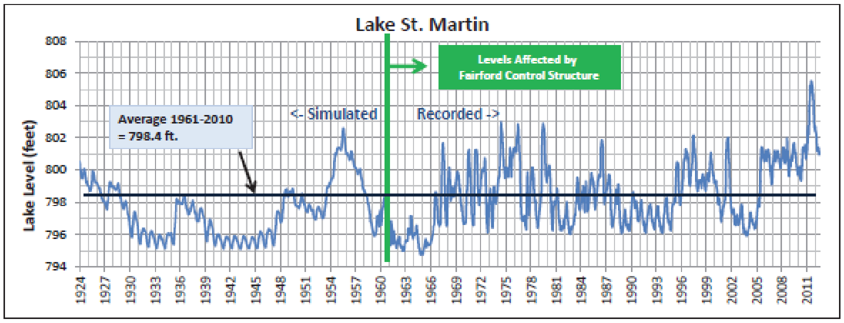


Figure 2.2: LSM levels before and after the FRWCS

Source: (Manitoba Government, 2013:31)

A comparison of LSM levels before and after the FRWCS was constructed shows that the water level has increased on LSM, since the creation of the FRWCS (see Figure 2.2). Figure 2.2 also shows that the lake experienced frequent rapid fluctuations in lake levels. These are caused by the rapid changes in Fairford River flows associated with stop log changes at the Fairford Structure. Under natural conditions prior to the FRWCS, LSM flows slowly fluctuated with changing Lake Manitoba levels (Manitoba Government, 2013). However, with FRWCS the flow change was rapid resulting in increased fluctuations in LSM levels. Under the current operating rules, the FRWCS remain wide open when the lake is above the top of the desirable range, but would be cut back to a more normal setting (60 percent capacity) once levels recede to the top of the normal range (Manitoba Government, 2013).

At 812.5 feet on Lake Manitoba, the FRWCS guidelines allow the passing of 7,300 f^3/s or approximately 207 cubic metres/s. A reduction to 60 percent capacity at that lake level would cut the Fairford flow from 1,620 f^3/s to 1,000 f^3/s (28 cubic metres/s) (Manitoba Government, 2013). If the outflow is cut to 60 percent capacity at that lake level, the Fairford River flow into LSM would be reduced by 3,000 f^3/s (cfs) or approximately 85 cubic metres/s. This would result in a rapid drop in the LSM level. However, at a lake level of 811 feet (middle of the recommended range), the FRWCS can pass 1,620 cfs or approximately 46 cubic metres/s. This smaller change in FRWCS flows would result in a smaller drop in LSM levels. Although the proposed modification in the operating rules would result in extended flows in the 7,000 cfs range, and they say that will not result in flooding on LSM (Manitoba Government, 2013). Delaying the flow decrease until the level of Lake Manitoba receded to 811 feet would smooth out the fluctuation associated with log changes at the Fairford structure.

The Manitoba Review Committee of 2013 recommended the following modification of the operating rules of Fairford Control Structure:

• During recovery from flood conditions on Lake Manitoba, the FRWCS should be kept wide open until Lake Manitoba recedes to the middle of the range;

• For recovery from drought, the FRWCS should be kept at 800 cfs until Lake Manitoba levels increase to middle of the range; and

• Under normal operating conditions, once outflow reaches normal, there should be no further stop-log adjustments, as long as Lake Manitoba remains within the range (Manitoba Government, 2013).

2.7 Water Levels and Flows Prior to 2011

Levels on Lake Manitoba at Steep Rock were close to average through most of the decade leading up to 2011, according to Figure 2.3. According to figure 2.3, lake levels were well above average, particularly in 2001 and from 2005 to 2010, indicating that the first decade of the 21st century was considerably wetter than normal in the Lake Manitoba basin.

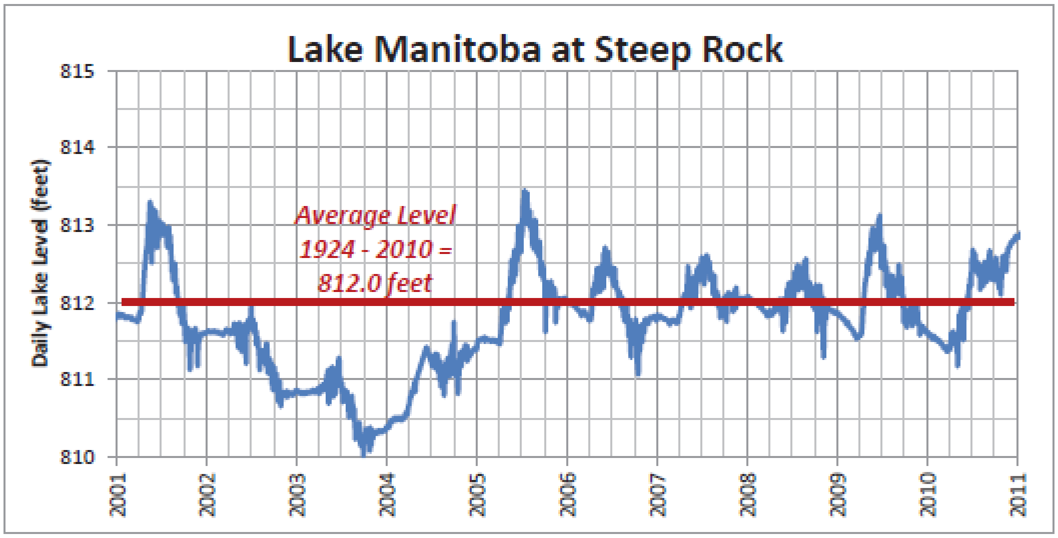


Figure 2.3: Lake Manitoba levels at Steep Rock for the years 2001-2011

Source: (Manitoba Government, 2013:25)

2.8 History of Flooding

Levels have been recorded systematically on Lake Manitoba since 1924. Levels on Lake Manitoba fluctuated on a multi-year cycle before 1961 when the FRWCS was put into operation. The only major flood recorded prior to 2011 took place in the 1950s. Figure 2.4 shows the levels on Lake Manitoba during this decade. Figure 2.5 shows the flows on the Fairford River.

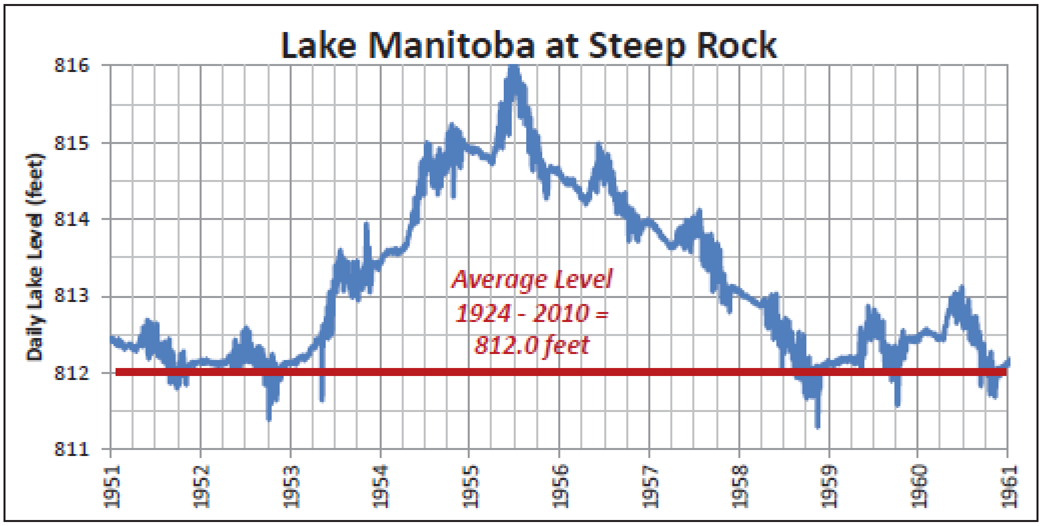


Figure 2.4: Lake Manitoba levels at Steep Rock for the years 1951-1961
Source: (Manitoba Government, 2013:26)

In 1955, Lake Manitoba levels peaked at 816.2 feet. It took three years for the level to recede to the long-term average level of 812.0 feet. During the five years from 1953 to 1957, the Fairford River flows averaged 5,600 cfs or 159 cubic metres/s. It is interesting to note that from 2005 to 2010 the average Fairford River flow was 5,700 cfs (161 cubic metres/s), but flooding on Lake Manitoba was minor.

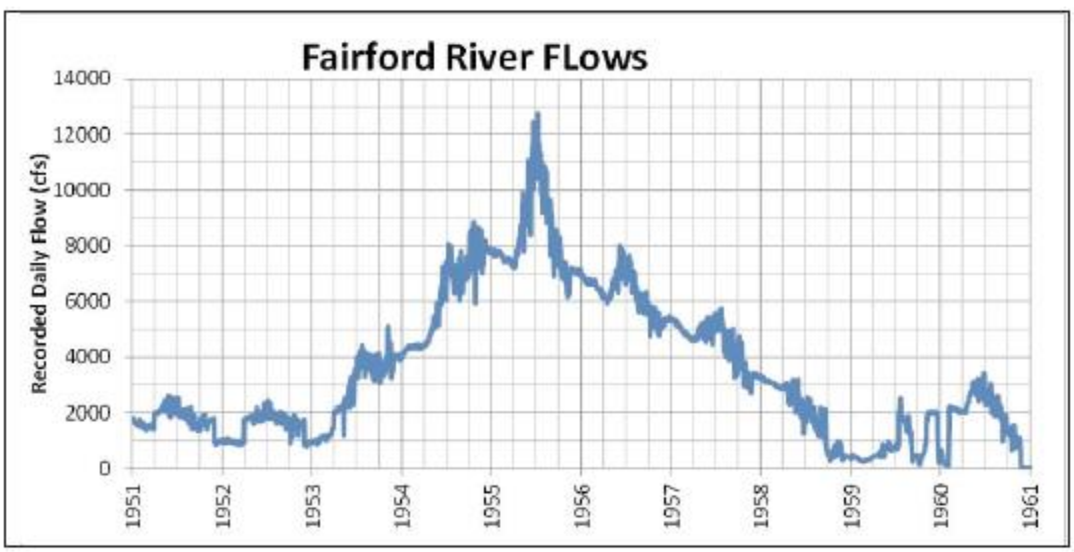


Figure 2.5: Fairford River flows for the years 1951-1961
Source: (Manitoba Government, 2013:27)

2.9 The 2011 Flood Event

Lake Manitoba levels were at 812.8 feet at the beginning of January 2011 (see Figure 2.6). This was the highest January level since 1958, before the FRWCS was in place. This level is an undesirably high mid-winter level for any year, but was of particular concern in light of the large flood that was being forecast for 2011. The situation was aggravated by the need to reduce winter flows at Fairford to 5,000 cfs to prevent frazil ice development on the Dauphin River downstream from LSM.

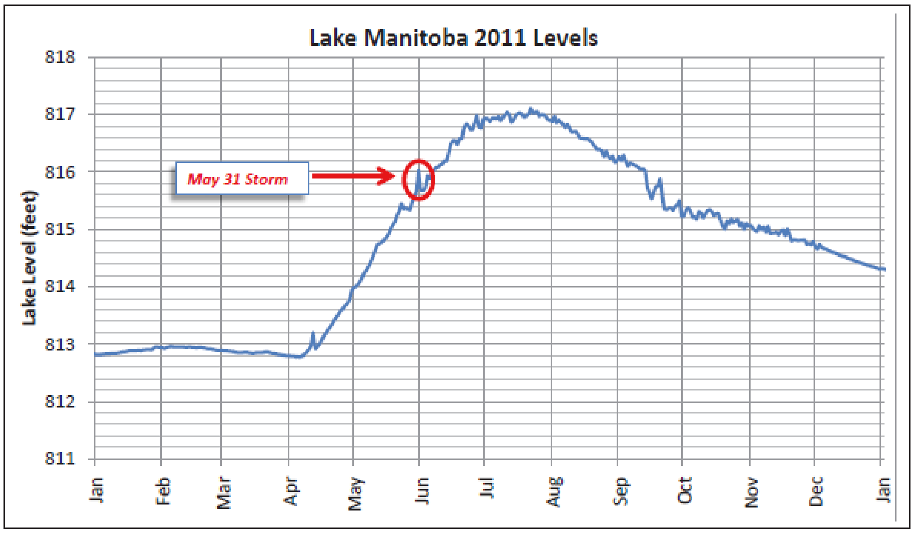


Figure 2.6: Lake Manitoba levels for 2011

Source: Manitoba Government, 2013:28.

In early April, levels began to rise quickly as flows on the Waterhen River increased and the PD was put into operation. By the end of May, the lake level was approaching 816 feet, almost as high as the record peak level in June 1955. The lake peaked at just over 817 feet in late July and started a slow decline. Because of the operation of the Emergency Channel, the winter flow reduction at Fairford to 5,000 cfs was not required. By the end of December 2011, the lake had receded to 814.3 feet and flows through the FRWCS were at 14,000 cfs. These were by far the highest winter flows ever recorded in the Fairford River.

2.10 History of Flooding

A long history of flooding has occurred at LSM. Much of the land around the lake is flat and prone to flooding. In addition, the groundwater in this portion of the Interlake is very close to the surface and the pressure in the confined aquifer – underground water that is contained above and below by layers of rock or soil – is artesian when released, meaning the pressure could naturally push the water to the surface. When conditions around LSM are wet, distinguishing between wetness caused by high lake levels and wetness caused by the high-water table and poor drainage is difficult.

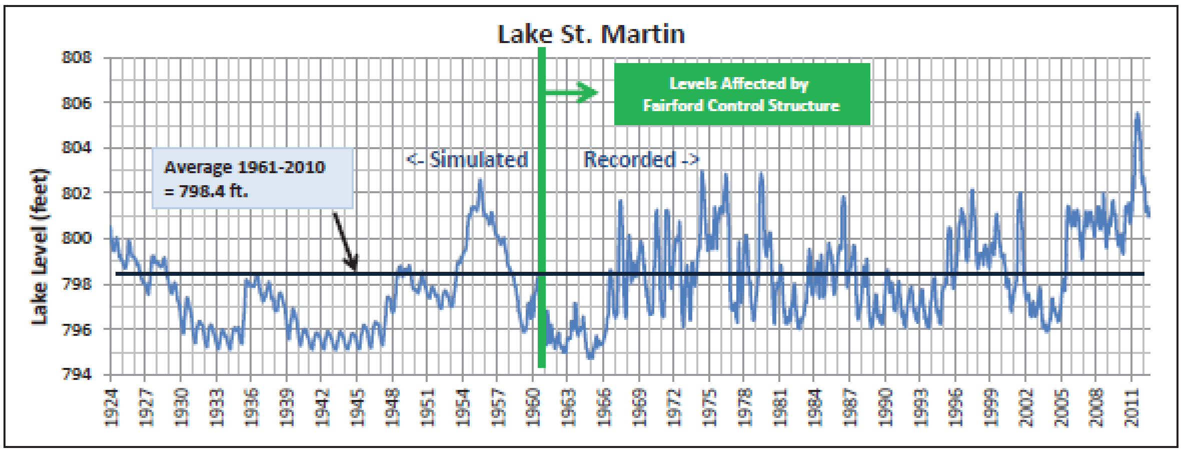


Figure 2.7: Lake St. Martin Levels pre- and post- Fairford River Water Control Structure and Portage Diversion

Source: (Manitoba Government, 2013)

Figure 2.7 shows recorded levels on LSM. Levels have been recorded since 1961. Levels back to 1924 were simulated based on Fairford River flows through the lake during those years as shown in Figure 2.7. Levels, before and after regulation, are generally within the same range although the low levels during the 1960s and the high levels during the 1970s were more extreme. The most obvious difference is the rapid fluctuations in lake levels since the FRWCS was put into operation. Some of the fluctuations are wind effects but others are a direct result of sudden changes in inflow to LSM when the log settings in the Fairford structure are changed.

2.11 Light Detection and Ranging (LIDAR):

Light Detection and Ranging is a remote sensing technology that uses pulsed laser light from a static or mobile source to measure distance to ground. A beam emitted from an optical-mechanical device, called a laser, in short pulses has repetitive high frequencies creates points that cluster with angular constant or variable spacing (Podhoranyi, 2013). A LIDAR system has three major components: laser, GPS receiver, and a scanner. Helicoptors or flights are used for gathering LIDAR data (NOAA, 2015). Airborne LIDAR and Terrestrial LIDAR are the two most commonly used LIDAR systems. LIDAR provides good DEMs for large areas:

> *"LIDAR, using the round-trip time of emitted laser light to measure ground distances from an aircraft, has been widely applied to acquire high-resolution DEMs for large areas."* (Huang, 2011, pg 422).

To make sense of the data scanned requires processing:

> "*The bulk of LIDAR data processing occurs when the individual scan data sets are merged to form a single model of the area of interest, termed the registration process. Georeferencing is performed when the scans are assigned geographic coordinates consistent with a preselected datum and projection*." (Stewart, et.al, 2009, pg 118).

LIDAR is very useful for determining wetland morphology, according to Huang (2011:425):

> "*LIDAR has shown its utility for resolving subtle landscape features by providing very high-resolution, high accuracy DEMs that capture detailed wetland morphology even in areas of extremely low relief. This allows the catchment area and spilling point of each wetland to be modeled accurately, as well as the above-water volume between the existing water surface and spilling point.*" (Huang, 2011, 425)

2.12 Airborne LIDAR

Airborne LIDAR uses a pulsed laser attached to a fixed-wing of an aircraft. Airborne LIDAR can be very accurate from 2 to 9 cm. Thoma et al. (2005) deduced elevation levels from reference points on bridges and LIDAR, finding a 2 to 9 cm bias range with roughly a 7 cm standard deviation. Similarly, James et al. (2006) found an elevation bias for airborne LIDAR of 14 cm and 7 cm standard deviation. Kinzel et al. (2006) measured airborne LIDAR elevations in a shallow river at two sites and found 19 cm with 11 cm standard deviation at one and 26 cm with 23 cm at the other.

2.13 Terrestrial LIDAR

Terrestrial LIDAR collects very dense points that are highly accurate, to allow precision in identifying objects. Terrestrial LIDAR is useful for managing facilities, conducting highway and rail surveys, and even creating three dimensional city models of exterior or interior spaces.

Terrestrial LIDAR is either: mobile or static. Mobile LIDAR has many sensors on moving platform to assemble point clouds. These sensors can be on boats, vehicles, trains, etc. Static LIDAR can be any fixed point in or outside a building where LIDAR point clouds are accumulated. Typically, mounting a LIDAR sensor onto a tripod provides a portable, laser-based ranging and imaging system. LIDAR is commonly applied to engineering, mining, surveying, and archaeology.

The 2011 LIDAR data used for my research was acquired by ATLIS Geomatics Inc., Winnipeg from July 21, 2011 through July 30, 2011. The project area is approximately 1951 sq. km in southern Manitoba. Optech Gemini sensor was used to collect the LIDAR data on a Piper Navajo. (Metadata, 2011)

2.14 Map Animation

Animation can portray a time series of geographical quantities. Animated maps create spatiotemporal patterns that prompt different mental models (Monmonier and Gluck, 1994). The pattern that shifts with time shows the historical spatiotemporal data conditions when compared to the current data. Evidence shows how animated maps allow users to have faster analysis of spatiotemporal data than static maps. Monmonier and Gluck (1994) found users find patterns in demographic time series difficult to decipher unless controlled interactively.

2.15 Digital elevation methods

A digital elevation model (DEM) shows elevation through topographical numbers in grid cells that are of equal size (Chaplot, 2006). These models showed food elevation by Lane (2003) during the 2000 York floods in the United Kingdom. An image processing step is required to segment the LIDAR information to yield elevations.

Summary

The focus on both the geography and the amounts of the water flow over time as well as the tools that help analyze these geographical information systems was covered in this section. This discussion of these areas provides a background to interpret the research results and their significance.

CHAPTER THREE: RESEARCH METHODS

This chapter describes the methods undertaken to: (1) collect historic water level data for FRWCS and PD; (2) analyze the data using excel graphs; (3) identify the key historical aerial images of LSM area to show impacts of control structures and diversions; (4) analyze the aerial images using geo-referencing and ArcGIS tools; (5) acquire the LIDAR data for LSM for the years 2011 and 2013; and (6) interpret the LIDAR data by LAS data tools in ArcGIS and Global Mapper software.

3.1 Historic Water Levels:

Objective One: To study the water level history of the FRWCS and PD and to analyze their impact on the LSM community.

The historic water level data was acquired from the Water Survey of Canada (WSC). The WSC is the Canadian authority, which collects, interprets, disseminates and standardizes Canada’s water resource data (WSC, 2015). The WSC maintains roughly 2800 active water gauges in Canada cooperating with the provinces and territories. The data required for FRWCS and PD water stations are available in public domain of WSC website having discharge flow in cubic metres per second with different time intervals. I chose to look at the monthly average for the flows for the period of 1961 to 2015. The data for PD was available for its first year of operation in 1970 and FRWCS the data was available since 1912 before the control structure in 1961. The following water gauge stations were used primarily for monitoring the water flow to determine the flow of water from Assiniboine River to Lake Manitoba and then to LSM:

1. Portage Diversion – Assiniboine River
2. Steep Rock Station – Lake Manitoba
3. FRWCS – Fairford River
4. Hilbre Station - LSM (see Figure 3.0)

The water stations used in this study started their operations at different time intervals in history. Hence, the availability of data is not uniform for the total study period (1923-2017).

- PD from 2002 – 2015.
- Steep Rock in Lake Manitoba has level data available from 1923 to 2016.
- FRWCS from 1954 - 1997, and 2002 – 2015.
- Hilbre @ LSM from 2002 – 2015.

Portage Diversion

PD was constructed on Assiniboine River near Portage La Prairie, Manitoba in 1970. It is used to divert water from Assiniboine River to Lake Manitoba to prevent flooding to the City of Winnipeg (Mudry et al., 1981). The water station number is 05LL019 and the longitude and latitude coordinates of this water station are 49° 57' 56" N and 98° 22' 49" W (Water Survey of Canada, 2014d).

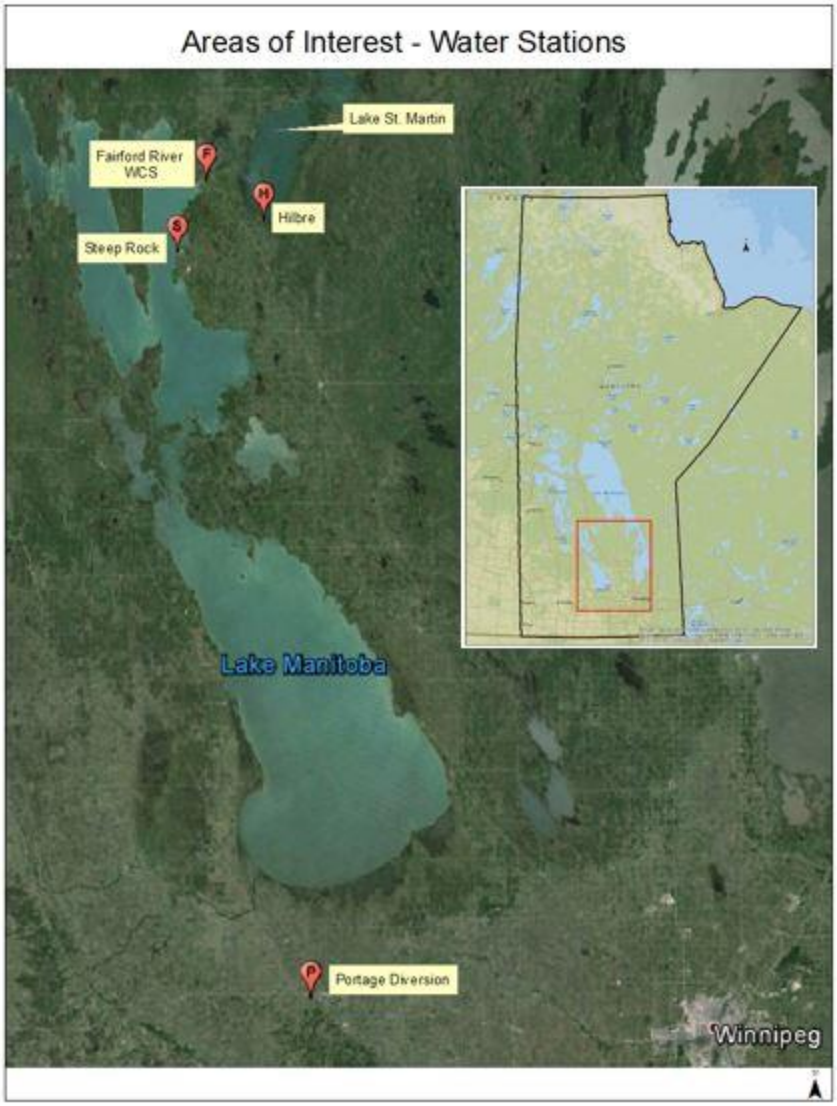


Figure 3.0: Canada Water Gauge Stations affecting LSM First Nation
Map source: ArcMap 10.2.2, 2016

Fairford River Water Control Structure

FRWCS was constructed on the Fairford River in Manitoba in 1961 to regulate Lake Manitoba in the range of 811.0 feet above sea level to 813.0 feet above sea level (Lake Manitoba Regulation Review Advisory Committee, 2003). The water station number is 05LM001 and the longitude and latitude coordinates of this water station are 51° 35' 14" N and 98° 42' 42" W (Water Survey of Canada, 2014b).

Along with the above mentioned two water stations, I also collected the water level data for: Hilbre water station to show the effect of flows on water levels in LSM; and Steep Rock water station to show the level of water on Lake Manitoba. These four water stations monitor water flow from Assiniboine at PD to Lake Manitoba and then into Fairford River, which is destined for LSM, where the water level is of concern. Hence, studying these four water stations is considered to be useful in analyzing the impact of flooding on LSM.

Steep Rock Water Station

Steep Rock water station was constructed on Lake Manitoba in 1923. The water station number is 05LK002 and the longitude and latitude coordinates of this water station are 51° 26' 38" N and 98° 48' 11" W (Water Survey of Canada, 2014c). Since this water station has been operating for the last 92 years, the data available at this station can be useful in understanding the water levels of Lake Manitoba before and after the construction of the PD (Mudry et al., 1981).

Hilbre Water Station

Hilbre water station was constructed near LSM in 1966. The water station number is 05LM005 and the longitude and latitude coordinates of this water station are 51° 30' 31" N and 98° 31' 44" W (Water Survey of Canada, 2014a). Studying the historic water level data at this station can help us better understand the flood levels at LSMFN.

The historical water level data of all the four water stations are combined from the year 1923 to 2013 and graphed. I identified patterns emerging regarding the rise and fall of water levels at some or all the four water stations related to the opening and operation of FRWCS and the PD.

Objective Two: To examine the historical raster data of LSM and estimate the change in land area that occurred due to constant flooding from 1948 to 2011.

The methods undertaken required that I: (1) digitize the historic aerial images; (2) calculate the changes in the land area; and (3) display the historic aerial data in a time slider tool.

3.2 Aerial Images Data

The historical aerial images of LSMFN reserve areas were obtained from the Department of Manitoba Conservation. The aerial images for this region are not available for every year from 1949 to present from the provincial government as the province only captures this aerial image every five or six years. Since these aerial images have to be purchased and were expensive I only chose years that reflected a change in operation to see the impact of those operations.

I chose the following years out of the available data:

- 1948 to see the natural levels prior to any control structures or diversion, which I call (pre-FRWCS),
- 1961 to see the impact of the Fairford River Control Structure as that is the year it started, (FRWCS) but were used minimally,
- 1970 to see the impact of one season of running the PD in combination with the Water Control Structure (PD),
- 1986 to see the impact of running the PD for more than a decade (Note: PD was not in operation every year but only flood years),
- 2011 (Super-Flood) when PD recommended flows were exceeded and FRWCS.

By analyzing these aerial images, I intend to determine the relationship between the construction of FRWCS (1961), PD (1970), and the rise of water levels at LSMFN.

Limitations for Objective 2 include that the aerial images available for LSM and LSMFN for the years 1948, 1961, 1970, 1986, & 2011 are not of the full area length of the reserve or the LSM shoreline. The total area covered by aerial images in 1948 is less than the area covered in 1961. And then these are less than those areas covered in the years 1970, 1986, & 2011. The agency taking the aerial images does not seem to take the same flight paths when taking the pictures. Hence, they do not cover the same total area each time. To overcome this limitation, I conducted my GIS analyses on the parts of the areas, which are available in all the aerial pictures from 1948 to 2011.

3.3 Scanning the Data

The aerial images were manually scanned using a high-resolution scanner and are saved in two file formats namely Tagged Image File Format (.tiff) and Joint Photographic Expert Group (.jpeg). There are two reasons to save the file in two different formats:

(1) **Usability in ArcGIS 10.2.2:** TIFF file format is the most used file format in ArcGIS desktop publishing world. TIFF supports true color, black-and-white, pseudo color and grayscale images, to be stored in either a compressed or decompressed format.

(2) **File Size:** The size of a TIFF file is ten times that of a JPEG file (Ex: 350MB to 30 MB). It is often difficult to move or transfer the TIFF files due to its large size. Hence, maintaining a JPEG image file for the same TIFF image file is advised by GIS analysts.

A scanned image does not contain spatial reference information. That means, when the scanned aerial image is projected onto the world map, the display is skewed from that in the real world. In order to display the scanned aerial image in conjunction to the real-world map, it was georeferenced to a map coordination system by projecting the flat image onto a curved surface of the earth. LSM falls under the map projection of North American Datum (NAD) 1983 Universal Transverse Mercator (UTM) Zone

14N and hence the scanned aerial images had to be projected in that coordinate system. When the scanned aerial images are georeferenced by defining its location using the map coordinate system, we can view, query, and analyze the data with other geographic data.

3.4 Tools for Geo-referencing

The Geo-referencing toolbar in ArcGIS 10.2.2 is used to geo-reference a scanned aerial image. A satellite imagery base map is added using ArcGIS 10.2.2 and that map is used as spatial reference for the scanned images. Ground control points on the base map are used to align the scanned image to the base map. The ground control points are locations that can be accurately identified on the scanned image and also on the base map. Many features such as roads, street intersections, or natural land features, such as rivers, are identifiable locations on maps. We can add any number of ground control points to get the accuracy of the image alignment. But after geo-referencing two images, I understood that five ground points (each corner of the image and one central point of the image) aligned better than the other combination of control points.

3.5 Steps to Georeference a Scanned Aerial Image

1. In ArcMap 10.2.2, I set the projected coordinate system to NAD 1983 UTM Zone14N and added the satellite imagery base map.

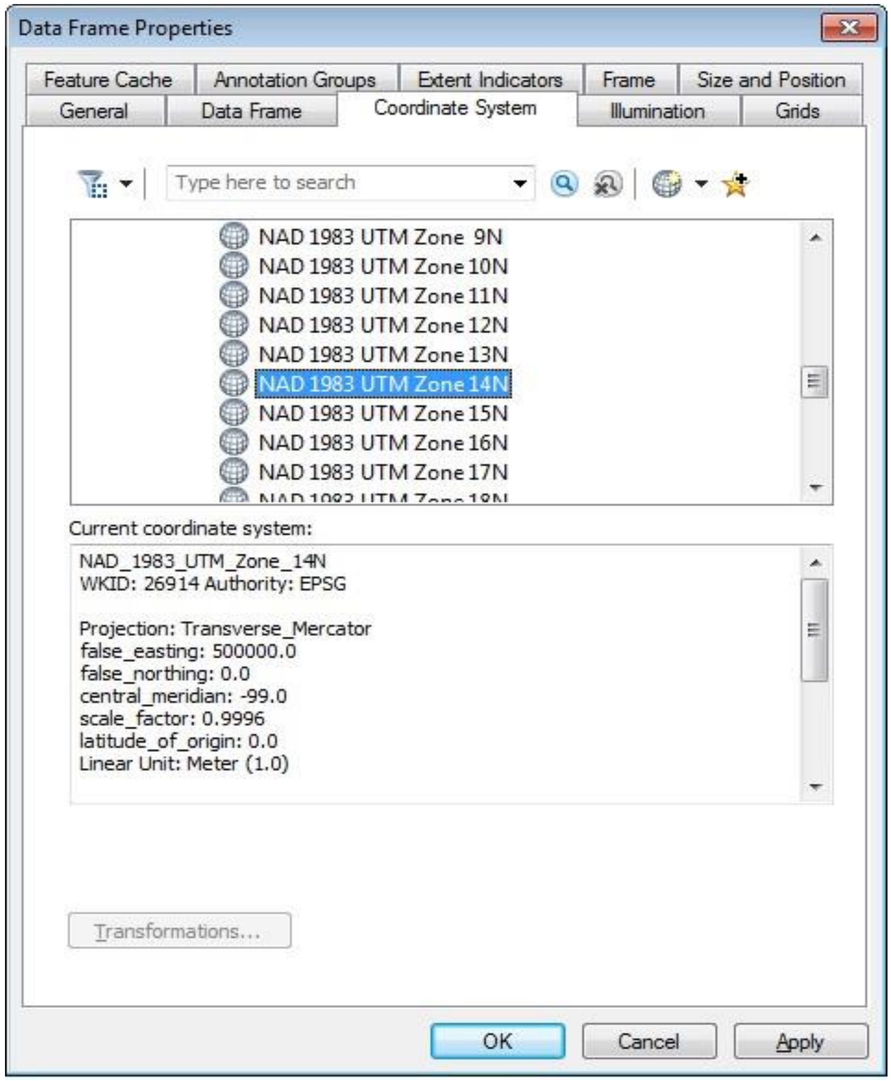


Figure 3.1: Setting the projection of coordinate system to NAD 1983 UTM Zone 14N

2. I added the scanned aerial image (.tiff) that has to be georeferenced.

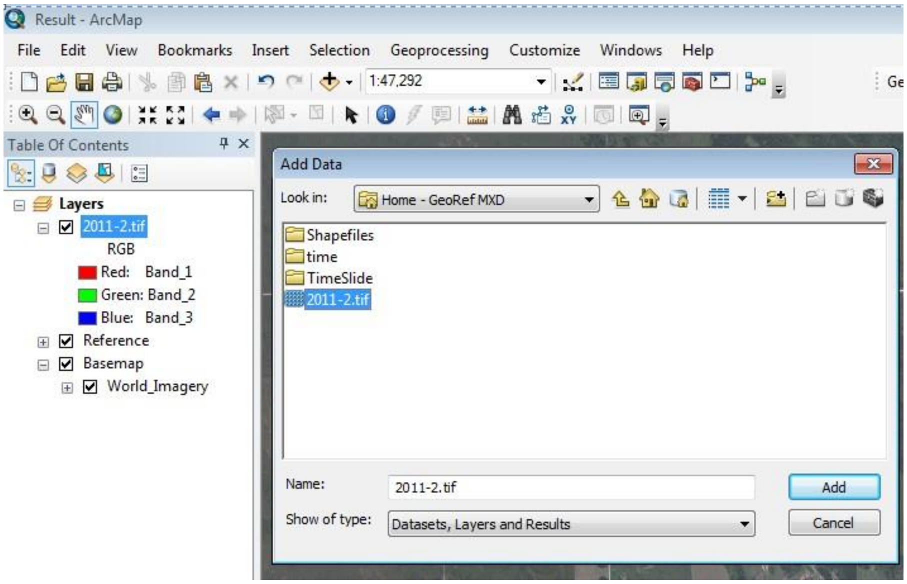


Figure 3.2: Adding the scanned aerial image (.tiff)

3. I displayed the georeferenced aerial image using the georeferencing toolbar. See figure 3.3;

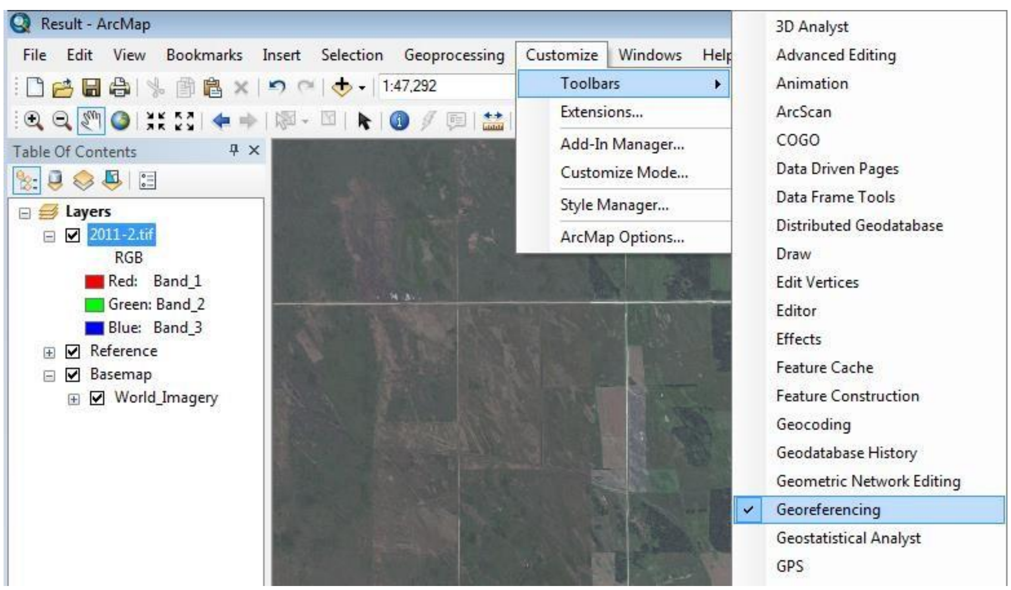


Figure 3.3: Georeferenced aerial image

4. I clicked the Layer drop-down arrow, and clicked the scanned image layer that has to be Georeferenced.
5. I clicked the Georeferencing drop-down menu and clicked the Fit To Display. This step displayed the scanned image in the same area as the base map.

Figure 3.4: Displaying the georeferenced image in the current display extent.

6. I clicked the Add Control Points tool specifically to add control points for the georeferenced

image.

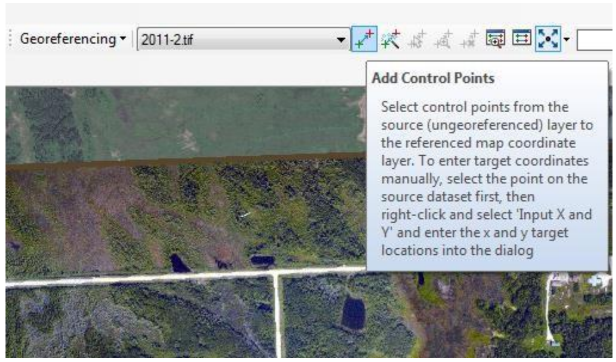


Figure 3.5: Adding control points to the georeferenced image.

7. I created a link between the scanned image and the base map by adding control points.

8. I repeated the above step at five points. These points included four corners and one center point to give the best georeferenced for an image (marked in red circles in the figure below).

Figure 3.6: Five control points of the georeferenced image.

9. The View Link Table button was used to check for any major residual errors in aligning the control points between the base map and the scanned image. The residual error for any link was not more than + or - 10m than the targeted points of that link so the targeted points are considered to be aligned correctly.

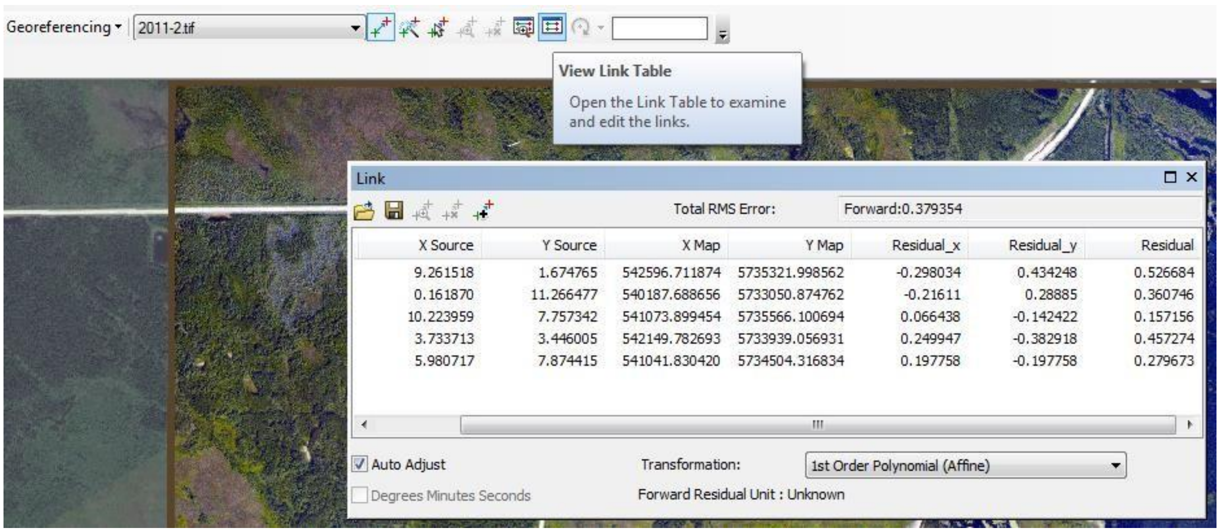


Figure 3.7: Residual error was less than +/- 10m

10. The scanned map is aligned with the base map accurately. In simple terms, the scanned image is georeferenced accurately when the residual error of each link is < or = to 10m.

11. To see if the residual error was less than 0.6 m, I updated the Georeferencing tool

Figure 3.8: Updated georeferencing tool to check the residual error

12. I selected Update Georeferencing tool to save the transformed image with the scanned image and I followed the same methods for each year namely 1948, 1961, 1970, 1986, and 2011.

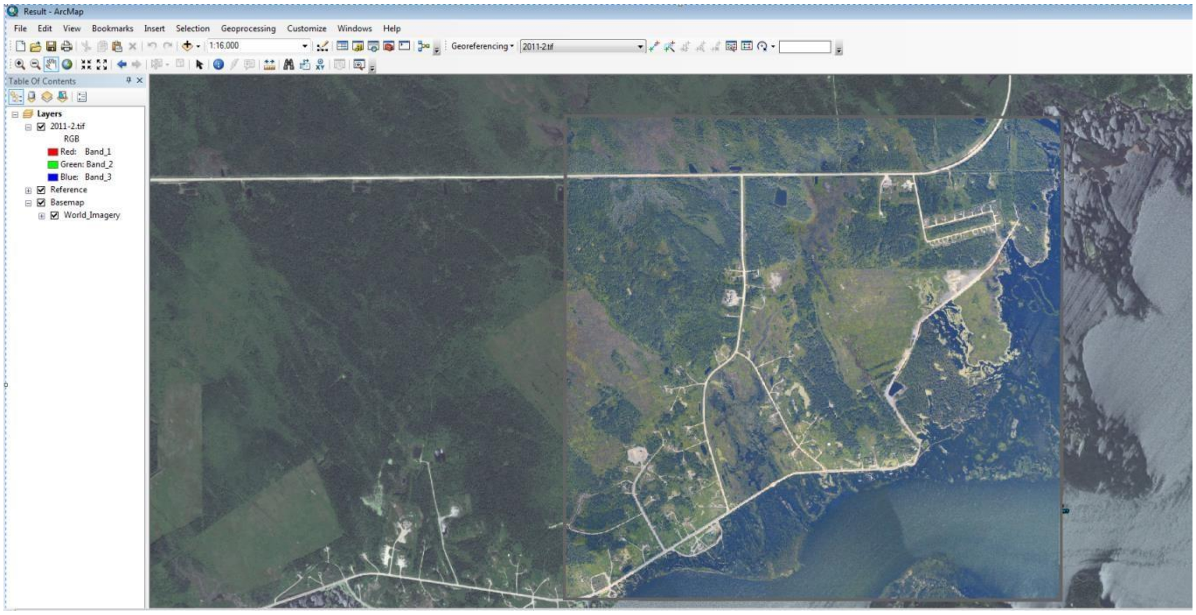


Figure 3.9: Scanned image is georeferenced to the base map.

I followed the above steps to georeference all the available 16 aerial images as listed below:

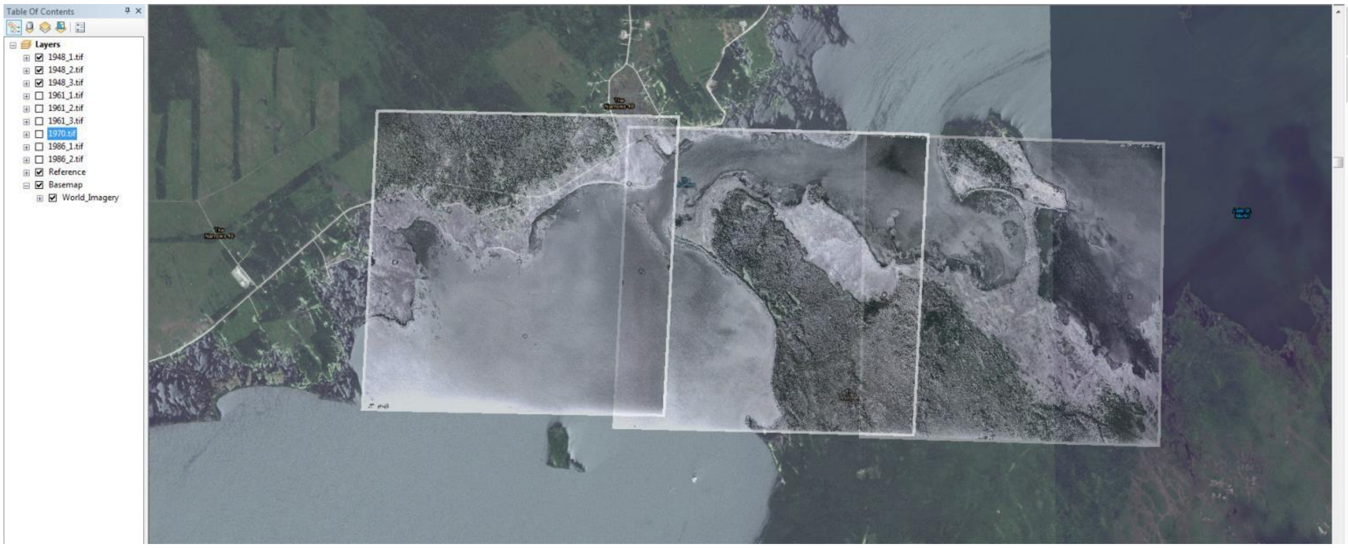


Figure 3.10: Three scanned images of the year 1948 is georeferenced to the base map

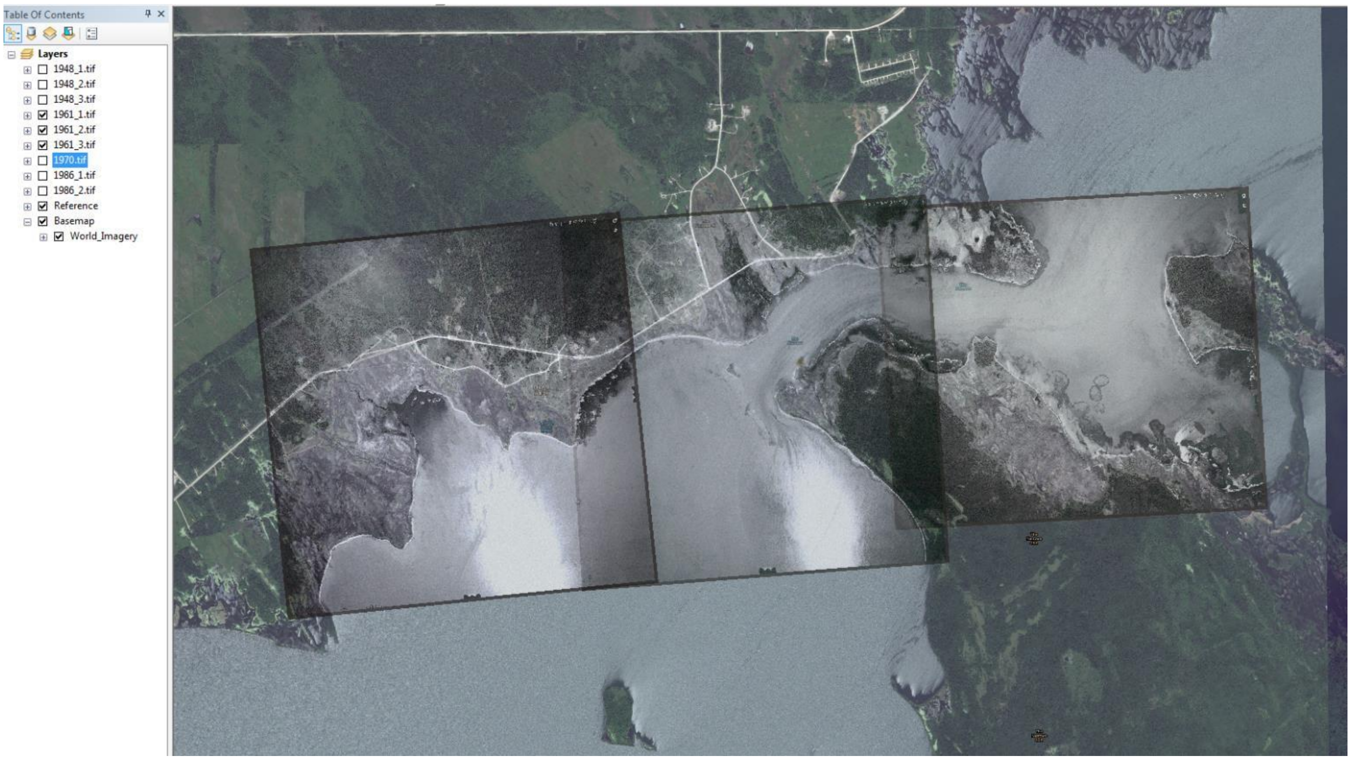


Figure 3.11: Three scanned images for the year 1961 georeferenced to the base map

Figure 3.12: One scanned image for the year 1970 georeferenced to the base map

Figure 3.13: Two scanned images for the year 1986 georeferenced to the base map

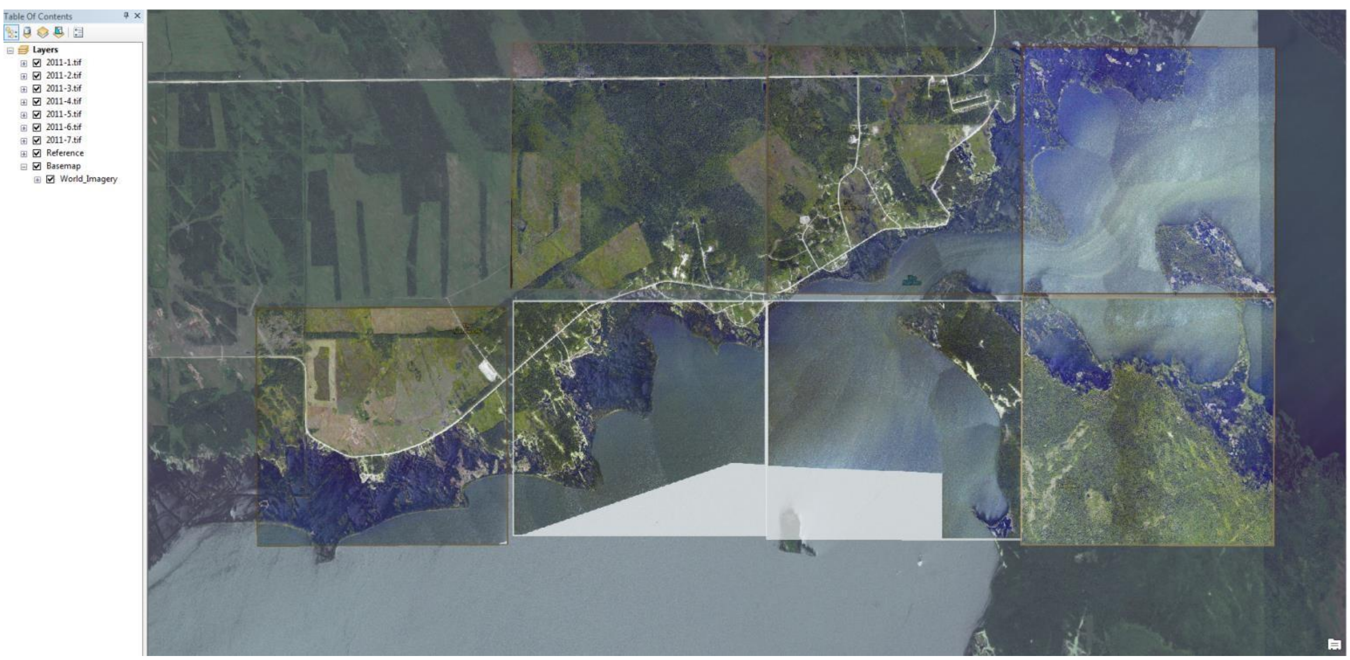


Figure 3.14: Seven scanned images for the year 2011 georeferenced to the base map

3.6 Analysis of Georeferenced Aerial Images using ArcGIS 10.2.2.

To analyze the impact of different water flows due to control structures and diversions I evaluated the LSMFN shoreline and Island in all of the georeferenced aerial images. This same shoreline for the reserve and Island was compared over a period of time (1948-2011). At the end of this analysis, I expect to know if the construction of the water control structures had any significant changes on the LSMFN community. To have a clear view of the marked area, the resolution was set to 1:5000 and it looks like the image in Figure 3.15 shown below:

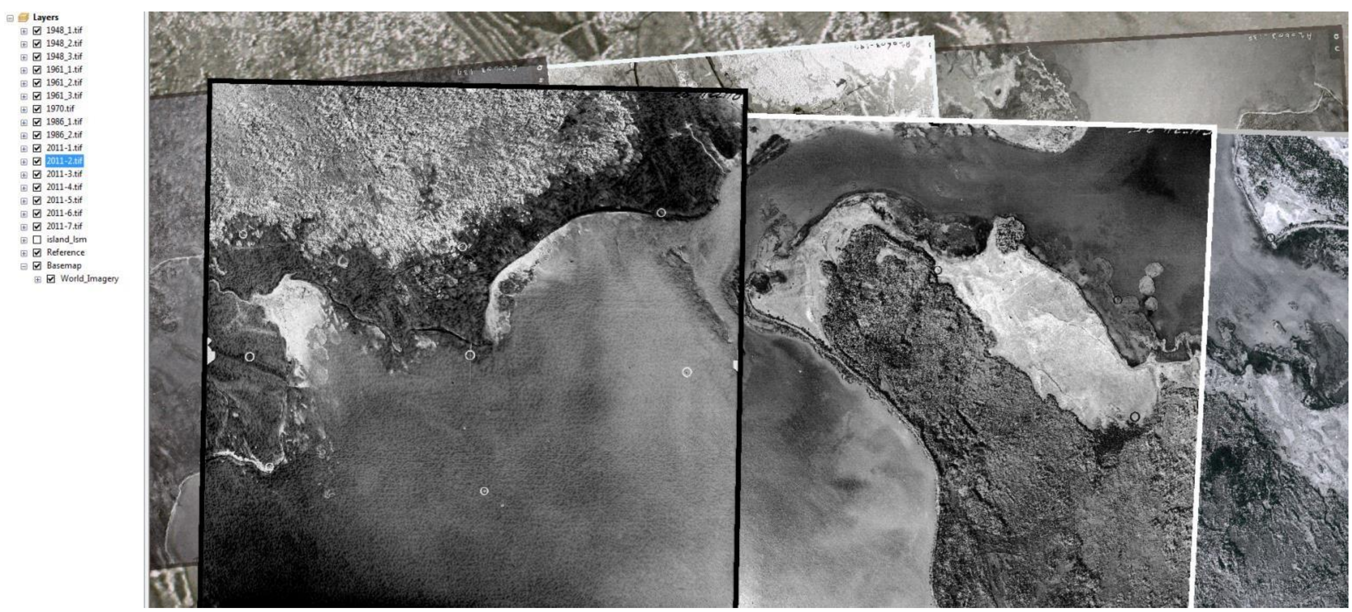


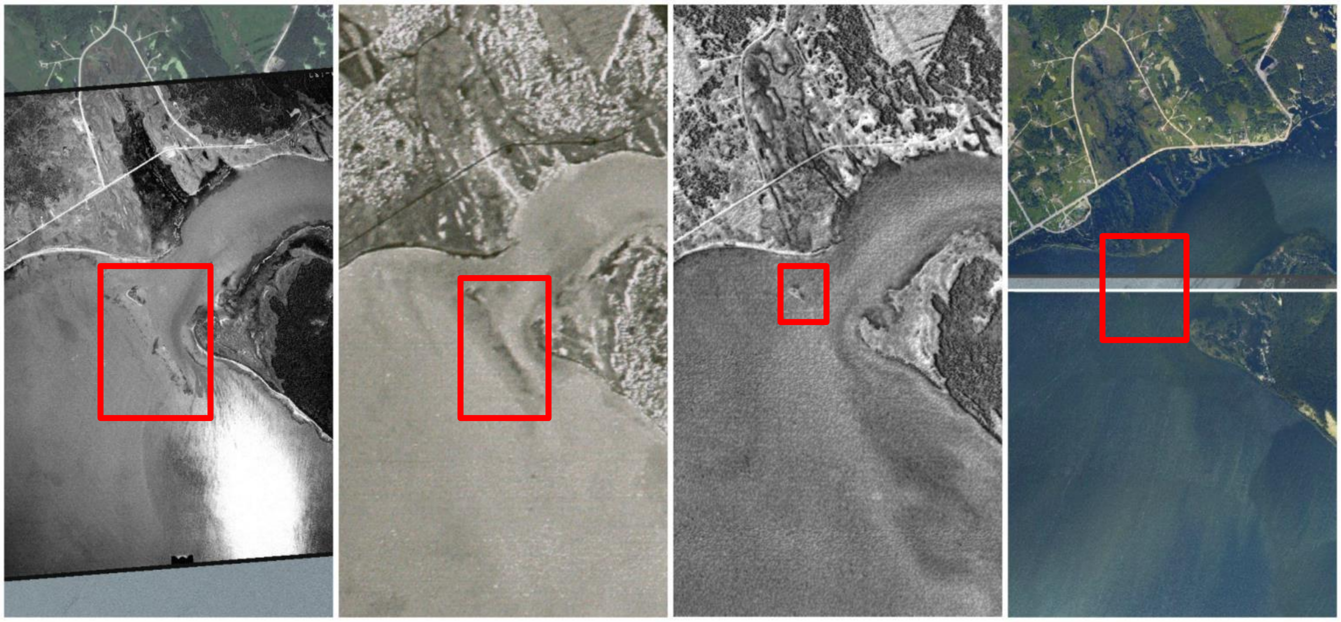
Figure 3.15: Same shoreline area reviewed for all georeferenced scanned images

Instead of analyzing all of the LSMFN shoreline at once, I focused my analysis on a smaller target area, the island of the coast of LSMFN, to observe the impacts for the island alone and test the method. Based on the results, I expanded my analysis for the entire shoreline under all the aerial images. For the analysis of the small island area near the shore of

LSM I started with the year 1948. The island, in the year 1948, is highlighted in the red block in the figure 3.16

Figure 3.16: The Disappearing Island at LSM in the year 1948

The Island is highly visible in the year 1948. As the operation of FRWCS began in 1961, the island became smaller and with the start of operation at PD in 1970, the island was much reduced. By the year 1986, 80 percent of the island was got submerged under the water indicating the rise of water levels at LSM over the years. By the year 2011, the island is completely submerged under water leaving no trace of it. I then calculated the area lost due to the flooding over the years. For this calculation, I used ArcGIS 10.2.2 with spatial analyst, 3D analyst and Editor tools to create new shapefiles and features from the existing georeferenced aerial images.



Year 1961 **Year 1970** **Year 1986** **Year2011**

Figure 3.17: – Shrinking Island off the shore of Lake St Martin First Nation shown in 1961, 1970, 1986 which finally disappear in 2011

3.7 Steps to create new shapefile from a georeferenced aerial image:

1. In ArcMap 10.2.2, I set the projected coordinate system to NAD 1983 UTM Zone14N and added the satellite imagery base map in Figure 3.18.

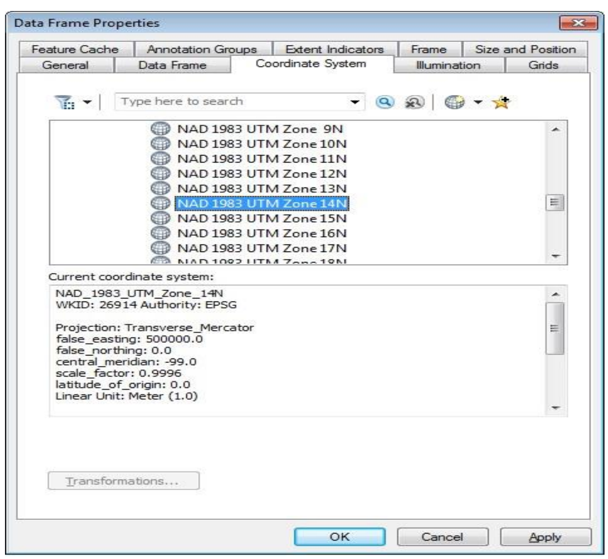


Figure 3.18: Setting the projection of coordinate system to NAD 1983 UTM Zone 14N

2. I added the georeferenced aerial image (.tiff) to the map in Figure 3.19.

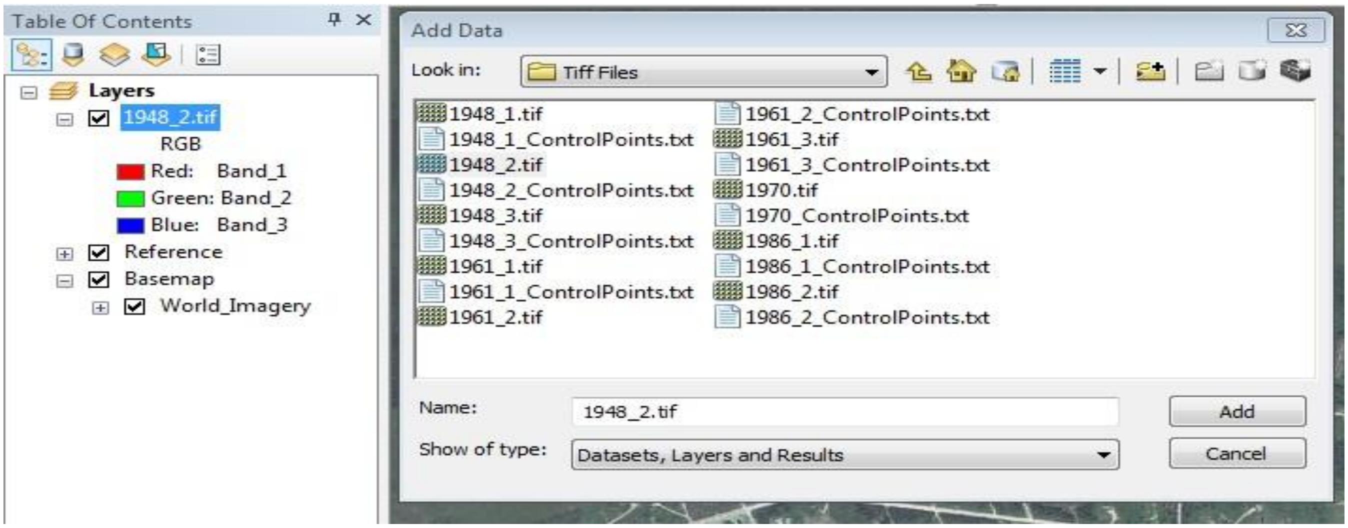


Figure 3.19: Adding the georeferenced aerial image to the map

4. I used the Editor toolbar and created a new shapefile and opened it in catalogue in Figure 3.20

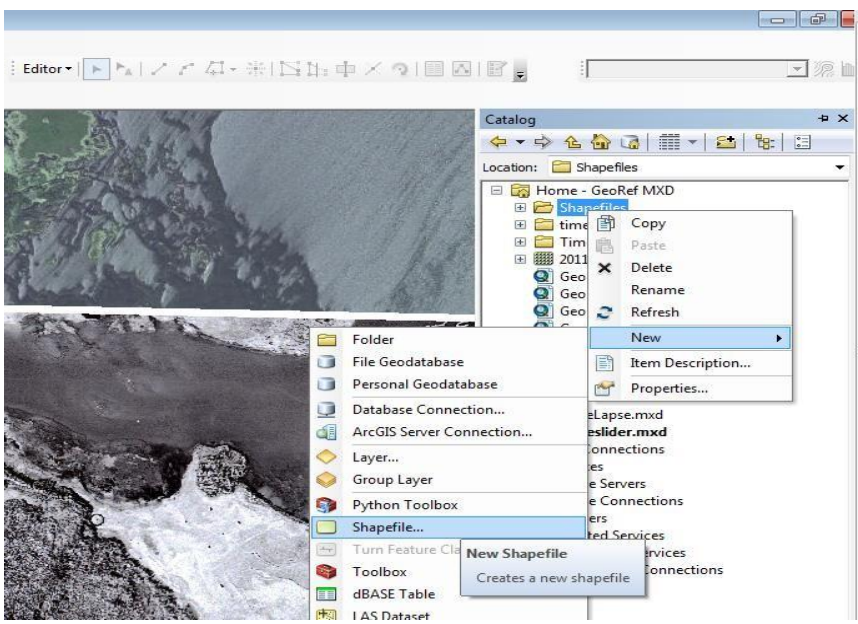


Figure 3.20: Using the editing toolbar to create new shapefile

4. I edited the properties and projection of the new shape file as shown in Figure 3.21.

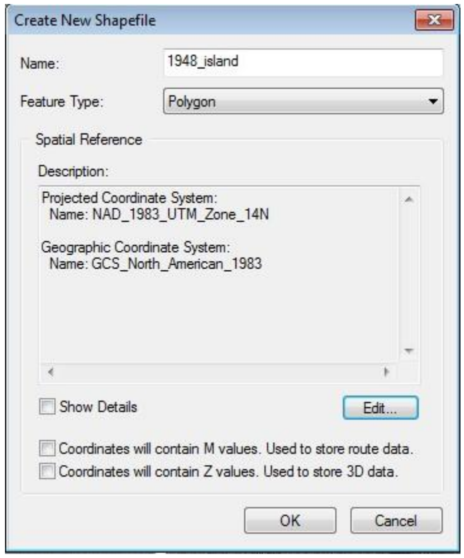


Figure 3.21: Setting the properties of the new shape file

5. I selected Edit Features and Clicked Start Editing as shown in Figure 3.22.

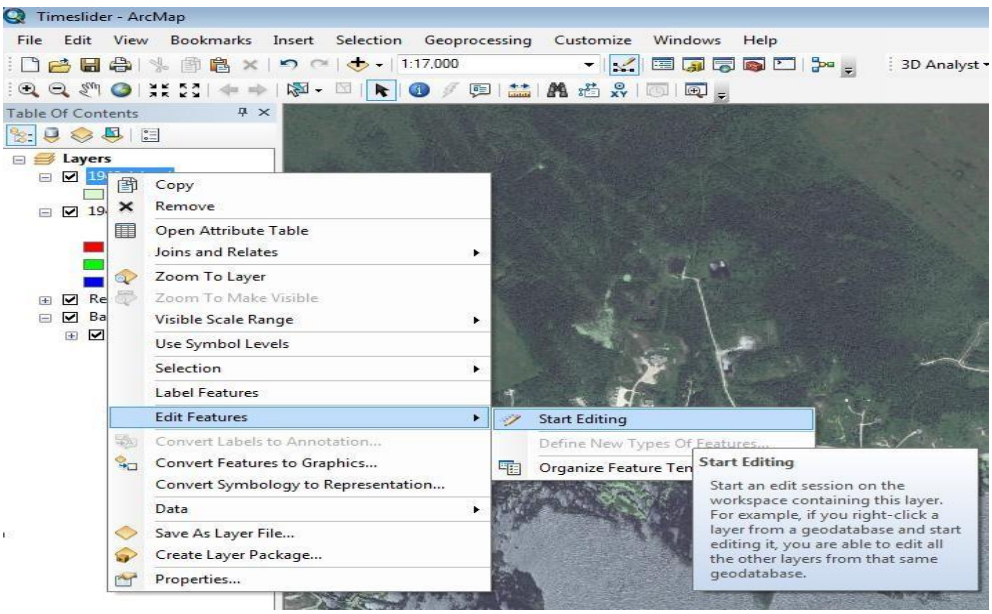


Figure 3.22: Editing the features of the georeferenced image

6. I zoomed in the island location and clicked the points to create a feature class as shown in Figure 3.23.

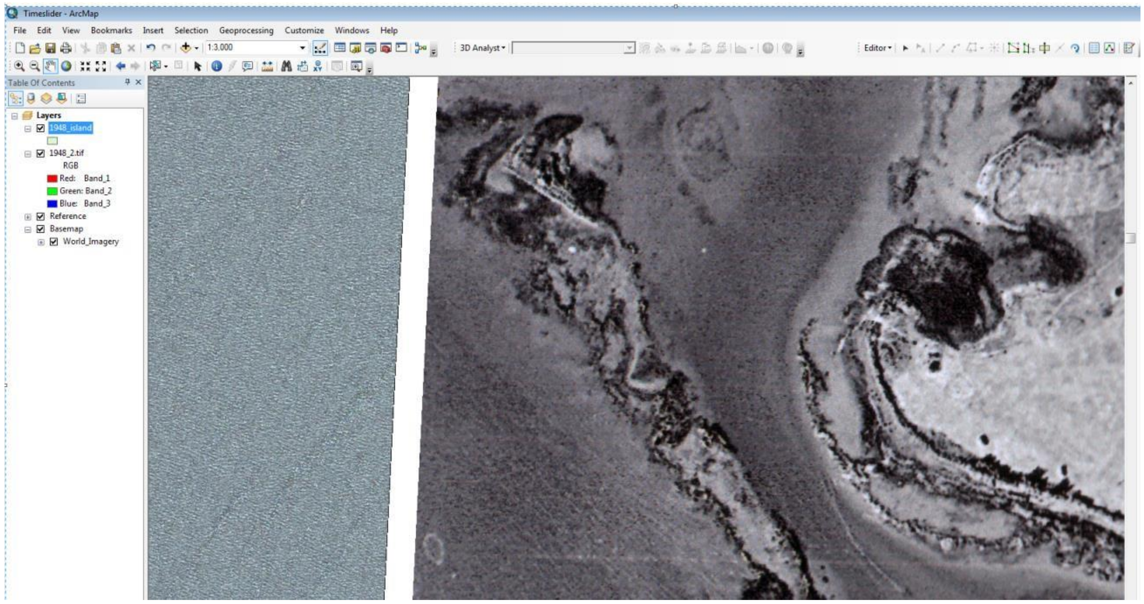


Figure 3.23: Creating feature class at the island location

7. I double clicked to finish the sketch. See figure 3.24.

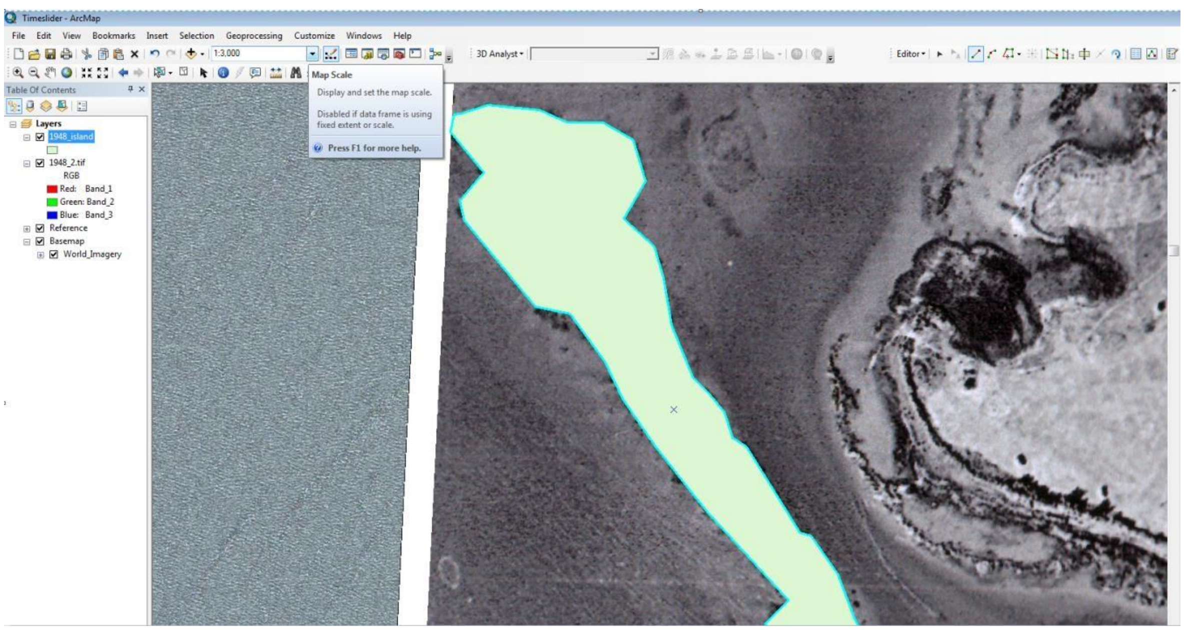


Figure 3.24: Finishing the sketch of the island location

8. I saved the edits and completed the shape file construction.

9. I right clicked the 1948_island shape file and opened the Attribute Table and named the polygon id as 1948 as shown in Figure 3.25.

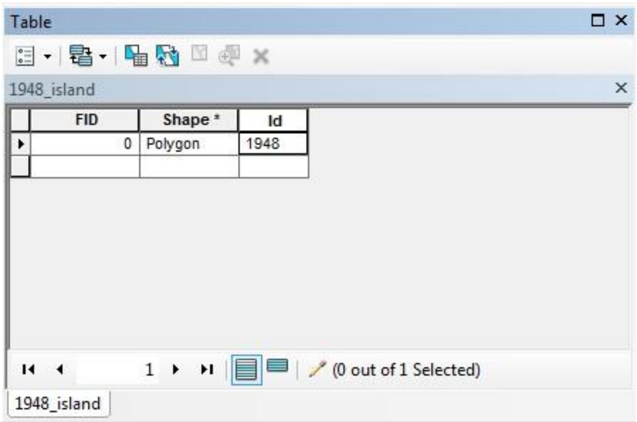


Figure 3.25: Naming the new polygon as 1948

10. I repeated steps 2 to 9 and created polygons of the selected island area for the years 1961, 1970, 1986, and 2011 in Figure 3.26.

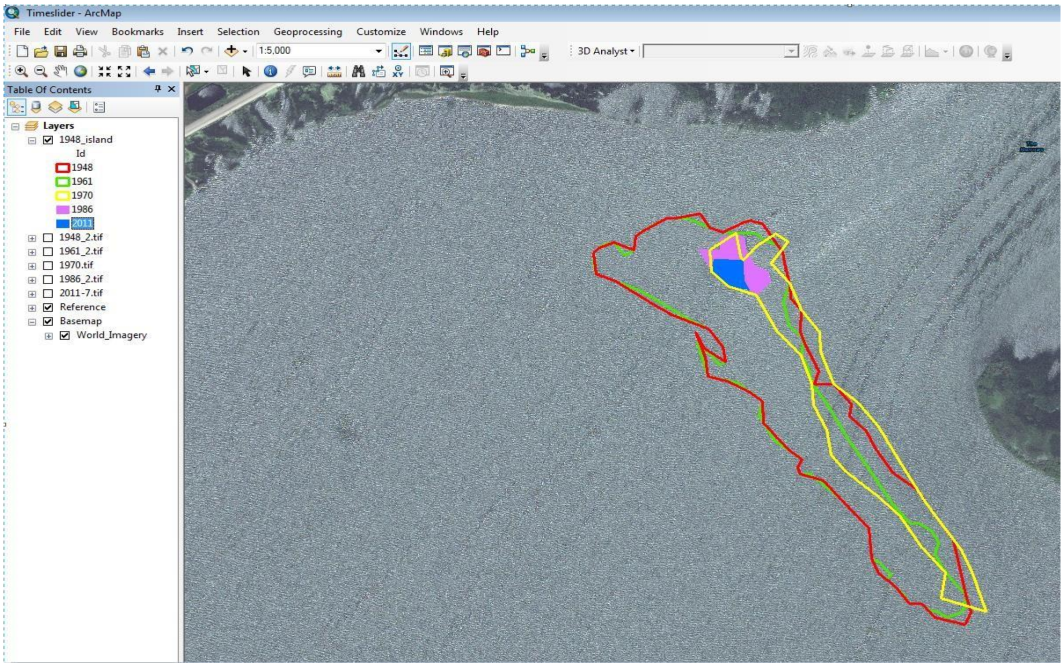


Figure 3.26: New polygons for the years 1948, 1961, 1970, 1986, & 2011

3.8 Calculating the area of each polygon

These new shape files allowed me to calculate the area of each polygon in square meters (sq m) using the Calculate Geometry tool, using the following steps:

1. I added a new field to the shape file, as shown in Figure 3.27.

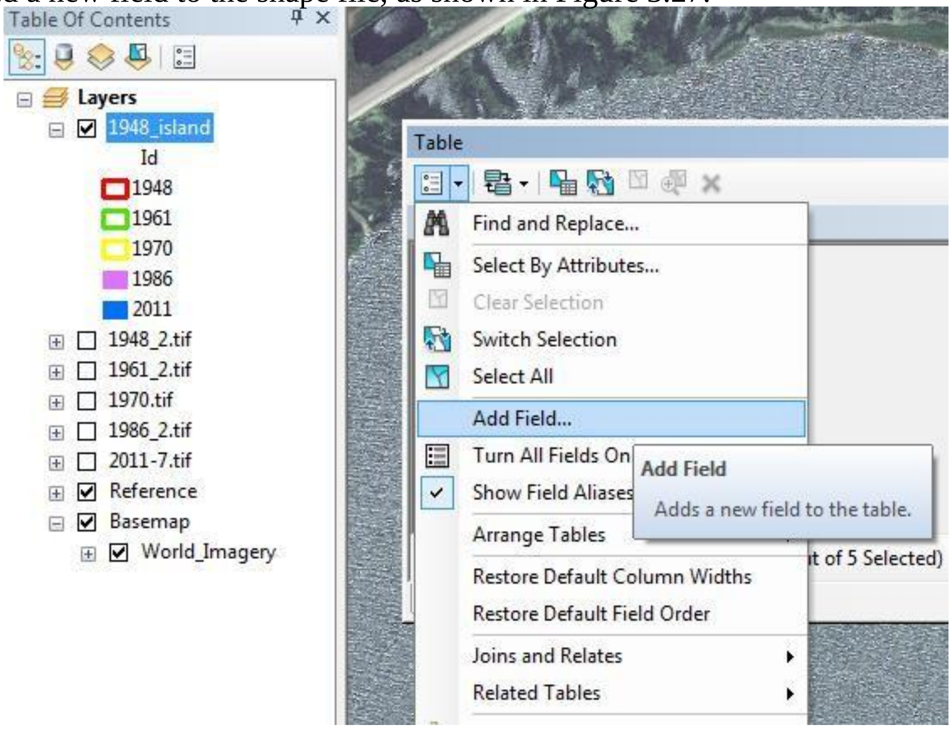


Figure 3.27: Adding new field in the shape file

2. Right clicked the new field (area_sqm) and selected Calculate Geometry (Figure 3.28).

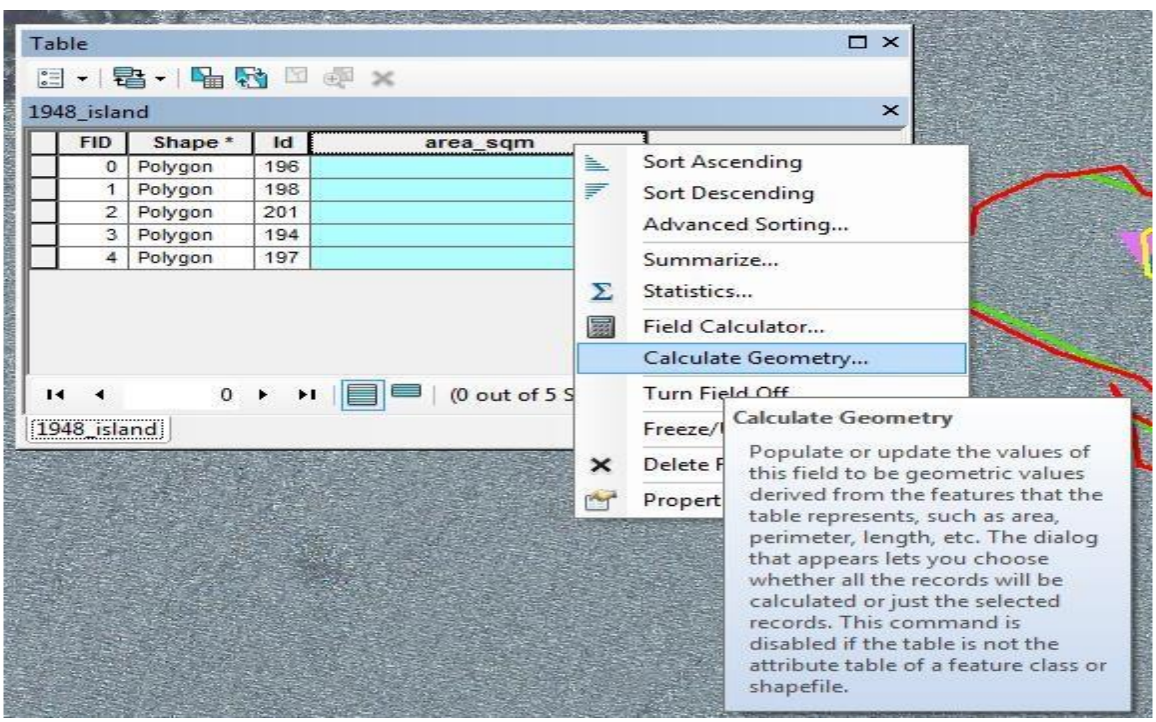
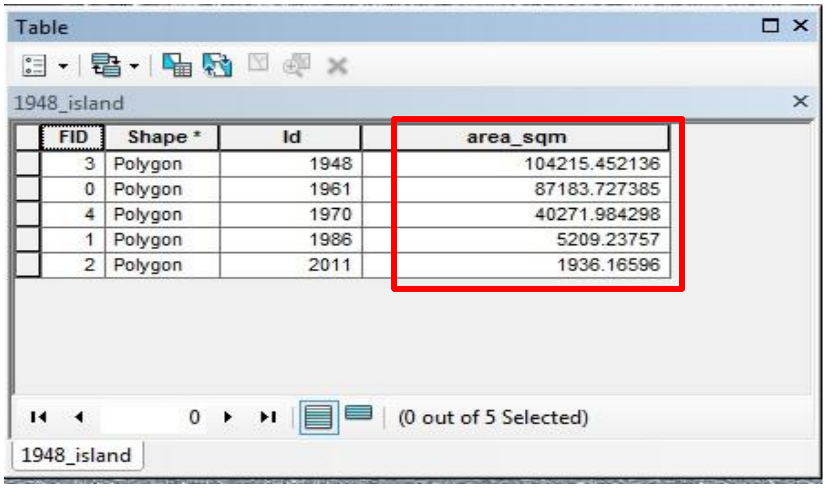


Figure 3.28: Calculating the Geometry of each polygon

5. The area of each polygon is calculated and displayed in the “area-square meter” field in the Attribute table, as shown in Figure 3.29.



FID	Shape *	Id	area_sqm
3	Polygon	1948	104215.452136
0	Polygon	1961	87183.727385
4	Polygon	1970	40271.984298
1	Polygon	1986	5209.23757
2	Polygon	2011	1936.16596

Figure 3.29: Area of each polygon displayed in sq-meter

3.9 Method for LIDAR analyses

Objective Three: To compare the 2011 and 2013 Light Detection and Ranging (LIDAR) data of LSM First Nation and analyze it using Data Elevation Models (DEM) of what areas are under water due to flooding.

The LIDAR data for the years 2011 and 2013 was collected from University of Manitoba Libraries with the assistance of the GIS Librarian Cynthia Dietz.

The LIDAR data was then analyzed using the following methods:

(1) In ArcMap 10.2.2, the Digital Elevation Model file of LSM FN obtained is rendered on a base map in Figure 3.30.

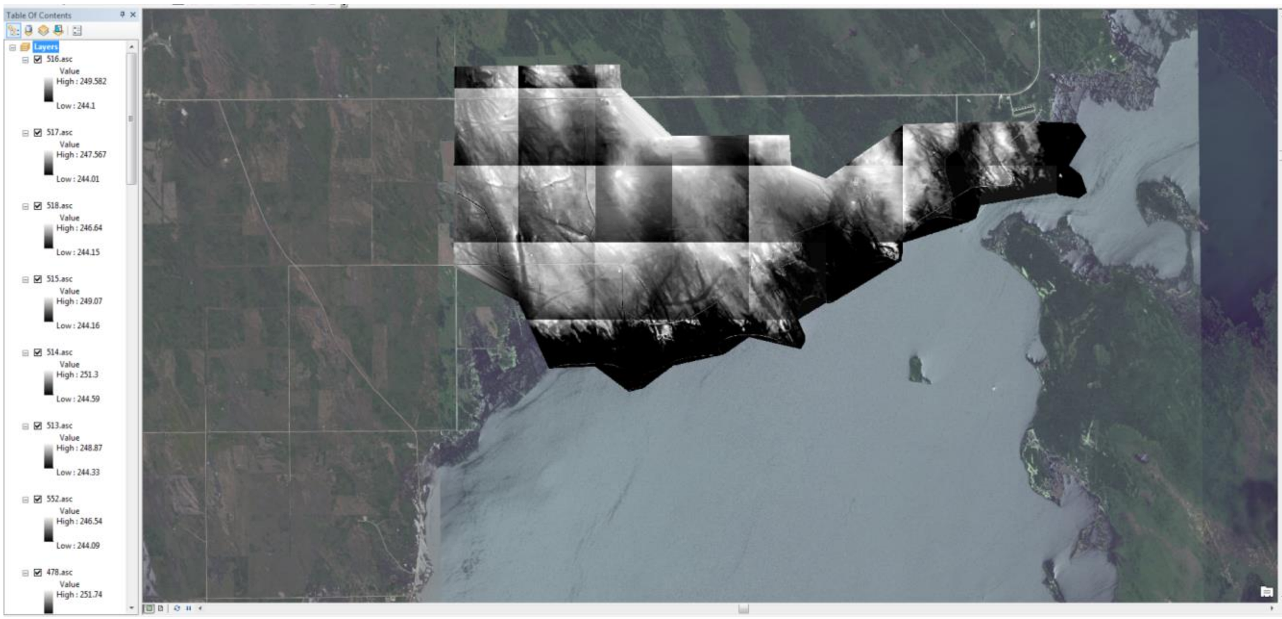


Figure 3.30: Elevation levels at LSM FN
Source: LIDAR 2013, University of Manitoba Library

(2) The elevation levels from the ground are classified using the symbology tab in the properties of each tile. In general, the elevation of LSMFN ranged from 243.9 m (area in Figure 3.31 in blue) to 255.78 m (Figure 3.32 with area circled in blue).

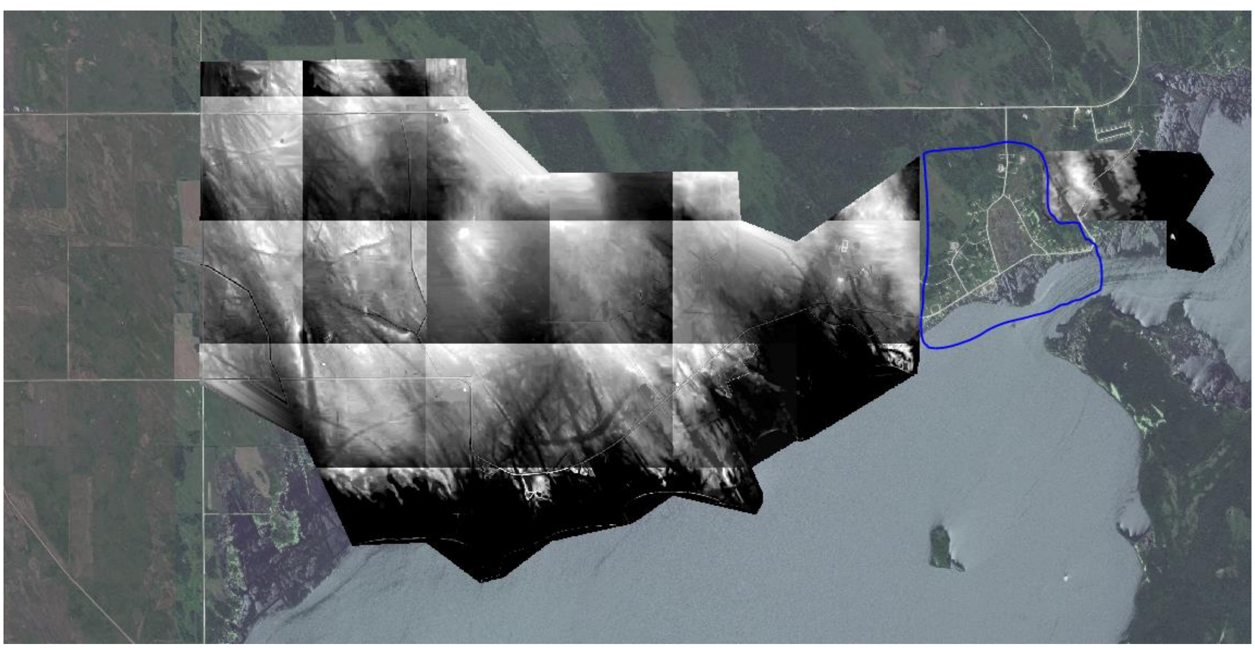


Figure 3.31: Low Elevation Areas at LSM FN marked in blue
Source: LIDAR 2013, University of Manitoba Library

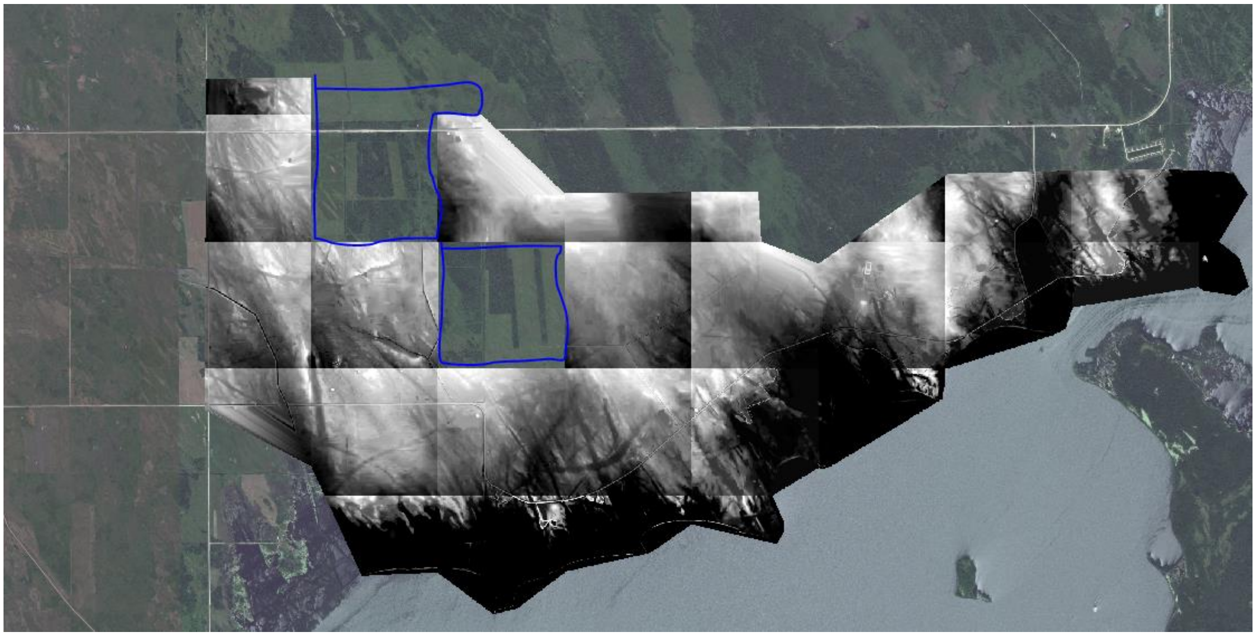


Figure 3.32: High Elevation Areas at LSM FN marked in blue
Source: LIDAR 2013, University of Manitoba Library

(3) 2013 LIDAR data is rendered on the DEM in Figure 3.33.

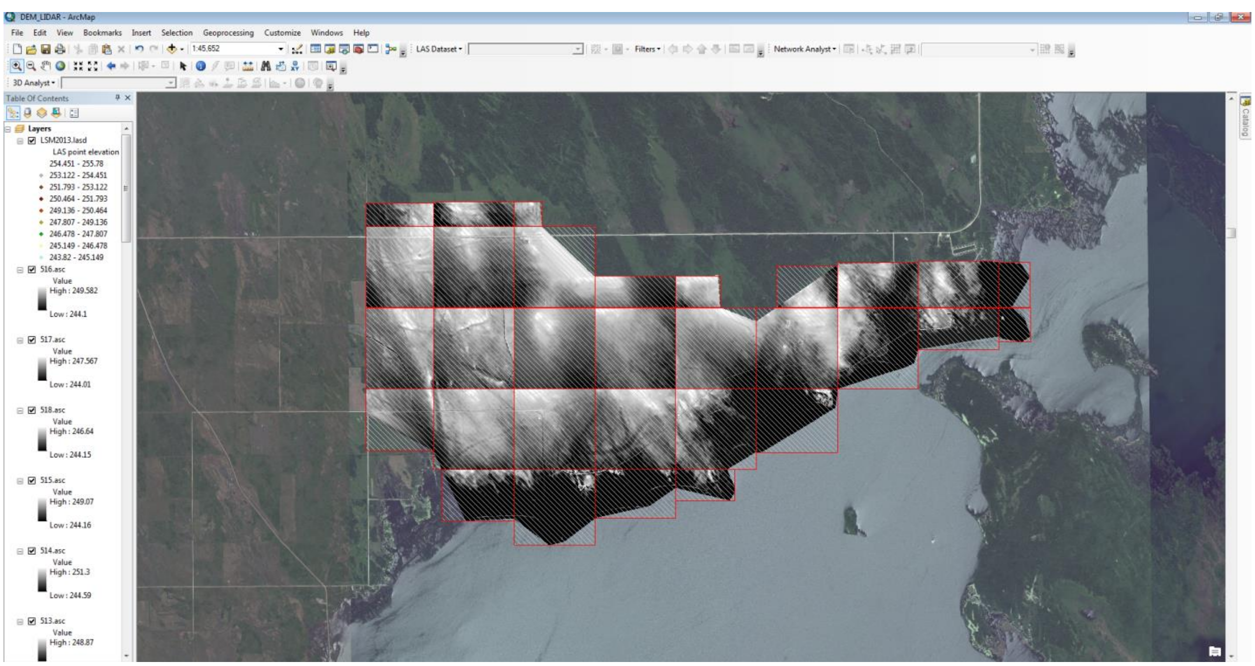


Figure 3.33: LIDAR 2013 data of LSM FN
Source: LIDAR 2013, University of Manitoba Library

(4) The elevation levels of the projected 2013 LIDAR data were classified into equal intervals from 235 m to 260 m by the following steps:

(i) Selected the properties tab of the LIDAR (.las) file.

(ii) Selected the classification method tab > natural breaks (Figure 3.34).

(iii) Selected the number of classes (Figure 3.35).

(iv) Selected the break values (Figure 3.36).

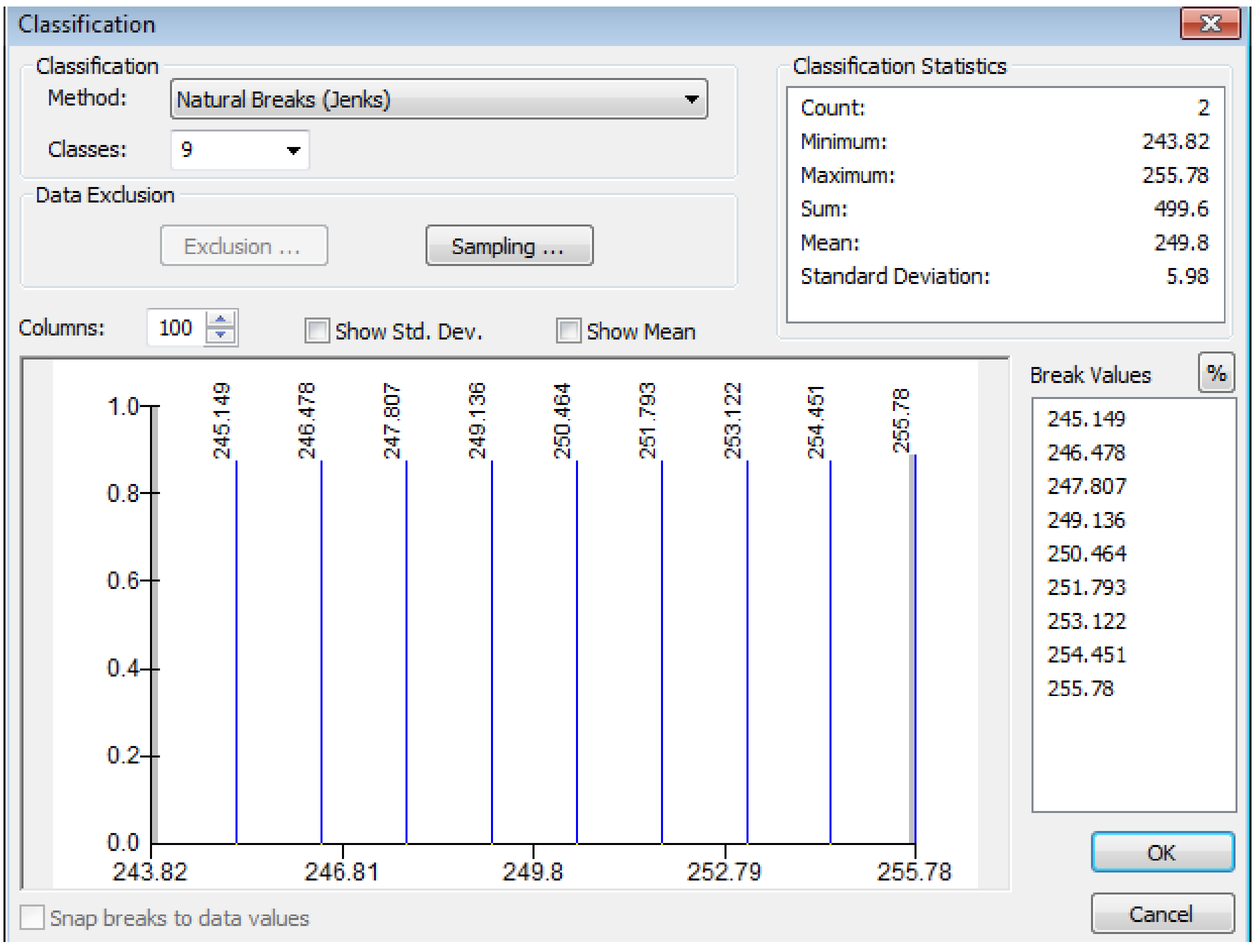


Figure 3.34: Classification step
Source: LIDAR 2013, University of Manitoba Library

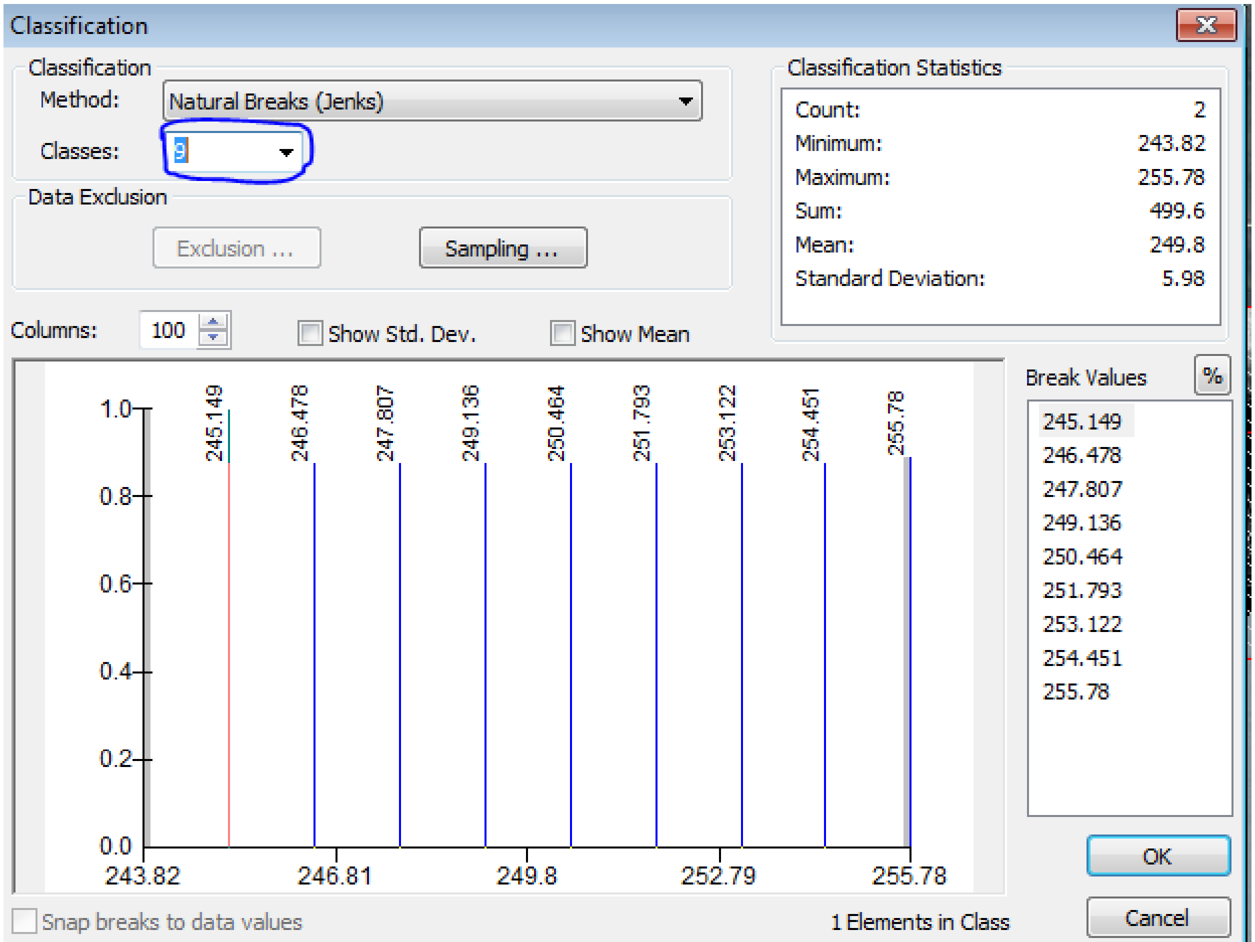


Figure 3.35: Selecting the number of classes
Source: LIDAR 2013, University of Manitoba Library

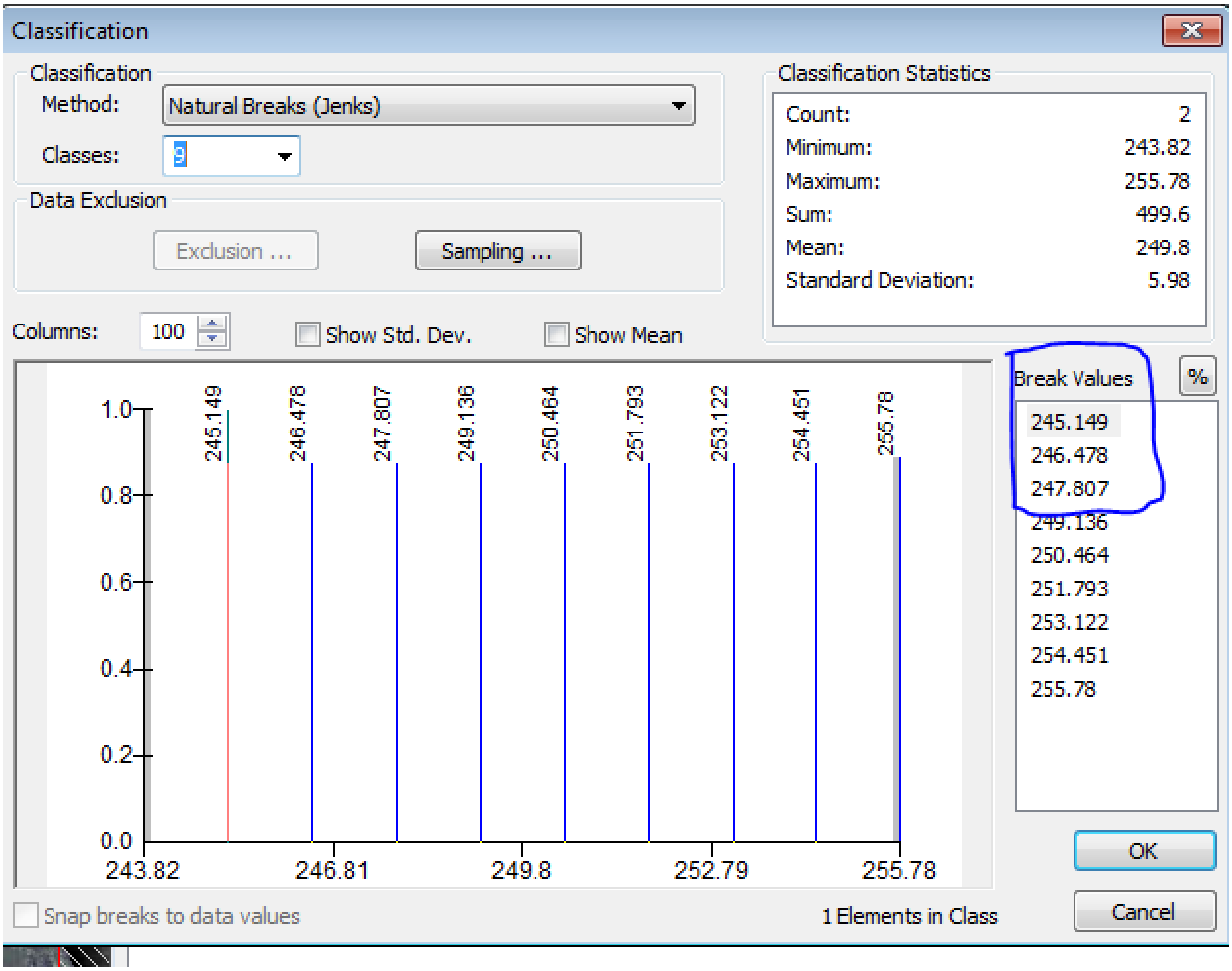


Figure 3.36: Entered the break values for elevation
Source: LIDAR 2013, University of Manitoba Library

(5) I repeated the above steps to find the elevation level.

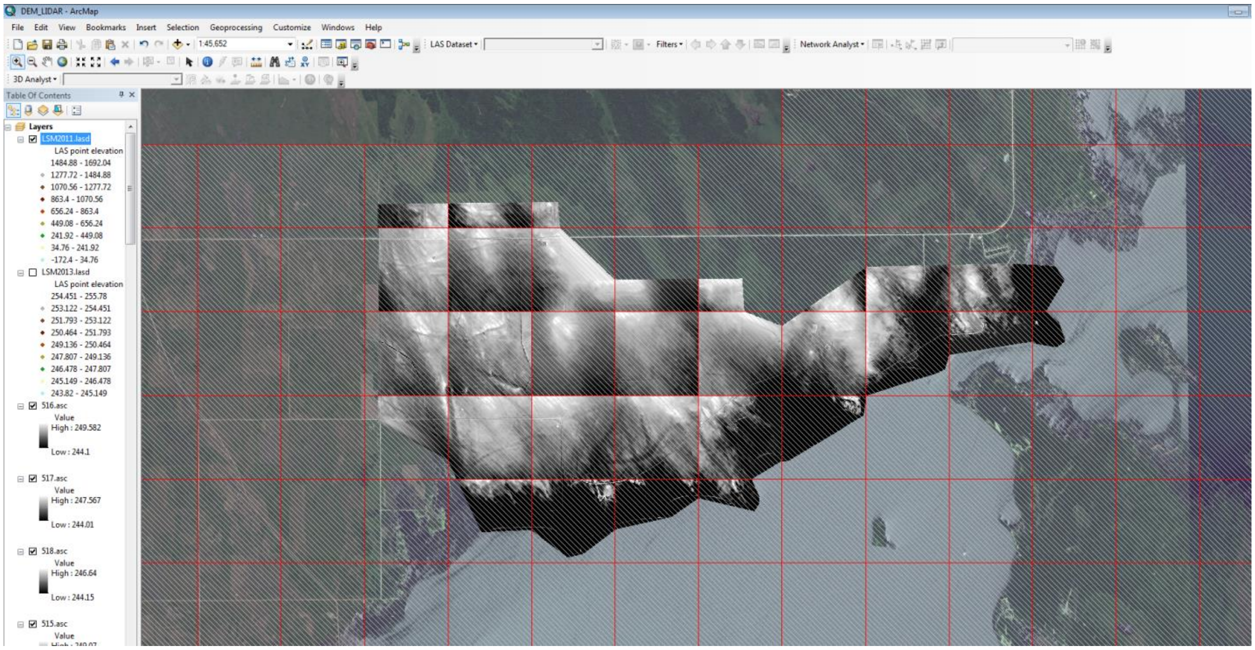


Figure 3.37: LIDAR 2011 data of LSM FN
Source: LIDAR 2011, University of Manitoba Library

(6) I projected both 2011 & 2013 LIDAR data, selecting same colors for both the elevation data for symbology and compared the two LAS files. The difference in the area is the change since the 2011 flood. Using the DEM elevation file, the volume of the area around a specific area is calculated.

(7) Analyzing elevation data points in terms of the smaller distance of feet instead of the larger distance of meters was used to provide a more nuanced visualization of elevation that shows the subtle difference. With a range of 1m in elevation, I scaled all those data points into 5 units. Whereas, with the range of 1ft. in elevation, I scaled the same data points into 15 units (1m=0.3048 ft.). Detailed analysis is possible when the elevation is viewed in feet instead of meters.

CHAPTER FOUR: RESULTS

4.1 Introduction:

This chapter discusses the results of (1) the annual water flow of FRWCS and PD, (2) the GIS analyses of historical aerial images, and (3) the LIDAR data analyses of 2011 and 2013.

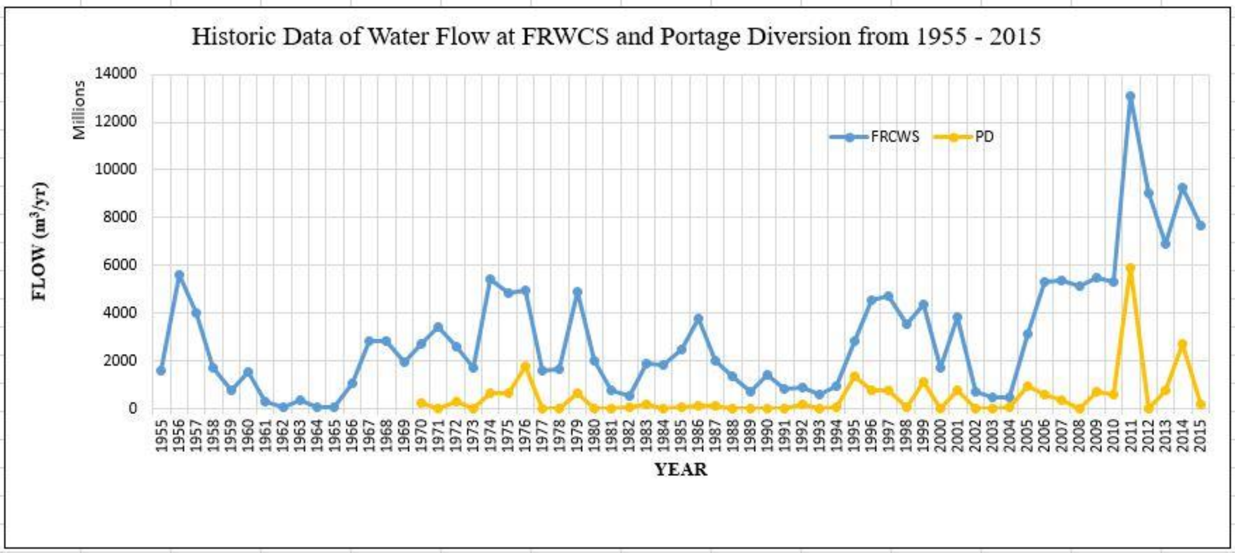


Figure 4.1 – Annual Water Flow at Fairford River Water Control Structure (FRWCS) and PD from 1955 - 2015

The discharge of annual water flow of Fairford River is available from 1955 to 2015 (see Figure 4.2). The FRWCS came into operation in 1961 and PD in 1970. Five peak periods are observed in the years 1956 (pre-FRWCS), 1967 (post-FRWCS), 1974 (post-PD), 2009 (pre-2011 super flood), 2011 (super flood), and 2014 (post-2011 super flood). Hence the data is analyzed at six intervals (i) 1955-1960, (ii) 1961-1970, (iii) 1970-2004, (iv) 2005-2010, (v) 2011, (vi) 2012-2015.

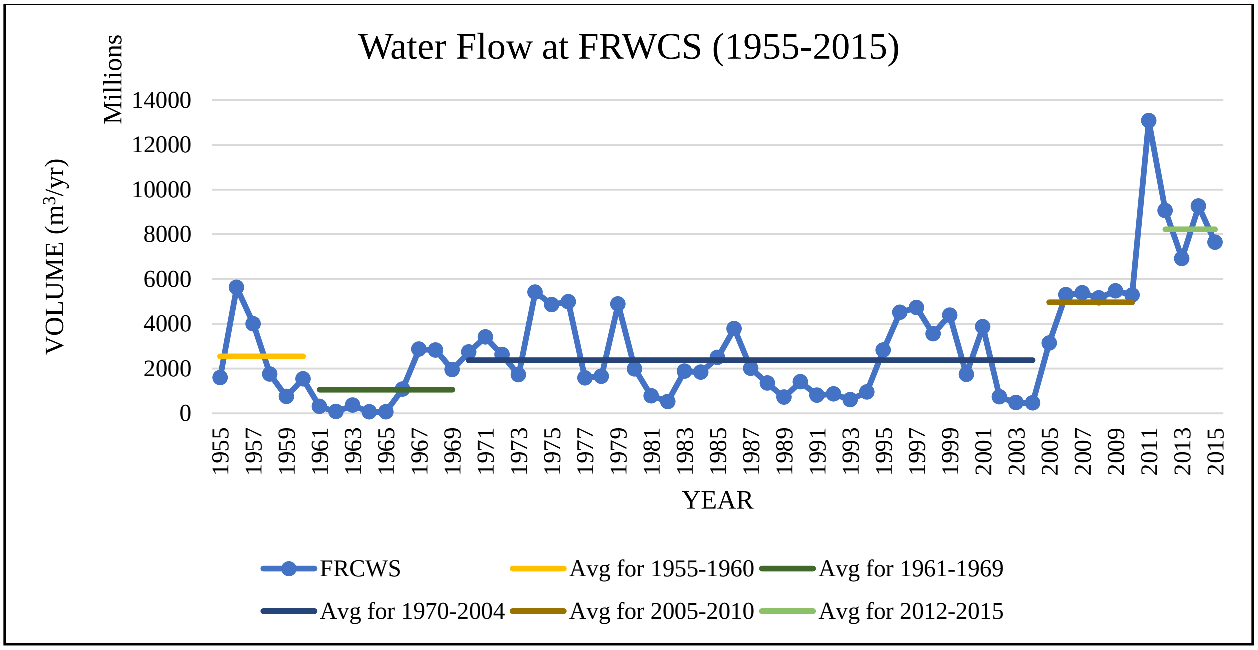


Figure 4.2 – Annual Water Flow at FRWCS (FRWCS) from 1955 - 2015

The annual average flow of water at Fairford River before the construction of water control structure was 2.5 billion m^3/yr. After the construction of FRWCS in 1961, the annual average flow of water was reduced by more than half to 1062 million m^3/yr but with two above average annual flows in 1967 (2.8 billion m^3/yr) and 1968 (2.8 billion m^3/yr).

After the operation of PD started in 1970, the average annual flow of water at FRWCS increased to 2.3 billion m^3/yr. The FRWCS exceeded this average annual flow 15 times in the next 35 years. From 2005, the average annual flow of water increased to 4.9 billion m^3/yr, which is more than double of the annual average (2.3 billion m^3/yr).

In 2011, during the super flood, the annual flow of water from FRWCS reached 13.1 billion m^3/yr, which is 5.5 times more than the annual average (2.3 billion m^3/yr). After the super flood, the annual average flow of water came down to 8.2 billion m^3/yr, which is still 3.5 times the annual average (2.3 billion m^3/yr). Figure 4.3 and Table 4.1 outlines the FRWCS average annual water flows.

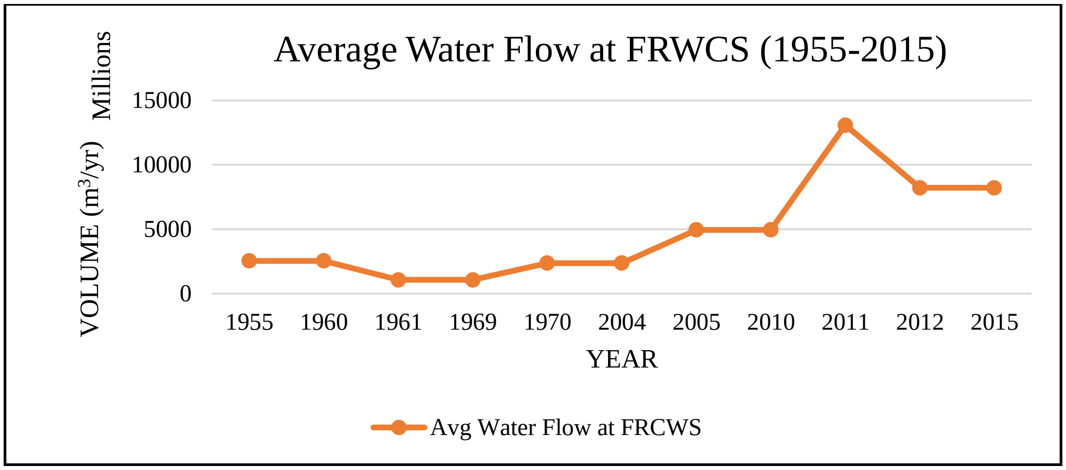


Figure 4.3 – Average of Annual Water Flow at Fairford River from 1955 - 2015

Year	**Event**	**Average Flow (m^3/yr)**
1955 – 1960	Pre – FRWCS	2.5 e9 (2538953856)
1961-1969	FRWCS in operation	1.8 e9 (1062010368)
1970-2004	PD in operation	2.3 e9 (2372422818)
2005-2010	PD in Operation	4.9 e9 (52393280)
2011	Super Flood of MB	1.3 e10 (13074220800)
2012-2015		8.2 e9 (8215711200)

Table 4.1: Average of annual flow of water at Fairford River from 1955-2015

The PD came into operation in 1970. The PD operates for a duration of three to six months only every year unlike FRWCS, which operates all through the year. Hence the volume of annual water is less when compared to FRWCS for the year. The discharge of annual water flow of PD is available from 1970 to 2015 (see Figure 4.4). The annual average water flow of PD is also studied for the same time periods as of FRWCS for consistency in data analysis. The data is analyzed at four intervals (i) 1970-2004, (ii) 2005-2010, (iii) 2011, (iv) 2012-2015.

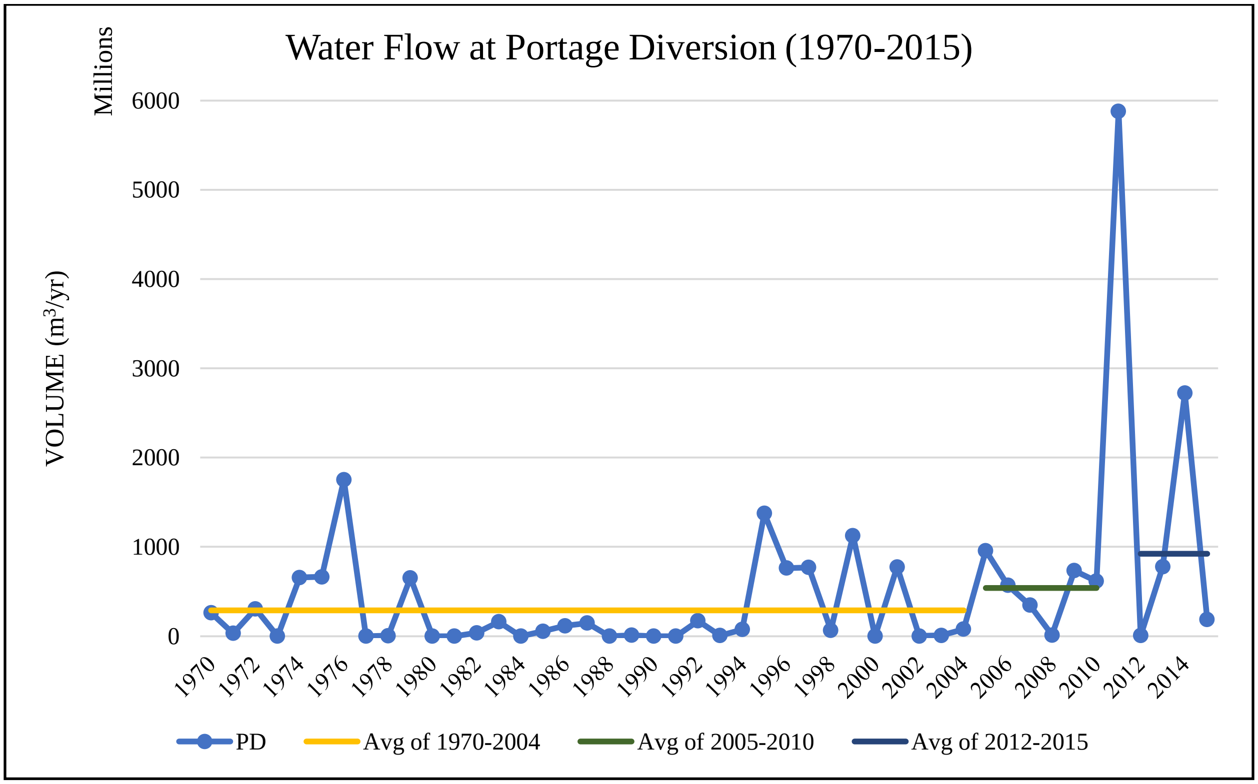


Figure 4.4 – Annual Water Flow at PD from 1970 – 2015

Source: Geebu constructed from Water Survey of Canada Data.

From 1970 to 2004, the annual average flow of water at PD is 2.8 billion m^3/yr. During this period of 35 years, the annual average flow of water was exceeded 10 times. The peak year of flow was in 1976 where the annual flow reached to 1.7 billion m^3/yr, which is six times more than the average (2.8 billion m^3/yr).

From 2005, the average annual flow of water increased to 5.3 billion m^3/yr, which is almost double (1.85 times) of the annual average (2.8 billion m^3/yr). In 2011, during the super flood, the annual flow of water reached 5.9 billion m^3/yr, which is more than 20 times the annual average (2.8 billion m^3/yr). After the super flood, the annual average flow of water came down to 9.2 billion m^3/yr, which is still 3.5 times the annual average (2.8 billion m^3/yr). Figure 4.5 and Table 4.2 outlines the PD average annual water flows.

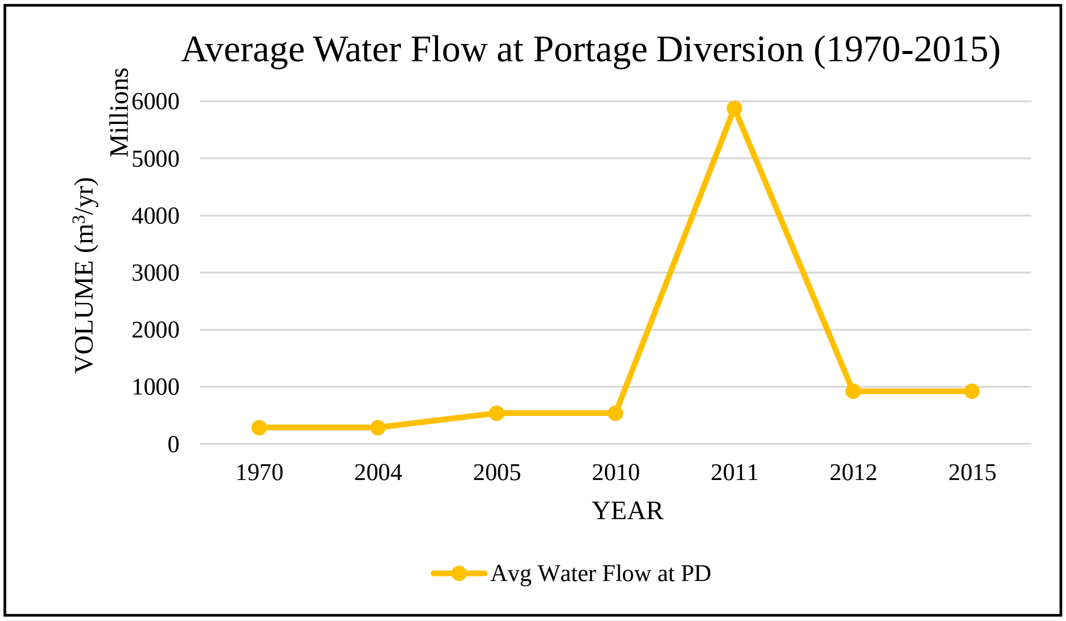


Figure 4.5 – Average of Annual Water Flow at PD from 1970 – 2015

Source: Geebu, compiled from Water Survey of Canada data

Year	**Event**	**Average Flow (m^3/yr)**
1970-2004		2.8 e7 (287550792.4)
2005-2010		5.3 e7 (539041334.4)
2011	Super Flood of MB	5.8 e9 (5879434464)
2012-2015		9.2 e8 (923161341.6)

Table 4.2: Average of annual flow of water at PD from 1970-2015

4.2 Higher water flows causes land to shrink

In the year 1948, the area of the selected island was approximately 21.5 acres. But after the start of operation at FRWCS in 1961, the area of the island decreased by 5.5 acres to approximately 16 acres. After the construction of PD in the year 1970, the area of the island is approximately halved to be only 7.5 acres compared to 1961. Since 1948 the Island lost 63% of the land mass by 1970. Due to the continuous flooding after 1970, the area of the island in 1986 was 1.5 acres and in the year 2011, the island disappeared as it was completely submerged under water. See table 4.3 to see the percent loss of original island size and acreage lost.

Year	Remaining Area (acres)	Percent of original island submerged
1948	21.50	0
1961	16	25.58%
1970	8	62.79%
1986	1.5	93.02%
2011	0	100 %

Table 4.3: Shrinking LSM island land from 1948 to 2011

4.3 Steps to Display the Analyzed Island Data in Time Slider Tool:

Since I had compiled a historic aerial dataset, I tried to project the dataset and visualize the changes in time using the time slider tool.

1. I selected the Properties tab from the Table of Contents

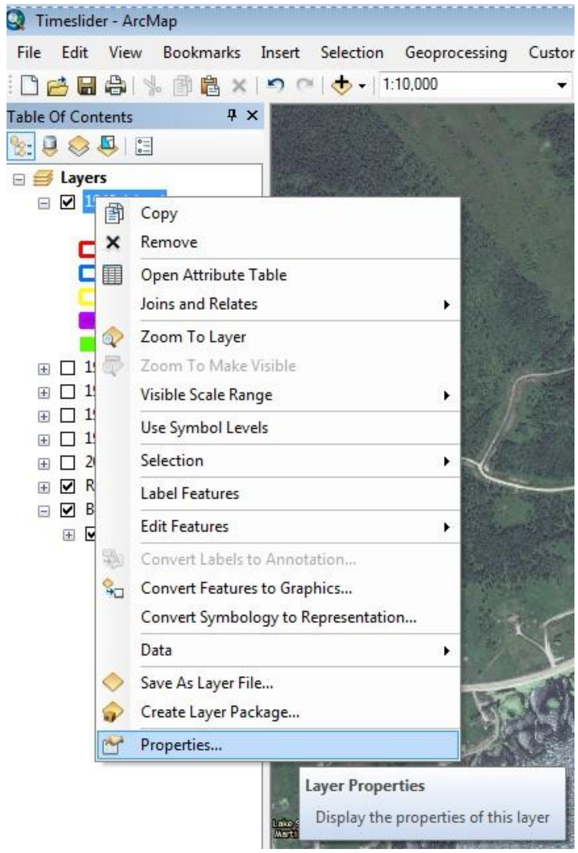


Figure 4.2.1: Selecting Properties to enable Time Slider Tool

2. I selected the Time tab and checked "Enable time on this layer". I set the properties matching the attribute table and clicked Apply.

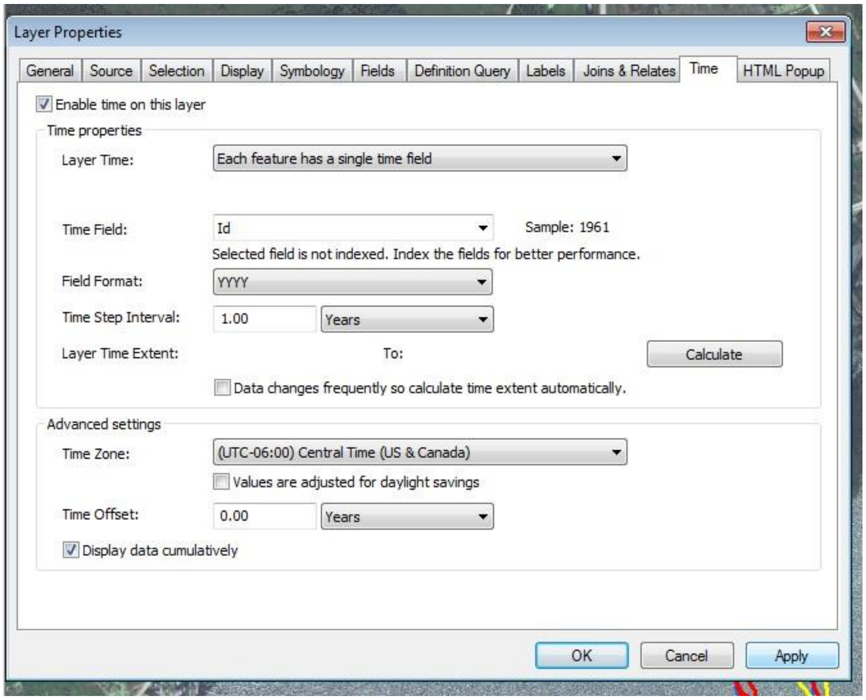


Figure 4.2.2: Enabling time slider tool

3. In the Toolbar option, I selected the time slider tool

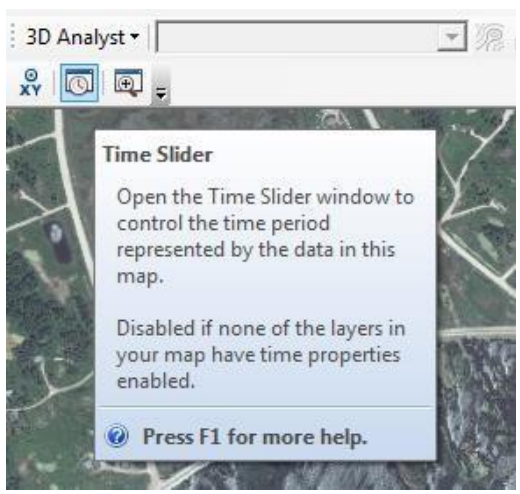


Figure 4.2.3: Selecting time slider tool

4. When the time slider is open, I selected the properties and set it to my desired animation.

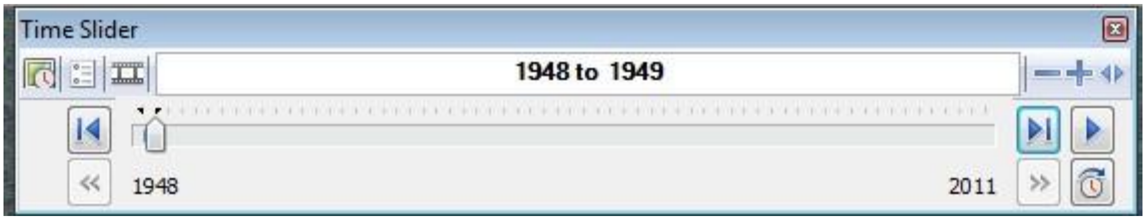


Figure 4.4: Selecting the animation

5. The time slider provides a series of animation showing the loss of the island area from the year 1948 to 2011 with red outline being the 1948 land mass, and the yellow outline representing the 1961 outline, in 1970 the outline is in green and finally in 1986 the island is the white point. In 2011 there is no remaining island and so no colour to represent it.

Figure 4.5: Animating time from 1948 to 2011 to show the loss of land due to flooding

The above analysis is only for that particular island through observing the aerial images manually. The next part of the analyses will be the total common area of the aerial images, which includes the shorelines of the LSMFN and the Narrows 49A.

4.4 GIS analyses of historical aerial images

The aerial images of LSMFN area for the year 1948 (Pre-water control structures) were geo-referenced using ArcGIS 10.2.2 and converted to shape files. The area in the red represents the land area from the 1948 aerial photos (see Figure 4.6). This piece of land belongs to LSMFN (The Narrows 49 and The Narrows 49A). There are two parcels of land in LSMFN specifically No.49 and across the water No.49A. All the First Nation members living on the reserve inhabited No.49 prior to the flood. To perform GIS analysis, the land area is divided into three areas namely LSMFN Land Reserve #49, LSMFN Land Reserve #49A, and Lake St Martin Island. The aerial images of the same area for the years 1961 (Post Fairford), 1970 (Post Fairford), 1986 (Post PD), and 2011 (Super-flood) are also georeferenced and divided into three parts for uniformity in analysis.

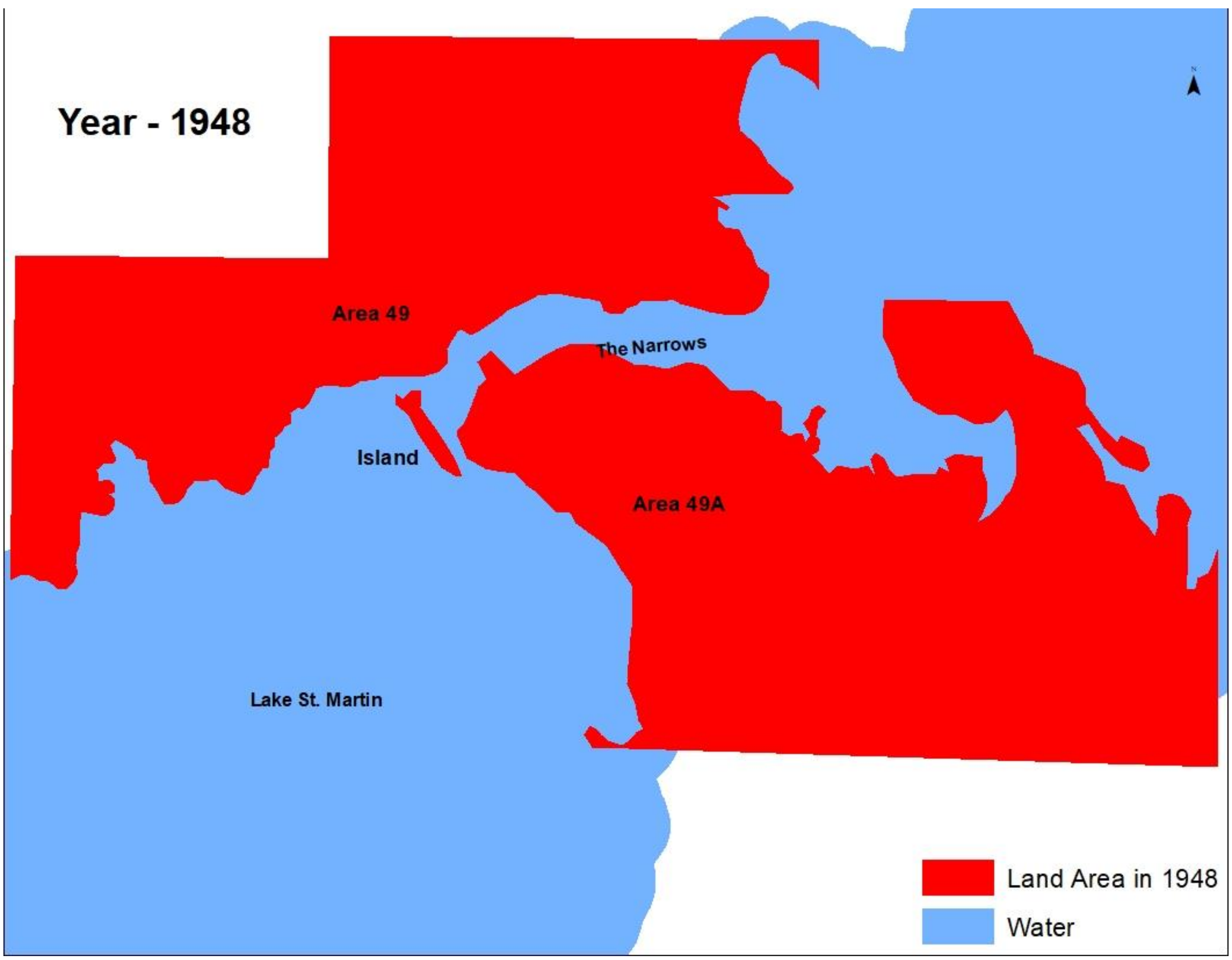


Figure 4.6: LSMFN in 1948
Source: Adapted from Manitoba Conservation, 1948

The land areas in red represent the land prior to the flooding in 1948 and the land areas in yellow represent that land in 1961, after the construction of FRWCS (see Figure 4.7). The FRWCS came into operation by 1954 and so can be seen to impact the water levels by 1961. In seven years of the FRWCS operation, the water levels at LSM increased and caused artificial flooding at LSMFN regions. When compared to 1948, the land area, which was under water permanently at LSMFN, is calculated to be 420 acres in 1961.

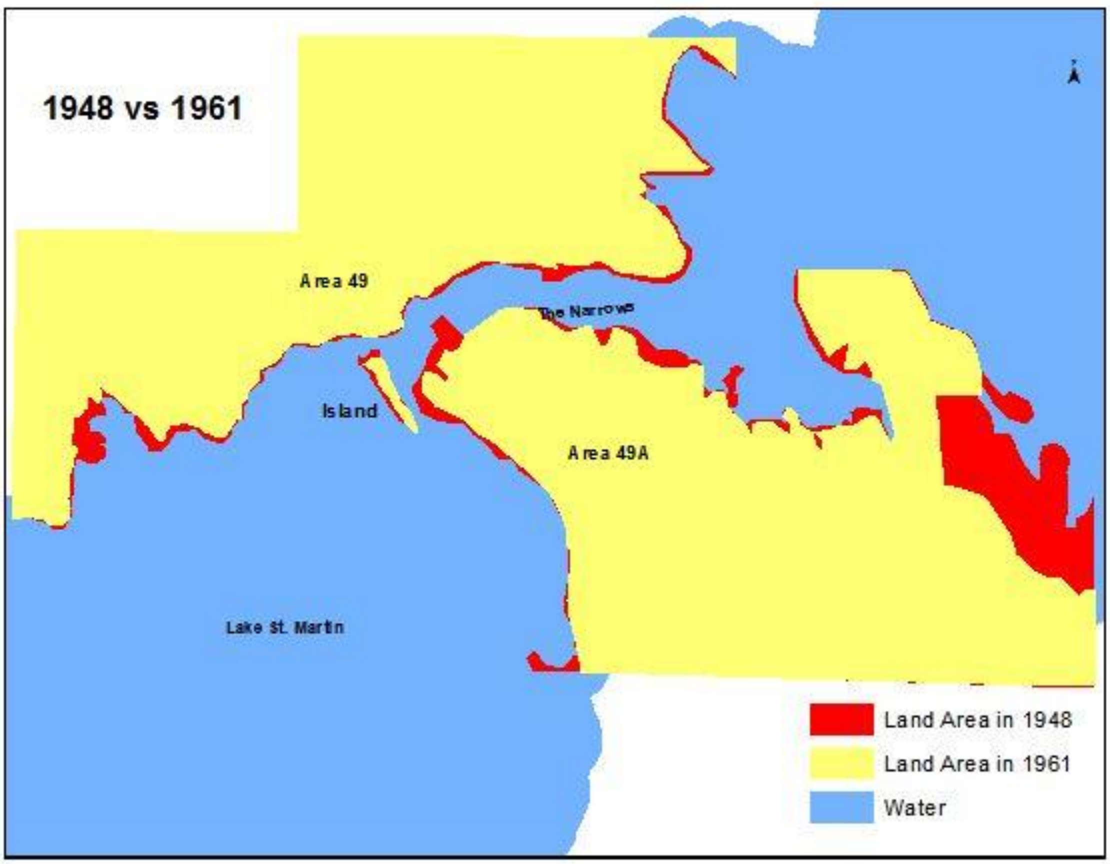


Figure 4.7: LSMFN in 1948 and 1961
Source: Adapted from Manitoba Conservation, 1948 and 1961

The land areas in red represent the land prior to the flooding in 1948 and the land areas in pink represent that land in 1970, after the FRWCS and perhaps with some testing of the PD (see Figure 4.8). The FRWCS came into operation by 1954 and so can be seen to impact the water levels by 1970. In 16 years of the FRWCS operation, the water levels at LSM increased and caused artificial flooding at LSMFN regions. PD came in place by 1970 but it is not evident whether it diverted floodwaters in 1970, as it would not be required to be in operation in all years. When compared to 1948, the land area, which was under water permanently at LSMFN, is calculated to be 902 acres in 1970.

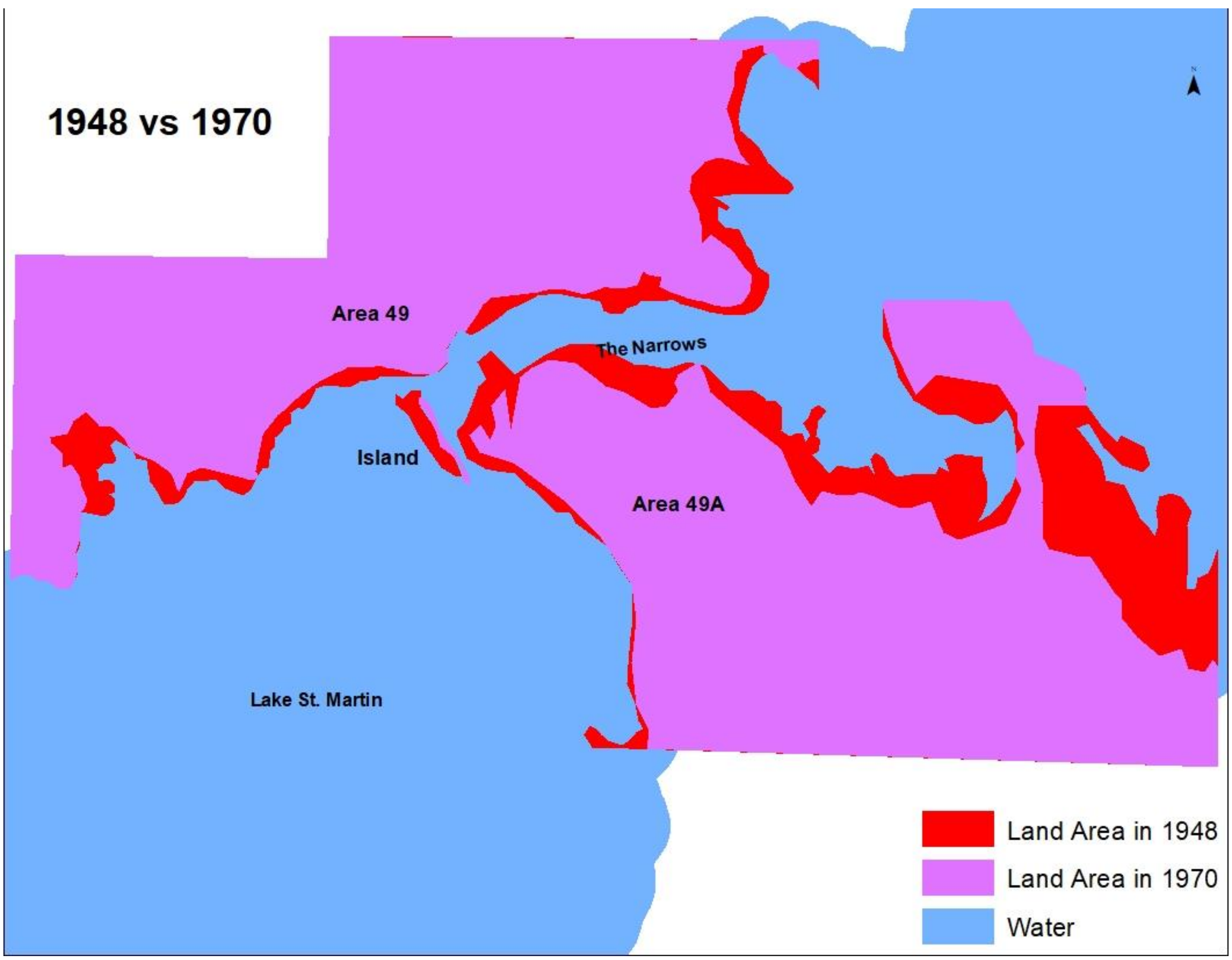


Figure 4.8: LSMFN in 1948 and 1970
Source: Adapted from Manitoba Conservation, 1948 and 1961

The land areas in red represent the land base in 1948, before artificial flooding, and the land areas in green represent that land in 1986, to show the joint impact of the PD and FRWCS (see Figure 4.9). The PD started its operation in 1970. Now, with both the FRWCS and PD active, the continuous flooding at LSM increased over time. When compared with 1948, the area under water is calculated to have lost 17% in 1986. The Island which was visible in 1970, is now almost submerged in water. Only 7 % of the Island is above water.

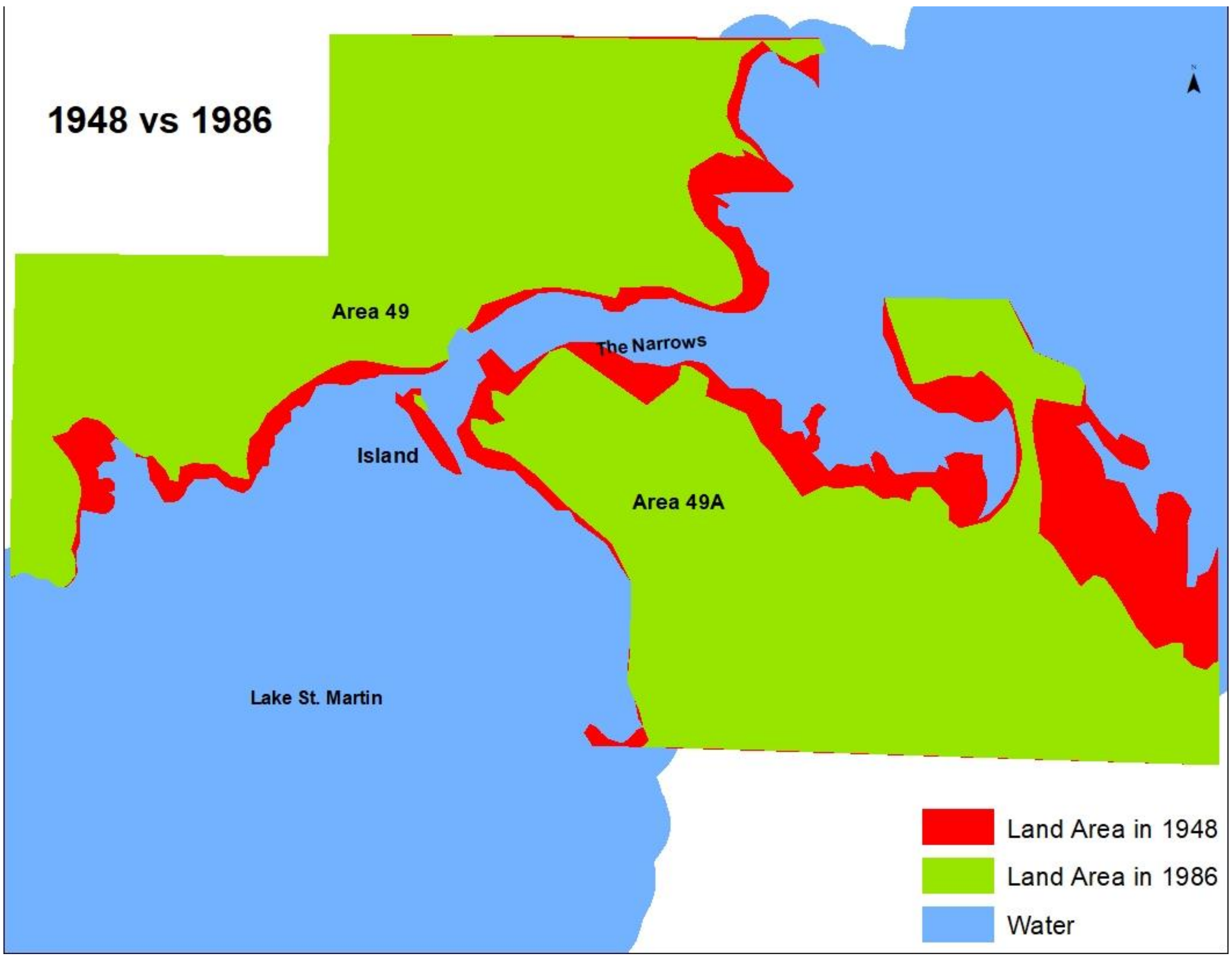


Figure 4.9: LSMFN in 1948 and 1986
Source: Adapted from Manitoba Conservation, 1948 and 1986

The area in the orange represents the land area in the year 2011 and the area in red represents the area in 1948 (see Figure 4.10). Visually, these images provide evidence that the previous shoreline was covered over by continuous flooding. The difference between the areas can be calculated by measuring the total areas of both the years. The total area under water is 1216 acres. The land lost from floods in 2011 inundated many residential housing and the community church as well. An island of 21.5 acres was completely underwater by 2011. Approximately 22% of land is lost between 1948 and 2011. The biggest loss of land was from the FRWCS as the PD was not in operation until 1970. The loss of land will be significantly higher if we can calculate the total area along the shorelines of LSM not only reserve land for LSMFN. But clearly, the difference between the land area prior to any water control structures and after the operations of Fairford and PD diminishes the land significantly.

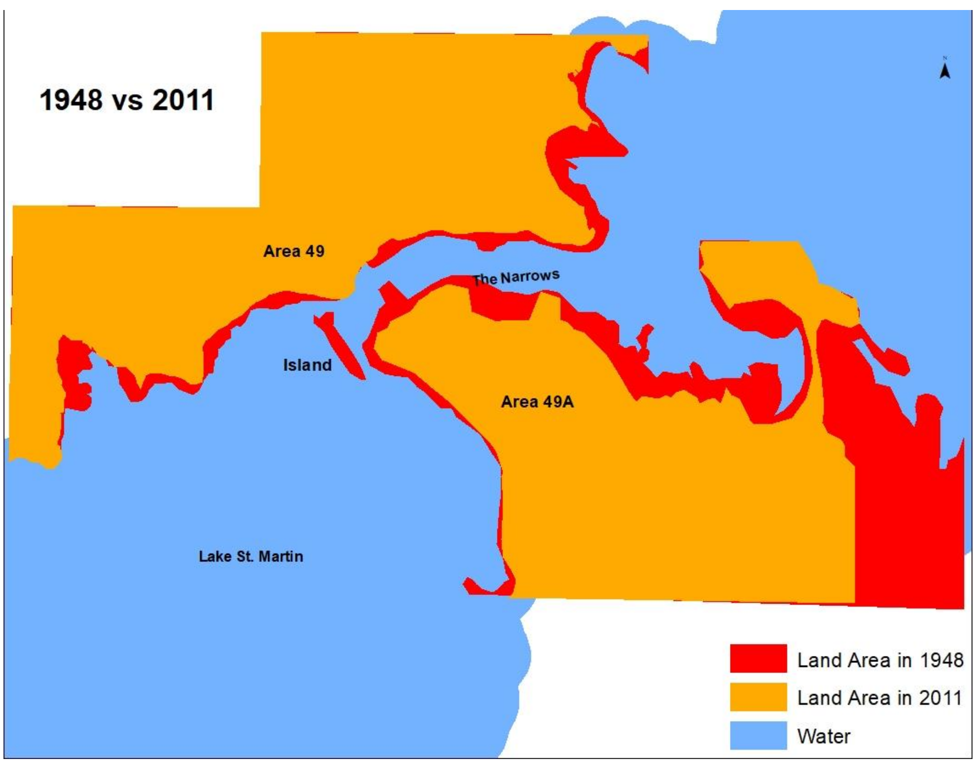


Figure 4.10: LSMFN in 1948 and 2011
Source: Adapted from Manitoba Conservation, 1948 and 2011

The following table summarizes the land mass calculations done by GIS analysis of the aerial images.

Year	Event	Area 49 (acres)	Loss of Land w.r.t 1948 (%)	Island (acres)	Loss of Land w.r.t 1948 (%)	Area 49A (acres)	Loss of Land w.r.t 1948 (%)	Total Area (acres)	Total Land lost w.r.t 1948 (%)
1948	Without any water control structures	2602		21.5		2965		5589	
1961	Fairford Structure in place	2500	102 (- 3.9%)	16	5.5 (- 25.6%)	2654	311 (- 10.5%)	5170	418.5 (- 7.5%)
1970	PD in place	2354	248 (- 9.53%)	8	13.5 (- 62.8%)	2325	640 (- 21.6%)	4687	901.5 (- 16.1%)
1986	Both water control structure in place	2348	254 (- 9.8%)	1.5	20 (- 93%)	2313	652 (- 22%)	4663	926 (- 16.5%)
2011	Super-flood	2331	271.20 (- 10.4 %)	0	21.5 (- 100%)	2041	924 (- 31.2%)	4372	1216.5 (- 21.8 %)

Table 4.4: Percentage of Lake St. Martin First Nation loss of land compared to the base year of 1948

4.5 LIDAR data analyses

The LIDAR data for 2011 and 2013 has elevation levels ranging from 240m to 260m or 790 ft to 850 ft with one foot equaling 0.3048 metres. In 2011, there is an increase of approximately 2 m (6 ft.) in elevation near the water shores and 0.3-1 m (1–3 ft.) all through the LSMFN.

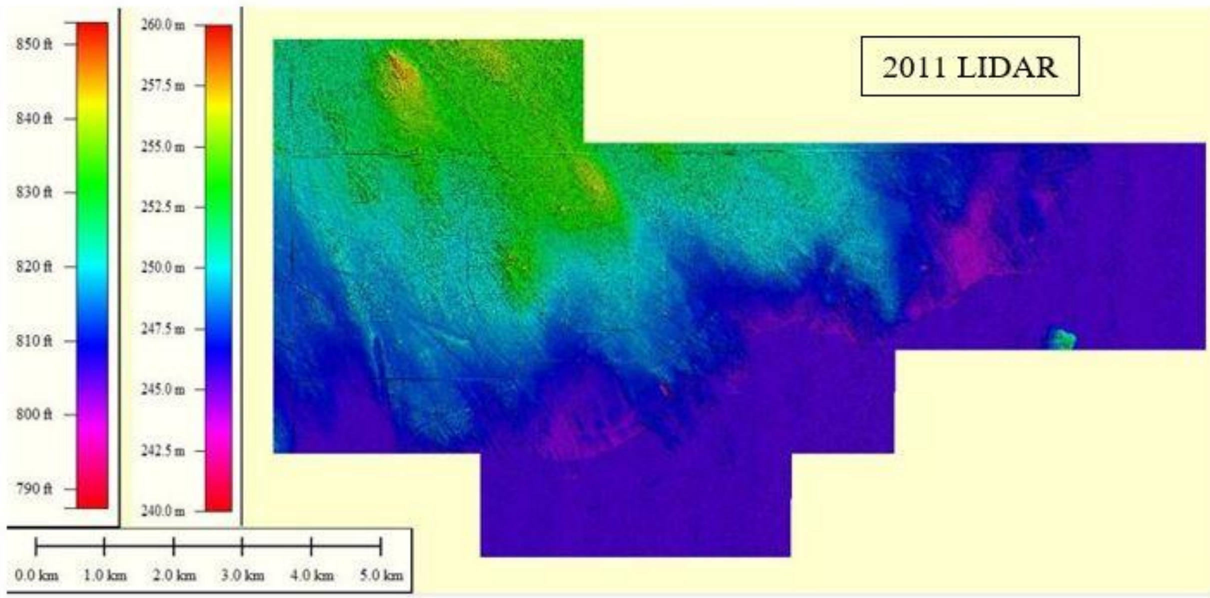


Figure 4.11 - Result of Lake St. Martin First Nation 2011 LIDAR data

The change in elevation levels can be observed for the same area in both the years (see fig 4.12). The elevation of the shoreline in 2011 was higher compared to 2013 due to the presence of water on land in 2011.

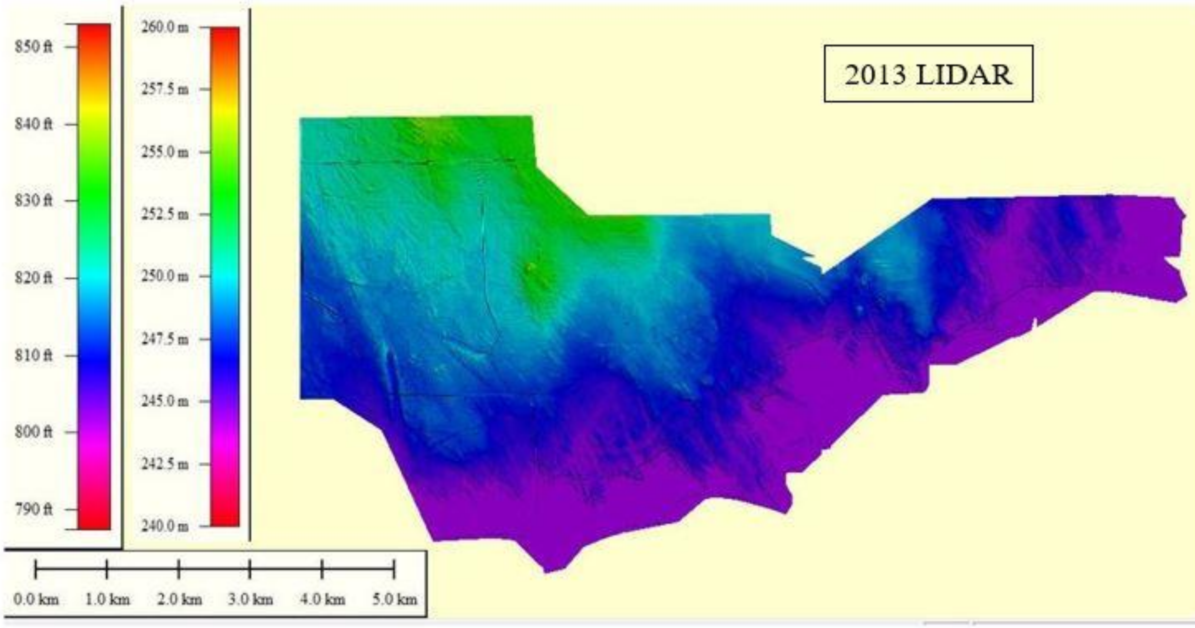


Figure 4.12 - Result of Lake St. Martin First Nation 2013 LIDAR data

To analyze the elevation levels for the years 2011 and 2013, two parcels of land in LSMFN are selected randomly. The selected lands are named Land A and Land B (see Figure 4.13).

Figure 4.13 – Selected smaller land parcels (A and B) within LSM First Nation Reserve

In 2011, the land areas near the shoreline is in dark sage dust in color showing the elevation at between 804 ft and 809 ft (245m and 246.5 m) (see Figure 4.14). In 2013, the same land area is seen in blue color showing the elevation levels to be in between 800 ft and 803 ft (243.8 m- 244.7m) (see Figure 4.15). There is an increase of 4 ft to 6 ft in elevation between the two years. The 2011 flood of Manitoba has increased the water levels at LSM and flooded LSMFN. The LIDAR data was acquired during the flood period. The presence of water on land has increased the elevation in 2011. After two years of flood and the opening of a water channel in 2012, the water levels came down to 800 ft. Similar results are observed for Land B in 2011 and 2013 LIDAR data (see Figure 4.16 and Figure 4.17).

Both land parcels had infrastructure such as roads, buildings, and residential houses. Community members abandoned their homes and reserve due to severe flooding. The increase of water levels at the community is evident with the LIDAR analyses.

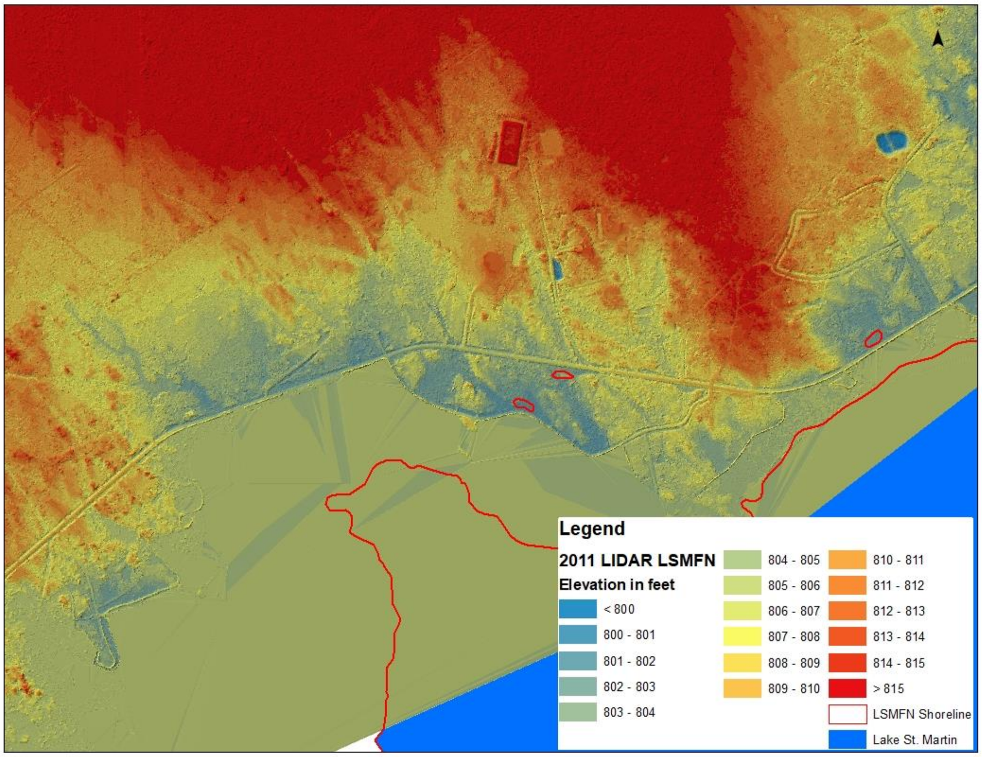


Figure 4.14 – Lake St. Martin First Nation Reserve Land A with 2011 LIDAR data

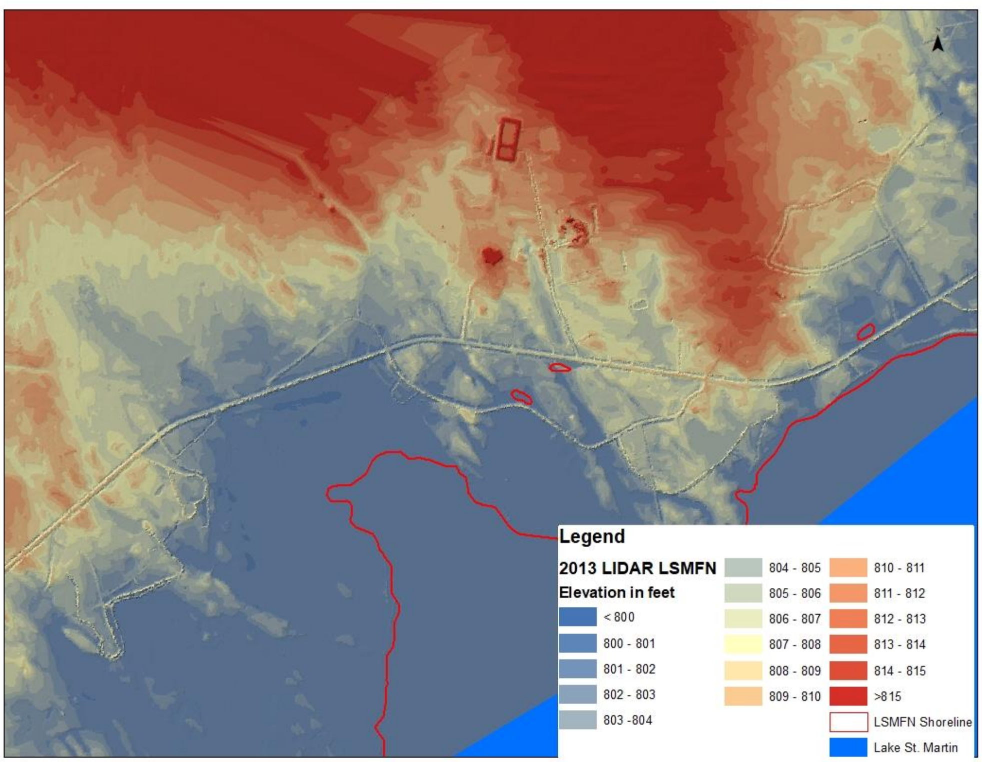


Figure 4.15 – Lake St. Martin First Nation Reserve Land A with 2013 LIDAR data

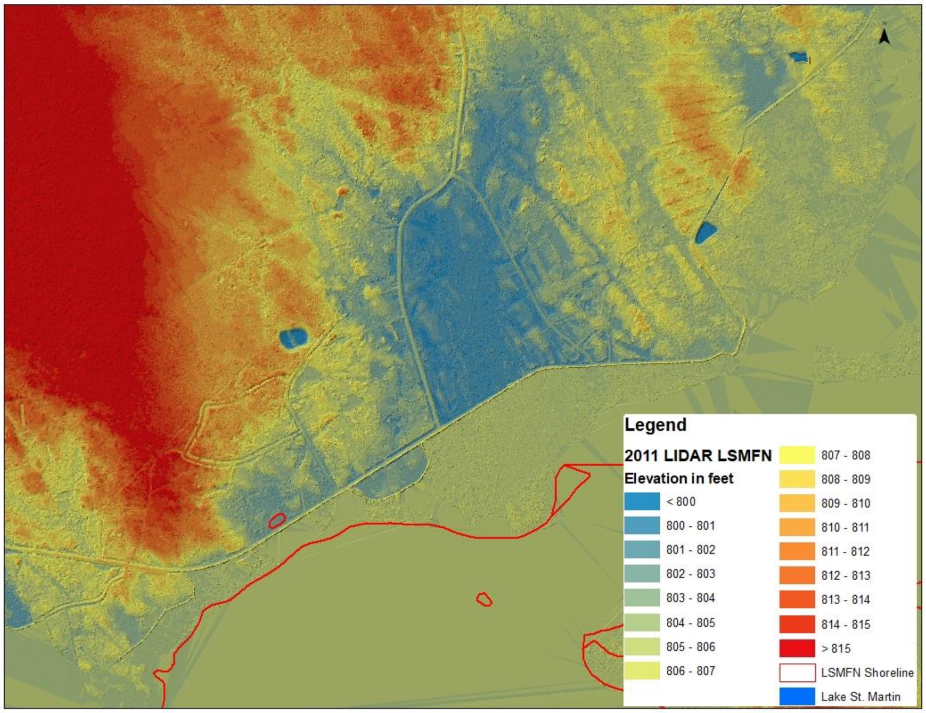


Figure 4.16 – Lake St. Martin First Nation Reserve Land B with 2011 LIDAR data

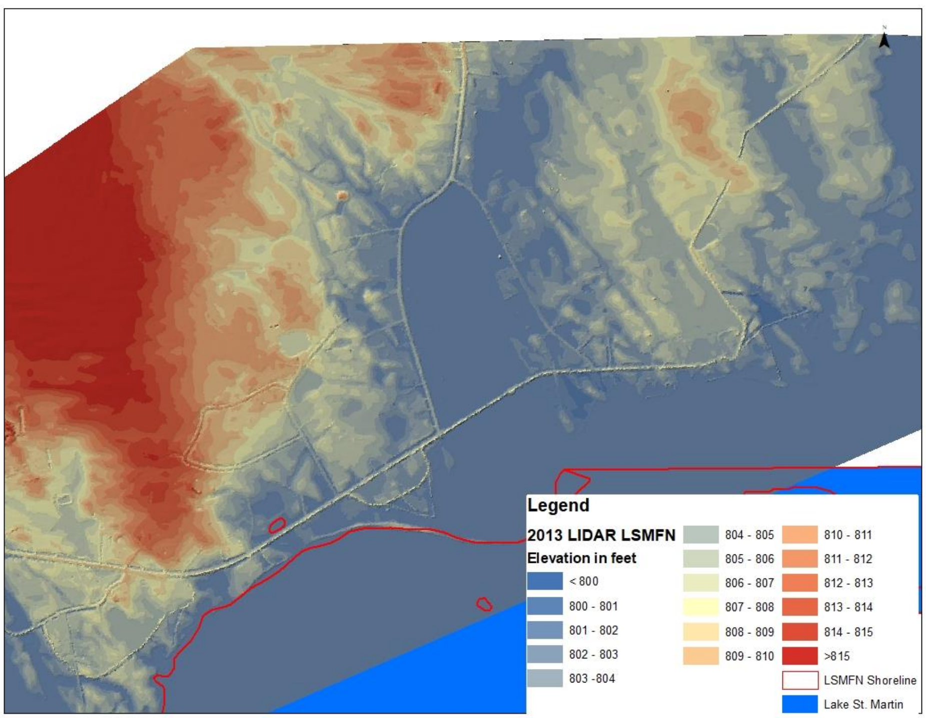


Figure 4.17 – Lake St. Martin First Nation Reserve Land B with 2013 LIDAR data

4.6 Summary:

The volume of water discharged from FRWCS was very high not only during the 2011 super flood of Manitoba but also for six years prior (2005-2010). During that six years period, the annual average flow increased from 2.3 billion m^3/yr to 4.9 billion m^3/yr, which is twice the average flow from 1970 to 2004. The construction of PD in 1970 has resulted in increase of water flow at FRWCS. The volume of water discharged at FRWCS from its start of operation in 1961 until the construction of PD in 1970 is 1.1 billion m^3/yr. After the construction of PD in 1970, the annual water flow at FRWCS has increased to 2.3 billion m^3/yr through 2004. This resulted in artificial flooding at LSMFN over the years. The increase in annual water flow at both FRWCS and PD from the year 2005 was too high for LSM and the communities around it. Even though the 2011 super flood of Manitoba resulted in permanent displacement of LSMFN, the artificial flooding caused due to the construction of FRWCS and PD had resulted in high water levels at LSM for many years.

The analyses of historical aerial images of LSMFN revealed that approximately 1200 acres of land (22%) was lost at the shores of LSMFN in between 1948 to 2011. The Area 49 which represents Narrows 49 of LSMFN has lost around 10.5% of land whereas the Area 49A which represents Narrows 49A has lost around 31% of land during 1948-2011. The small island, which is roughly 21.5 acres of land situated between Narrows 49 and Narrows 49A was completely lost by the year 2011. These results are limited only to the common areas of land data available from the aerial images. The loss of land will be much higher if the total area of LSMFN is available for all the years i.e. 1948, 1961, 1970, 1986, and 2011.

The 2011 LIDAR data analyses shows that LSMFN was largely underwater during the 2011 super flood of Manitoba. The water levels at LSM increased by 6ft during the flood and thereby flooded LSM and the neighboring communities around it. The 2011 LIDAR was 6 ft above the baseline of 1948 compared to the 2013 LIDAR data, which is 3ft higher than the baseline.

CHAPTER FIVE: CONCLUSION

The construction of FRWCS in 1961 and PD in 1970 had a negative impact on LSM First Nation. The diversion of water from these two control structures increased the water levels in LSM over the years, where it accumulated. The matching profiles show that the high-water levels on the Assiniboine River flows into LSM through the PD and potentially from other inputs into lake, e.g. Waterhen, etc.

The 2011 super flood of Manitoba displaced LSMFN community permanently. For more than six years, the community members have had no community to call home and have lived away from their own reserve, which is considered unlivable as no structures are allowed to be built in the flood prone and swampy area that was once their home. Their area was flooded and compromised to protect the City of Winnipeg from a devastating flood in 2011 with provincial government officials diverting the floodwaters to swamp their community.

The land area available for GIS analyses for the year 1948 was approximately 5600 acres which includes three land parcels – Area 49 (2600 acres), Area 49A (2950 acres), and Island (21.5 acres). After the construction of FRWCS in 1961, the water levels at LSM increased and resulted to loss of land of around 430 acres reducing mostly Reserve land 49A, which was across the water but also 100 acres from Reserve 49. Land in Reserve Land 49 was reduced from 2600 acres to 2500 acres. As well, land in Reserve Land 49A was reduced to 2650 acres with more than a quarter of the Island being reduced from 21.5 acres to 16 acres. With this land disappearing beaches became very narrow or disappeared.

After the construction of PD in 1970, and FRWCS running in operation for 16 years, the water levels continued to rise at LSM. This resulted to loss of land of around 900 acres. And after another 16 years of operation of both FRWCS and PD, in 1986, approximately 16.5% of total land was lost and the island is reduced to 1.5 acre from 21.5 acres. By this time much of the beaches had disappeared and good farming land was becoming swampy and unsuitable for raising cattle.

The 2011 super-flood of Manitoba resulted in 22% of loss of land and the island went completely under water. 22% of total area was lost in 2011 when compared to 1948 and it was approximately 1225 acres. The shoreline disappeared and the houses and land were swampy and water-logged. The aerial imagery analyses made it evident that the community of LSMFN lost land. The high-water levels during the flood made it impossible to stay in their reserves and the prolonged period of flood caused the permanent displacement of the members.

The time-slider tool used in the analyses visually showed the loss of land over the years and the GIS tools calculated the approximate loss of land. There is significant amount of loss of land when the operation of water control structures started in 1961 and then further loss in 1970. This animation was helpful to show how each control structure and diversion brought higher and higher levels to this area until islands and shoreline were submerged.

The elevation of LSM is 243.2m (798 ft). Whenever there is an increase in the water levels of LSM, flooding occurs at LSMFN. Over this 50-year period of time, the water diverted by the control structures resulted in artificial flooding continuously to LSMFN. In 2011, the water levels at LSM reached peaks and it flooded all through the community lands. The LIDAR analyses in 2011 revealed an increase of 6ft (2m) in elevation on the shores of LSM and 3 ft (1m) in elevation next to the shores. In 2013, the elevations at the higher altitude reduced by 3 to 5 ft (1-1.6m) and the shores of LSM showed an elevation of 243.2 m which indicates that most of the shoreline is still under water. The water channel was constructed at the northeast of LSM to reduce the water levels and allow the continued use of Lake Manitoba and then LSM to divert water headed towards Brandon and Winnipeg. However, the emergency channel seemed to have minimal impact on water levels. Most of the shorelines was still under water at 243.2 m elevation in 2013 and today in 2017.

The flooding of LSM is a cautionary tale about how control structures and diversion paths can be used to reroute water flooding to impact people who are marginalized. The control structures and operating water levels are determined without the consent of the community leaders and members of the FNs who have suffered the impacts for many years, and now impact the future location of the reserve and people's livelihoods. These structures were built without environmental assessments or health impact assessments, inconsiderate of the damage they would wrought on Indigenous people who have a strong and ancestral connection to the land. Consultation on operating water levels as well as compensation for the damages should be given to the communities, considering not only the 2011 flood but the years of impacts since the building of the FRWCS and PD.

5.2 Future Research

After six years of displacement, the LSMFN community is now allocated to relocate on land adjacent to the former reserve land. Since the land is close to the former reserve, it is important to study the soil saturation at the new location. The prolonged flood at LSM and the presence of water for longer duration can influence the soil saturation and building new infrastructure on such swamp land is not desirable. LIDAR data can be used to estimate the elevation level of the new location but it is not completely enough to understand the soil saturation levels. The use of traditional ecological knowledge of elders of LSMFN community would be critical in understanding the ground reality of the new location. The combination of LIDAR data and traditional ecological knowledge would provide a way to analyze and study the new LSMFN location. This study will immensely benefit the LSMFN community, as they have suffered enough and should not be at risk of more flooding and displacement.

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