2011 Flood: Technical Review of Lake Manitoba, Lake St. Martin and Assiniboine River Water Levels

October 2013

Manitoba

Executive Summary

The Assiniboine River and Lake Manitoba experienced unprecedented flooding in 2011. Water levels on Lake Manitoba peaked in late July, 2011 although a significant windstorm on May 31 caused even higher wind affected water levels on the south basin of the lake. It was during this storm event that many homes and cottages in the south basin of the lake were destroyed or damaged.

The topographic features of the lower Assiniboine River are noteworthy because they have consequences during large flood events. Historic floods have resulted in water overflowing the low banks of the river and spreading out across the prairie, often inundating large areas of land. After the last ice age, from Portage la Prairie downstream, the Assiniboine River built an alluvial fan, a collection of channels built by the river depositing sediment as it descends to the lower level of the glacial Lake Agassiz plain. The river in this stretch is unstable since portions of the riverbed are perched above the elevation of the surrounding land. As a result, the river has changed its course numerous times over the past millennia, abandoning its channel in favour of lower, more stable routes, which are later abandoned. The former channels, called paleochannels, radiate in an arc of 180 degrees with some flowing north to end in Lake Manitoba and others continuing east to join the Red River. These channels play a significant role during flood events because, when the river overflows its banks, the paleochannels convey a portion of the overflows downstream to neighbouring watersheds.

Although the water levels in 2011 were the highest ever recorded, large flood events are not unknown on the Assiniboine River or Lake Manitoba. There are a number of large flood events recorded on both water bodies. Significant floods were experienced on the Assiniboine River in many years prior to official records in the nineteenth century and in at least a dozen years since that time. The flood of 1882 is particularly significant, as it was a very large flood event that occurred early in the period of human settlement with only minimal alteration of the landscape and little in the way of flood control infrastructure present. During the 1882 flood, it was well documented that overflows from the Assiniboine River occurred and that some of these overflows followed paleochannels to Lake Manitoba. Overflows from the Assiniboine River to Lake Manitoba were also documented in the 1922 and 1923 flood events, although an embankment constructed in 1936 prevented any subsequent overflows to the lake.

Manitoba operates a number of flood control structures, which provide flood protection on the Assiniboine River and Lake Manitoba. The Shellmouth Dam on the Assiniboine River, along with dams on the Souris River, located upstream in North Dakota and Saskatchewan, serve to reduce peak flows on the Assiniboine River by holding back flows. The Portage Diversion diverts flows from the Assiniboine River to Lake Manitoba, lowering flows on the Assiniboine River but raising water levels on Lake Manitoba. Dikes and embankments on the Assiniboine River raise the channel capacity of the river, reducing overflows and consequently allowing for higher flows downstream on the river. Finally, enhancements to the outlet of Lake Manitoba constructed as part of the Fairford River water control structure allow higher than natural outflow from the lake, allowing artificial lowering of water levels on Lake Manitoba but artificially increasing inflows to Lake St. Martin.

Artificial flooding occurs when operation of flood control infrastructure causes water levels on a water body to be higher than what the water level would have been if all of the flood control infrastructure was not present. The recorded water levels are referred to as regulated levels, while the levels that would have occurred in the absence of water control works are referred to as unregulated levels. Unregulated levels must be computed for any water body by removing the effect that all water control structures had on the water body in question. In addition, since overflows to Lake Manitoba from the Assiniboine River were reported in past flood events, most or all of which were significantly smaller than the 2011 flood, overflows from the Assiniboine River to Lake Manitoba must also be estimated in order to compute the unregulated level of the lake.

Following the 2011 flood, Manitoba Infrastructure and Transportation conducted an analysis to determine the unregulated flows on the Assiniboine River, and subsequently, to quantify the overflows that would have occurred from the river to Lake Manitoba under a pre-development landscape. The department then computed the unregulated water levels on Lake Manitoba and Lake St. Martin, both with the modelled overflow from the Assiniboine River and assuming that no overflows reached Lake Manitoba.

The operation of water control infrastructure reduced the peak flow on the Assiniboine River at Portage la Prairie from an estimated 64,200 cfs (1,820 cms) under unregulated conditions to the recorded flow of 53,100 cfs (1,500 cms). The results from the modelling of overflows calculated that overflow from the Assiniboine River to Lake Manitoba would have peaked at 5,400 cfs (153 cms). The total volume of the overflow from the Assiniboine River to Lake Manitoba would have been approximately 402,000 acre-feet (496,000 dam^3). A large portion of the overflows would have flowed overland to the La Salle River or back into the Assiniboine River downstream in the vicinity of Headingley.

The peak regulated level on Lake Manitoba was 817.05 feet (249.037 m), and the computed unregulated peak level was 816.75 feet (248.945 m) with Assiniboine overflows and 816.55 feet (248.884 m) without overflows. This means that the level on Lake Manitoba was artificially elevated by a maximum of 0.3 feet (9 cm) in late July. The results also indicate that on May 31, the date of the windstorm that caused much of the damage to homes and cottages on Lake Manitoba, the wind-effect eliminated regulated lake level was 815.72 feet (248.632 m), while the unregulated lake level was 816.24 feet (248.790 m) with overflows and 816.08 feet (248.741 m) without overflows. Thus, at the time of the May 31, 2011 windstorm, the regulated lake level was well below the unregulated level.

Artificial flooding on Lake Manitoba occurred from approximately June 22 until August 30, 2011 and the recorded peak water level on Lake Manitoba was up to 0.3 feet (9 cm) higher than the peak water level would have been in the absence of water control infrastructure. This incremental 0.3 feet (9 cm) of water would have resulted in a portion of additional land being inundated. The actual effect of the artificial flooding, in terms of damage caused as compared to the damage that would have been caused under unregulated conditions, is unclear. Any incremental effects from artificial flooding would likely be limited to the relatively small portion of land that would have been inundated by the incremental 0.3 feet (9 cm) of water. In other words, flood damages that occur below the unregulated peak water level were not made worse by artificial flooding. Further, the south basin of Lake Manitoba actually experienced higher wind affected water levels during the May 31 storm, when Lake Manitoba was approximately 0.5 feet (15 cm) lower than it would have been under unregulated conditions. Therefore, any damages in the south basin of the lake are likely attributable to the earlier, wind-affected flood event, rather than the later period of artificial flooding.

The results of the modelling on Lake St. Martin showed that, from January until late February 2011, prior to spring runoff, the recorded Lake St. Martin water level was approximately one foot below the unregulated water level. This benefit was quickly negated when the flows through the Fairford River water control structure were increased late in the winter of 2011. The operation of the Fairford River water control structure, which lowers water levels on Lake Manitoba during high water periods, serves to artificially increase inflows and causes artificially high water levels on Lake St. Martin. The Portage Diversion, by increasing inflows to Lake Manitoba, also adds to the total volume of water that flows through Lake St. Martin. As a result of the operation of these two structures, the water levels on Lake St. Martin were artificially high from early March until early December, 2011. Lake St. Martin reached a maximum level of 805.60 feet (245.547 m) versus an unregulated peak level 803.17 feet (244.806 m), meaning that water levels on Lake St. Martin were artificially high by up to 2.4 feet (0.73 m). The Lake St. Martin emergency channel helped to significantly reduce water levels on Lake St. Martin much faster than they would have dropped under unregulated conditions. This is illustrated by the steeper decline in recorded lake levels beginning on November 1, 2011, the date that the emergency channel began operation. Operation of the Lake St. Martin emergency channel dropped the recorded water level on Lake St. Martin below the unregulated water level in December 2011.

There are two further important conclusions. First, the results showed that until 2011 the Fairford River water control structure was successful in regulating the levels on Lake Manitoba within the target range in most years since it came into operation, including years in which the Portage Diversion was used. The benefits of the structure on Lake Manitoba are illustrated by considering that the increased outflow capacity meant that under regulated conditions Lake Manitoba dropped below flood stage (814 feet (248.107 m)) by February 2012, whereas under unregulated conditions the lake would have remained above 815 feet (248.412 m) until August of 2012. In fact, under unregulated conditions the lake would have been above flood stage of 814 feet (248.107 m) well into 2013. Finally, there is a distinct possibility that in 2011, under unregulated conditions, the huge volume of flows on the Assiniboine River may have resulted in the river relocating from its present channel to follow an overflow path to form a new, more stable channel. The ramifications for Manitoba’s environment, infrastructure and economy would have been enormous. Therefore, in addition to the flood control benefit provided by water control works, these works also limit the flows on the river to help keep the lower portion of the Assiniboine River in bank and ultimately maintain the river’s present course in a potentially unstable and naturally dynamic reach of the river.

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Conversion Factors

CONVERSION TO METRIC UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimetres	mm
in	inches	2.54	centimetres	cm
ft	feet	0.3048	metres	m
mi	miles	1.609	kilometres	km
		AREA		
mi^2	square miles	2.590	square kilometres	km^2
ac	acres	0.405	hectares	ha
		VOLUME		
ft^3	cubic feet	0.02832	cubic metres	m^3
ac ft	acre feet	1.23348184	cubic decametres	dam^3
		FLOW RATE		
ft^3/s	cubic feet per second	0.02832	cubic metres per second	m^3/s

CONVERSION TO IMPERIAL UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimetres	0.0393701	inches	in
cm	centimetres	0.393701	inches	in
m	metres	3.28084	feet	ft
km	kilometres	0.621371	miles	mi
		AREA		
km^2	square kilometres	0.386102158593	square miles	mi^2
ha	hectares	2.47105381467	acres	ac
		VOLUME		
m^3	cubic metres	35.3146667	cubic feet	ft^3
dam^3	cubic decametres	0.810713194	acre feet	ac ft
		FLOW RATE		
m^3/s	cubic metres per second	35.3146667	cubic feet per second	ft^3/s

1.0 Introduction

In the spring and summer of 2011, Manitoba experienced unprecedented flooding in many areas of the province. The Assiniboine River and Lake Manitoba were particularly affected, both enduring record high water levels for an extended duration. Lake Manitoba also experienced a significant wind event while water levels were high. The result of these two factors was that many residents, farmers, cottagers and businesses suffered losses either directly or indirectly, and a significant amount of local and provincial infrastructure was damaged by flooding.

The Assiniboine River rises in eastern Saskatchewan and is fed by eastern flowing tributaries in Saskatchewan, including the Qu'Appelle River, tributaries on the south side of Riding Mountain, and by the Souris River (see Figure 1). From about Brandon to Portage la Prairie the river channel is closely confined as it cuts down through the glacial Assiniboine Delta. At Portage la Prairie it emerges from this confined channel and flows along an alluvial ridge, perched above the nearly flat Lake Agassiz plain. There the river has deposited a large low-angle alluvial fan with its apex just southwest of Portage la Prairie near the inlet of the Portage Diversion. Historically, during large flood events the river would break out of the channel near Portage la Prairie and floodwaters would spread out across the fan. Some of the flow would continue eastward to Winnipeg, some flowed northward to Lake Manitoba and the remainder flowed south into the La Salle River.

In 1970, the Portage Diversion was completed. This channel was designed to take excess flood flows in the Assiniboine River and divert them into Lake Manitoba. The diversion has been successful in preventing flooding along the Assiniboine River on a number of occasions, but the record flood in 2011 exceeded the combined capacity of the river channel and the design capacity of the Portage Diversion. The flood was the largest ever recorded on the Assiniboine River and was much longer in duration than any previously recorded flood. Flooding along the Assiniboine River was averted by surcharging the diversion channel, that is, by running a greater flow through the channel than its designed capacity. This large volume of water that flowed into Lake Manitoba contributed to raising the lake to record high levels, such that a year later the lake was still above the top of its desirable range.

Lake Manitoba is Manitoba's third largest lake, covering an area of approximately 4,700 km^2 (1,810 mi^2). The lake receives inflows from the Waterhen River and numerous smaller tributaries. Its sole outflow is through the Fairford River, where water flows into Lake St. Martin. Lake Manitoba and Lake St. Martin have a long history of both high and low lake levels depending on the inflows, once largely determined by climate and weather conditions. Construction of the Fairford River water control structure in 1961 at the upstream end of the Fairford River allowed for control of the outflow from Lake Manitoba. Water control works included channel improvements which permitted a greater than natural outflow from the lake. The Fairford River water control structure was designed to regulate the water level on Lake Manitoba, and its enlarged capacity included consideration of the predicted increased inflows due to operation of the Portage Diversion. Its construction was further driven by a high water event in the mid-1950s, which caused significant damage to agricultural production around the lake.

Lake St. Martin is located downstream of, and receives the bulk of its inflow from, Lake Manitoba via the Fairford River. Lake St. Martin is approximately 345 km^2 (133 mi^2) in size with a generally low and swampy shoreline. The Dauphin River is the sole outflow from Lake St. Martin. It originates in the northeast corner of the lake and flows to Lake Winnipeg in Sturgeon Bay.

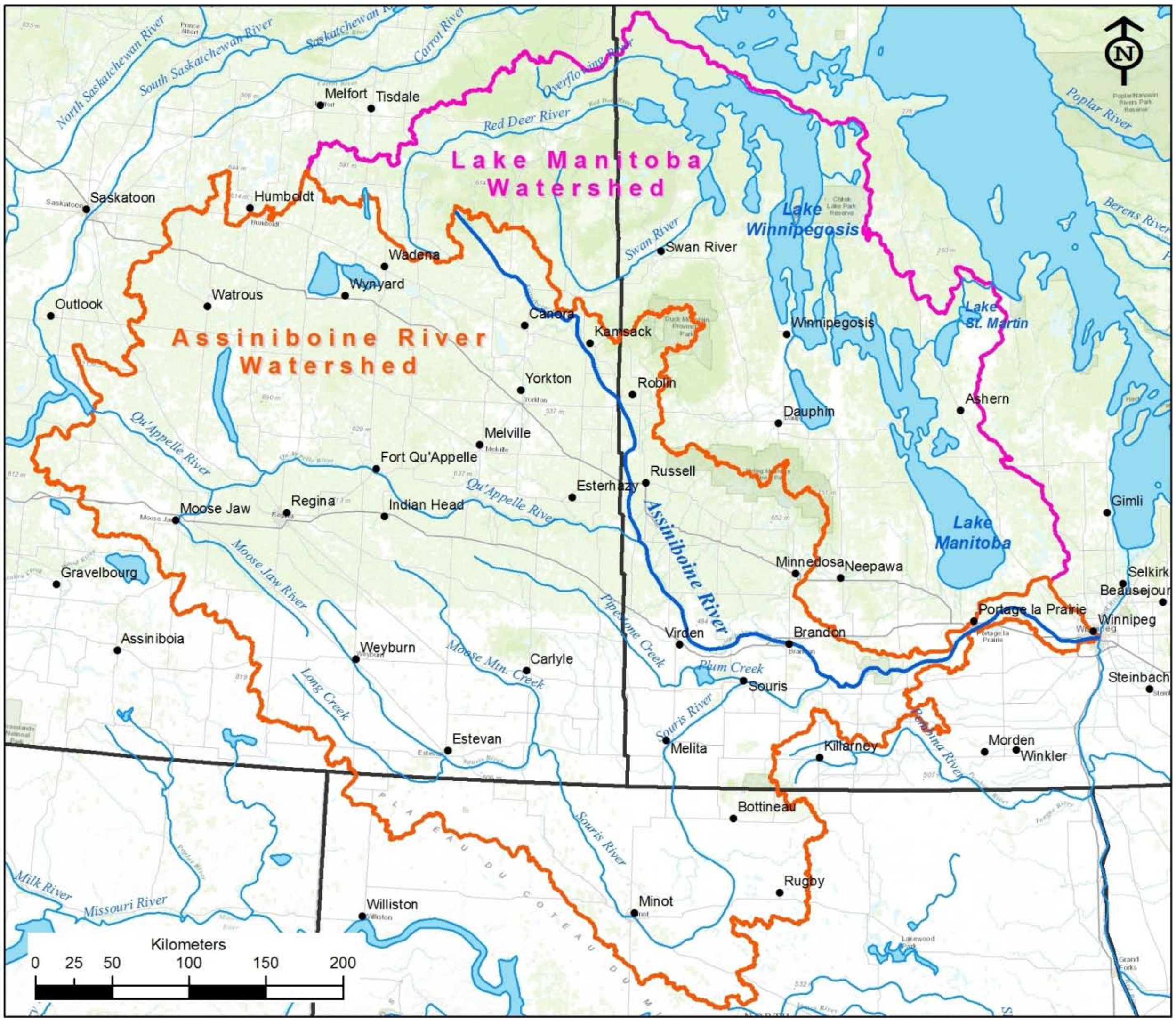

Figure 1: The Assiniboine River and Lake Manitoba basins.

The Province of Manitoba owns and operates a number of water control structures, such as dams and diversions, as well as flood protection structures such as community dikes. Many of these water control structures are operated in whole or in part to provide flood protection to communities and other interests. In 2011, the capacity of these structures to provide flood protection on both the Assiniboine River and Lake Manitoba was exceeded and a number of extraordinary measures were taken in order to provide flood protection where possible. However, in some areas such as around Lake Manitoba, extensive flooding did occur and the flood damage to homes, farms, businesses and infrastructure was significant. There is a perception among some people that the end result of the operation of provincial water control structures was that those living on the shores of Lake Manitoba were flooded artificially in order to save people and properties in other parts of the province.

The purpose of this report is to examine the 2011 flood events on Lake Manitoba, Lake St. Martin and the Assiniboine River, and also to examine how the flood events are linked. Given the unprecedented flooding that occurred on Lake Manitoba in 2011, this report will examine the causes of that flooding and also examine the question of whether and by how much Lake Manitoba was artificially high in 2011 as a result of the operation of provincial water control structures.

This report is presented in six chapters. Following this introduction, Chapter Two examines the geography and history of flooding on these water bodies and then provides an overview of the water control structures relating to these water bodies. Chapter Three examines regulated and unregulated water levels and discusses the concept of artificial flooding. Chapter Four reviews the flood events on Lake Manitoba, Lake St. Martin and the Assiniboine River in 2011. Chapter Five presents the analysis of regulated and unregulated lake water levels using the information presented on the inflows to and outflows from the lakes. Finally, Chapter Six summarizes the findings and provides a number of conclusions.

Where available, data in this report is based on final published hydrometric data from the Water Survey of Canada. Published data is considered more accurate than the real-time data that would have been available at the time of a flood event, as published data has been subject to technical review and a rigorous quality management process but it is often not available until many months or even years after a flood event. Other hydrometric data has been quality controlled, or in the case of wind-effect eliminated levels, calculated by provincial engineers. For clarity and consistency, the discharge and stage information in this report is presented in imperial units (with metric units in brackets). Distances and areas are reported in metric units (with imperial units in brackets).

2.0 Background

The lower Assiniboine River (downstream of Portage la Prairie) has an unusual geologic history, which is crucial to an understanding of the 2011 flood event and its consequences for Lake Manitoba. This chapter will provide an overview of the landscape and geologic history of the Assiniboine River, the Lake Manitoba and Lake St. Martin basins, and provide a summary of the recorded flood history.

2.1 Geography

At the close of the last ice age, as the ice sheet receded northward, the ice sheet released an immense volume of melt water, most of which flowed from the west into Lake Agassiz through large glacial spillways, which carved wide, deep valleys 30 to 60 metres (100 to 200 feet) below the level of the prairie. One of the largest of these spillways is now occupied by the Assiniboine River in the reach above Brandon. Most of its significant tributaries also flow within former spillways. This large melt water channel entered Lake Agassiz east of the present location of Brandon where it deposited the Assiniboine Delta, visible in dark grey between Brandon and Portage in Figure 2.

2.1.1 Assiniboine River

The Assiniboine River rises in eastern Saskatchewan on the upper prairie level above the Manitoba Escarpment. Within Manitoba, the Assiniboine River flows through three distinct zones, each with very different channel characteristics. Upstream of Brandon, the main stem of the river and its most important tributaries flow within a very large valley (spillway) cut by glacial melt water in the late stages of the last glaciation. The floor of this spillway valley provides a natural floodplain for the river and the valley provides a significant storage volume. This feature of the valley made the construction of the Shellmouth Dam near Russell both technically and economically viable. In this zone of the Assiniboine River, the major tributaries are the Qu'Appelle, Shell and Little Saskatchewan Rivers.

Between Brandon and Portage la Prairie, the river has eroded downward through sediments of the glacial Assiniboine Delta, a large delta formed where a glacial melt water channel emptied into glacial Lake Agassiz. The head of this delta was approximately at Brandon and its furthest eastern extent was just west of Portage la Prairie (see Figure 2 - the delta is visible as the dark grey area, labelled Glaciofluvial Sediment, between Brandon and Portage la Prairie). The Assiniboine River has cut a narrow valley through these sediments as it drops through a vertical distance of approximately 150 metres (492 feet) to the Lake Agassiz/Red River Plain (Figure 8). In this valley, the river is highly confined with a narrow valley floor. The Souris River is the primary tributary contributing flow to the Assiniboine in this reach.

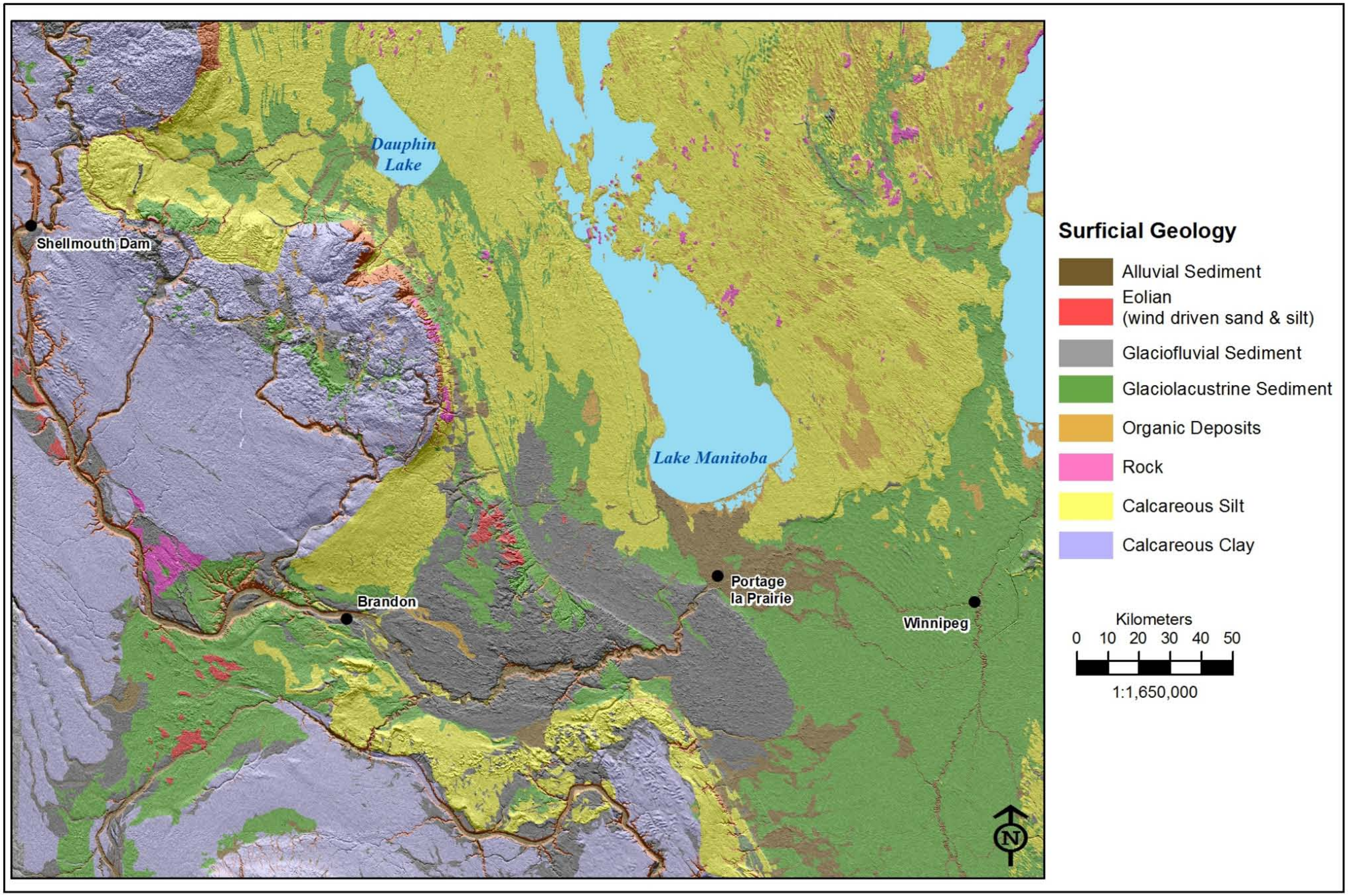

Figure 2: Surficial geology of Manitoba. The Assiniboine delta is visible as glaciofluvial sediment in dark grey between Brandon and Portage la Prairie, and the alluvial fan is visible in brown stretching to the north and east of Portage la Prairie.

Near Portage la Prairie, the river emerges from the confinement of the delta reach onto the relatively flat Lake Agassiz/Red River plain (the floor of former Glacial Lake Agassiz) and at this point it can flow in any direction within an arc of about 180° from roughly northwest to roughly southeast (see Figure 3). The slope of the river channel within the delta reach to the west is relatively high, so the river water velocities are relatively high and the waters of the river carry significant amounts of sediment. However, the slope of the land in the flat Lake Agassiz/Red River plain is much less, and so the velocity of the river water flowing over this plain is much lower. At slower speeds, the sediment-carrying capacity of the river waters as they flow over the plain is greatly reduced, and the sediments carried by the river waters as they flow through the delta reach are deposited onto the plain.

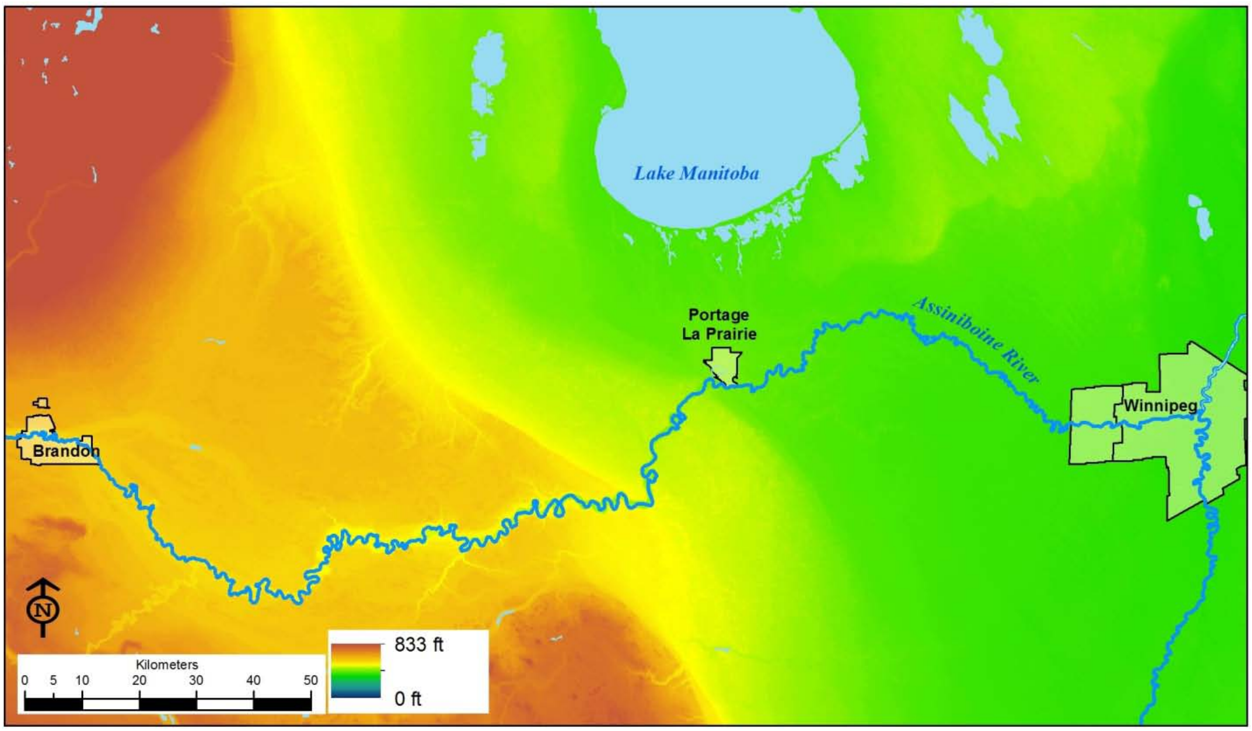

Figure 3: Land surface elevations of south-central Manitoba.

The deposition of sediment in this reach of the river results in the river building its channel into an alluvial ridge. The alluvial ridge is built from sediments deposited along the channel as levees and within the channel itself, a process which gradually elevates the channel above the adjacent terrain until the river is flowing along a ridge (rather than in a depression at the lowest elevations, which is the norm) (see Figure 4). It may be useful to visualize the alluvial ridge like a ramp that the river has built through deposition as it descends to the Lake Agassiz plain. In those portions of the alluvial ridge where the bed of the Assiniboine River (bottom of the river channel) is actually at a higher elevation than the surrounding prairie, it is sometimes referred to as a perched river. This is an inherently unstable situation and, if the natural levee is breached for some reason (perhaps during a large flood, bank collapse, ice jam, etc.), the flow will escape into the lower surrounding area and the channel downstream of the breach will be abandoned, usually permanently, in favour of another route through the lower terrain (see Figure 5). This process of sudden abandonment is called avulsion. Each avulsion is followed by the build-up of sediments along the new channel until it too has formed an alluvial ridge, which eventually leads to another avulsion episode.

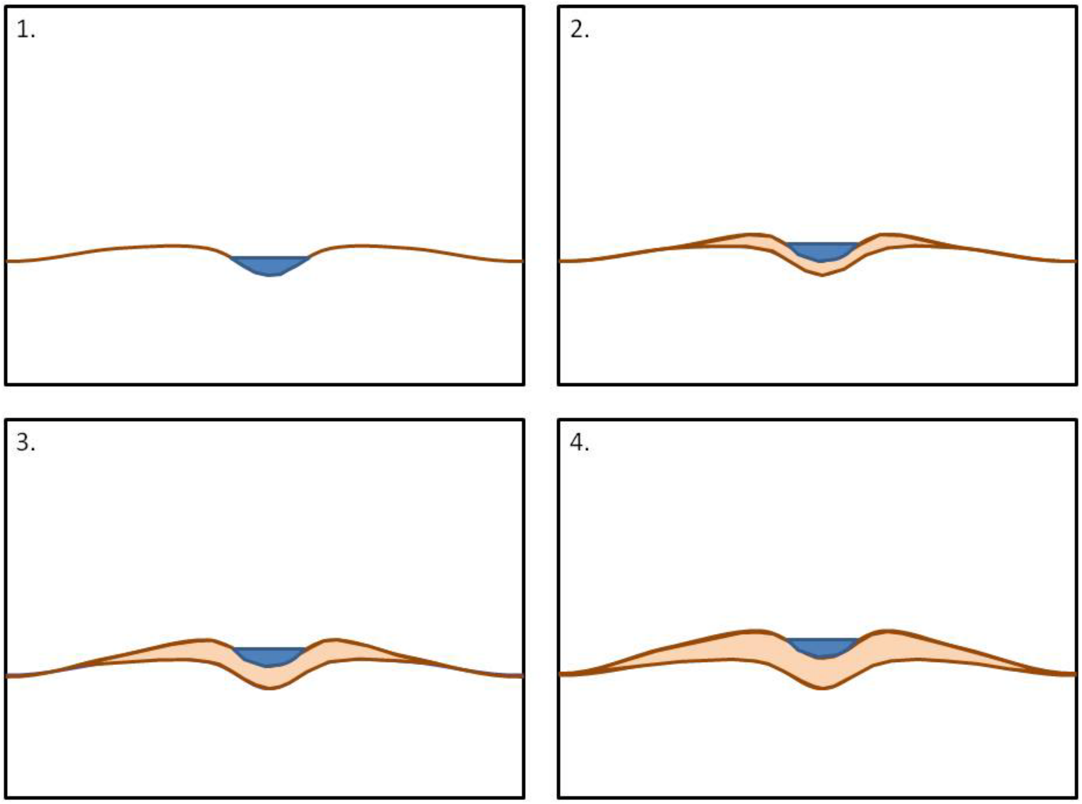

Figure 4: Formation of an alluvial ridge. Note that deposition builds up natural levees on each side of the stream as well as in the bed of the stream.

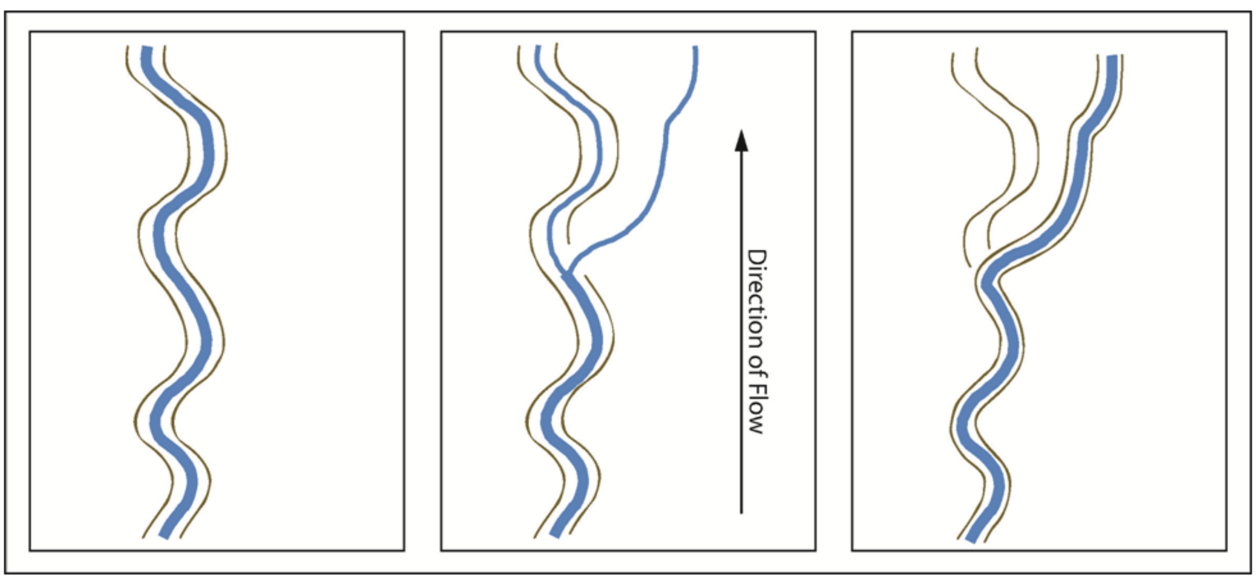

Figure 5: Sequence of events leading to avulsion on the alluvial fan. The top of the natural levees on the alluvial ridge are shown as the brown line next to the river.

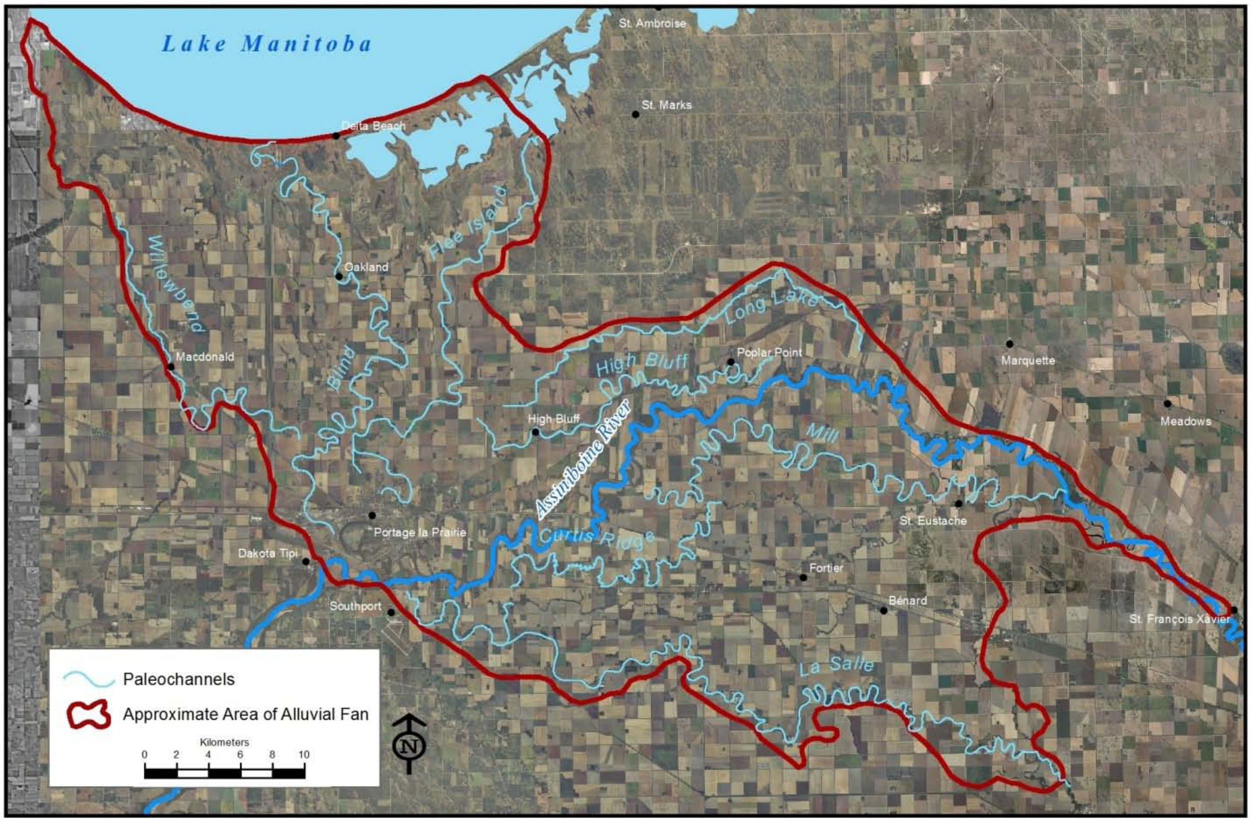

Figure 6: The alluvial fan and location of paleochannels in the lower Assiniboine River.

The repeated formation and abandonment of alluvial ridges has produced an alluvial fan, which radiates outwards from its apex southwest of Portage la Prairie at the point where the river leaves the Assiniboine Delta and enters the Lake Agassiz/Red River plain. The alluvial fan is an accumulation of sediment deposited by the river. The fan is thickest (that is highest) near Portage la Prairie and thins outward (down-fan) to the north, east and south. The extent of the alluvial fan along with many of the channels that formed the fan can be seen in Figure 6 above, and the alluvial fan is visible as the brown area north and east of Portage la Prairie in Figure 2.

Near the fan apex, the alluvial fan is a broad dome of sediment. Further downstream, the individual alluvial ridges become progressively more distinct and the fan consists of finger-like ridges separated by lower zones where the Lake Agassiz clay plain shows through (See Figure 7). Eventually the alluvial fan ends, beyond about 20 to 35 km (12-22 miles). From this point eastward, the topographic relationship between the river channel and the surrounding terrain is inverted into a more normal situation where the river channel is cut into the Lake Agassiz clays as a depression, which deepens as it approaches its junction with the Red River. A generalized profile of the Assiniboine River between Brandon and Winnipeg is shown in Figure 8.

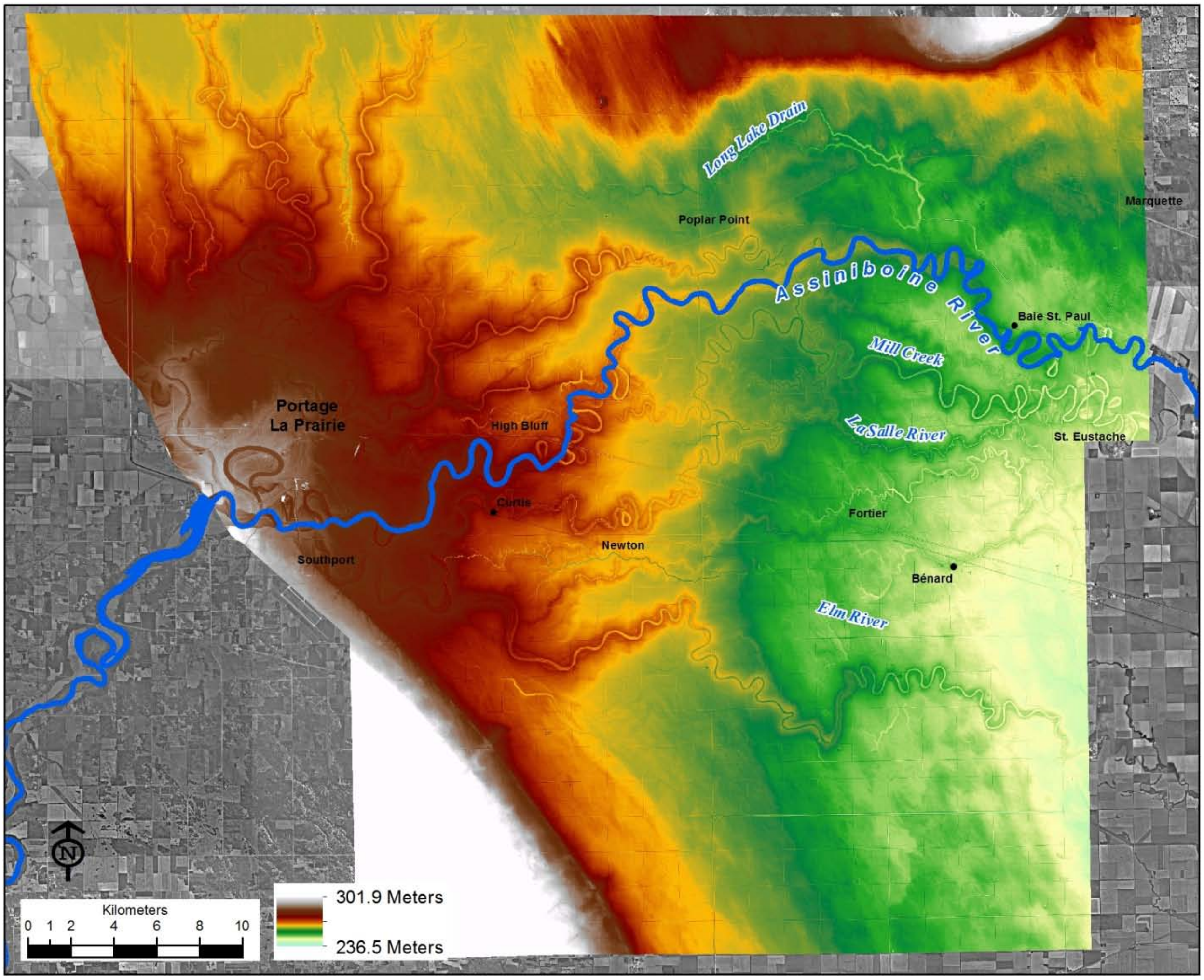

Figure 7: Land surface elevations of the Assiniboine River alluvial fan generated from LiDAR data. Many of the paleochannels are visible, along with the adjacent higher land formed by sediment deposition.

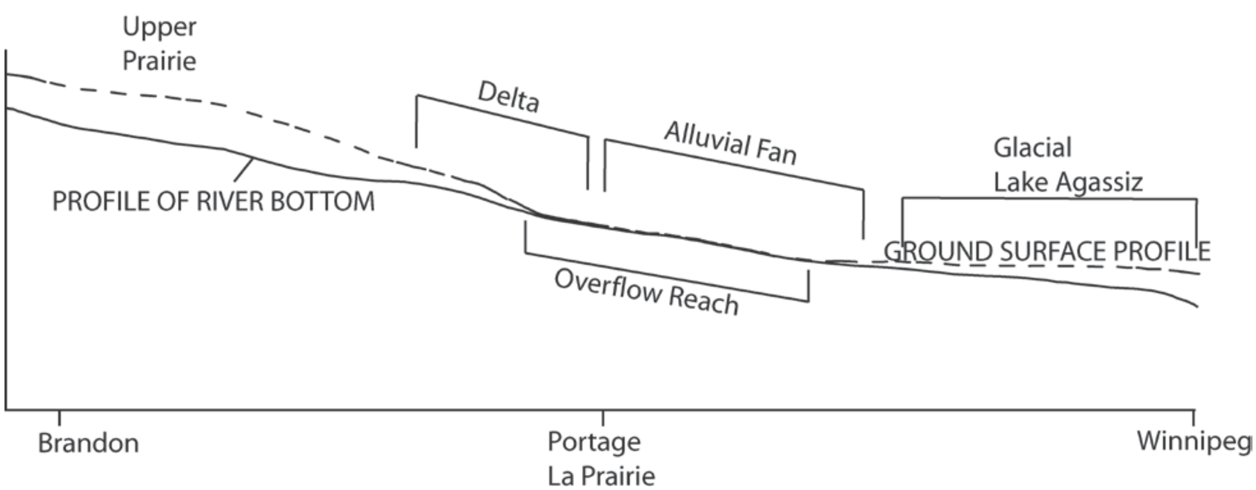

Figure 8: Generalized profile of the Assiniboine River to illustrate the topography and the major features, such as the Assiniboine Delta and the alluvial fan that the Assiniboine River crosses between Brandon and Winnipeg.

The abandoned paleochannels on the alluvial fan are often indistinguishable on the ground having been in-filled by centuries of sedimentation during floods. However, they are strikingly clear from the air (see Figure 9). Some of the paleochannels are now used by smaller streams; for example, the present LaSalle River flows eastward through a paleochannel of the Assiniboine River to join the Red River at St. Norbert.

Figure 9: Air photo showing the Assiniboine River on the left edge of the photo and Mill Creek paleochannel. North is oriented towards the top of the photo (Photo courtesy of Dr. Bill Rannie).

The evolution of these paleochannels over the past 7,000 years is shown schematically in Figure 10. The paleochannels divide into two groups: those which end in Lake Manitoba (Willowbend, Blind/Fort la Reine, Flee Island) and those which ultimately end in the Red River (current Assiniboine, LaSalle, Long Lake/High Bluff).

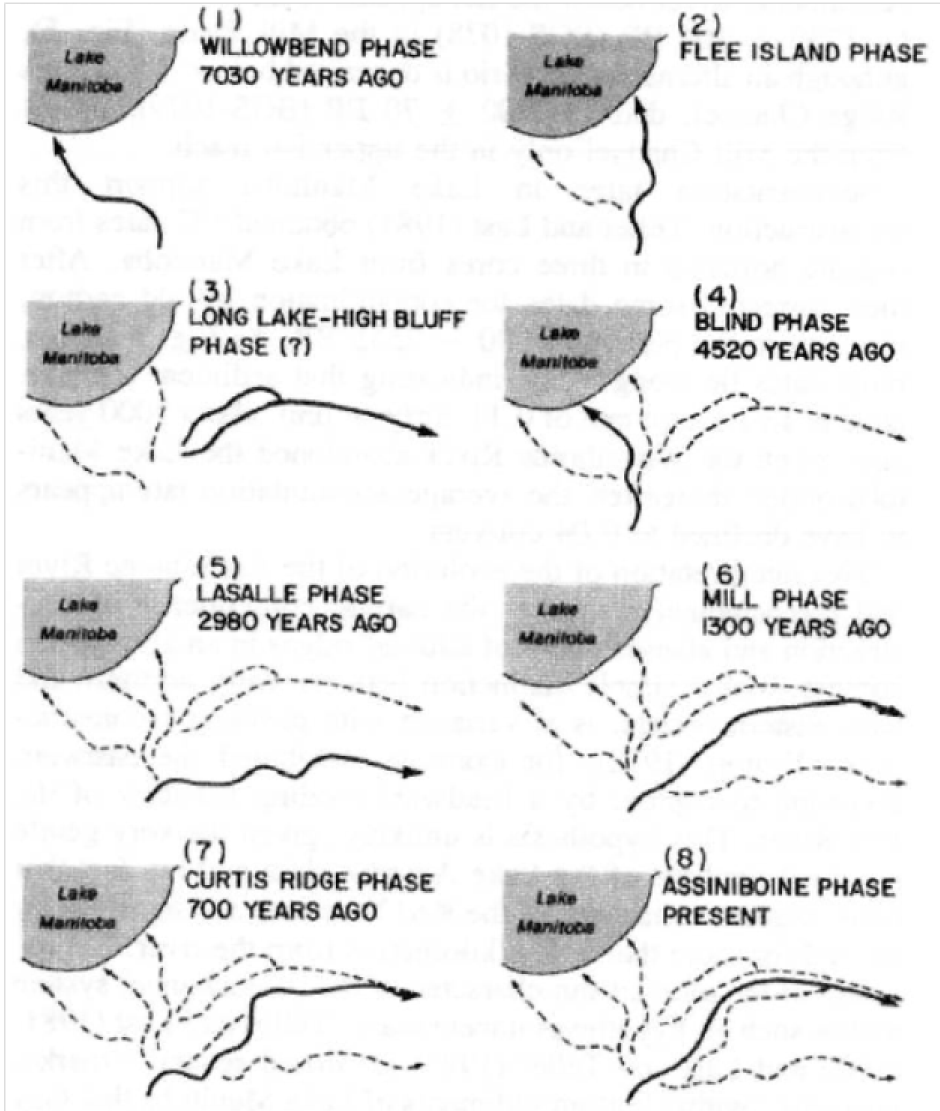

Figure 10: Sequence of paleochannel evolution of the Assiniboine River (Rannie, Thorleifson, & Teller, 1989)© 2008 Canadian Science Publishing or its licensors. Reproduced with permission.

The alluvial fan/paleochannel complex has several consequences for flow during the largest floods on the Assiniboine River. During large flood events, flows cannot be contained within the existing river channel and so flow overland and by paleochannels over the alluvial fan. The quantities and distribution of overflows will be explored in more detail later in the report, but it is useful to anticipate that discussion here.

- Under unregulated conditions, most overbank flow during large floods spreads away from the river and much of this flow may not return to the main river channel.
- Some of the overbank flow will travel overland away from the river, but a potentially large amount will follow one or more of the paleochannels.
- The paleochannels that flow to Lake Manitoba have the potential to convey some floodwater to the lake.

- Some of the overflow to the north could travel eastward via the Long Lake channel to ultimately rejoin the Assiniboine River further down the fan.
- Overflow to the south would either follow the La Salle Channel to join the Red River in south Winnipeg (inside the Floodway West Dike), or re-enter the main Assiniboine River channel further down the fan, perhaps along the Curtis Ridge/Mill Creek paleochannels.

It is also important to note that the present Assiniboine River channel is potentially unstable during the largest floods. In such large floods, the natural ridges/levees or man-made dikes would be breached. In such a situation, there is the potential for a new avulsion to occur, which could cause the river to relocate to a lower, but unpredictable, position (this scenario is discussed further in section 6.6).

2.1.2 Overflows from the Assiniboine River

One of the questions addressed in this report is what would have become of the water that would have overflowed the banks of the Assiniboine River under unregulated conditions? Based on information from historic records, Figure 11 below provides a general overview of the pattern that overflows from the Assiniboine River would be expected to follow. The blue arrows represent the flows in the present Assiniboine River Channel, while the green arrows represent overflows in paleochannels, or across the prairie. In general, overflows on the north side of the river would be expected from the vicinity of Portage la Prairie to approximately Baie St. Paul (see Figure 7 for location of High Bluff and Baie St. Paul), with a portion of the flows rejoining the Assiniboine River main channel. To the south, a large portion of the overflows would flow into the La Salle River watershed, a portion of the flows would make their way back into the Assiniboine River in the vicinity of St. Francois Xavier and a portion of the flows would follow the La Salle River to join the Red River upstream of Winnipeg. A portion of the flows would be stored on the floodplain, either in depressions or in the soil; some would flow north to Lake Manitoba via some of the old paleochannels (Prairie Farm Rehabilitation Administration, 1952) (Morris, 1955) (Rannie, 1990). The potential flows to Lake Manitoba will be examined more closely in sections 2.2.1 and 5.2.

Even prior to the large Assiniboine River flood of 1882, early explorers documented the linkages that existed between the Assiniboine River and Lake Manitoba. For example, Henry Youle Hind's *Narrative of the Canadian Red River Exploring Expedition of 1857 and of the Assiniboine and Saskatchewan Exploring Expedition of 1858* contains the following*:*

> "The name Prairie Portage is derived from the existence of a carrying place nine miles long, between this part of the Assiniboine and Lake Manitobah. It is stated by half-breeds at the settlement, that at seasons of extraordinary high water, canoes can approach each other from the Assiniboine and Lake Manitoba, so as to leave but a very short distance for the portage; and instances have occurred of water, during periods of high floods, flowing from the Assiniboine into Lake Manitoba by the valley of Rat River." (Hind, 1860, p. 184)

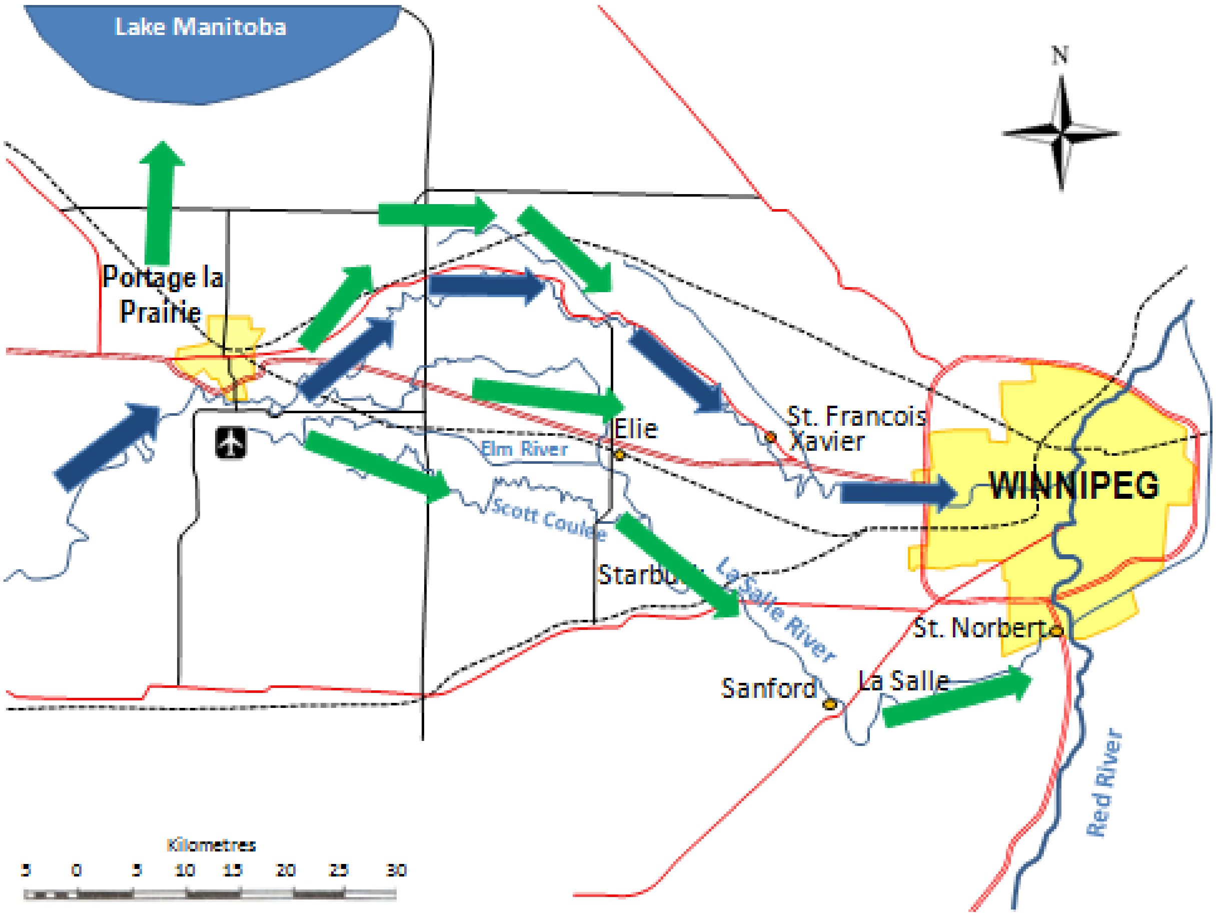

Figure 11: Schematic showing expected distribution of flows and overflows under unregulated conditions at the 2011 peak.

Man-made diking on the Assiniboine River has acted to prevent much of this overflow that would otherwise naturally occur under high flow conditions. The dikes on the Assiniboine River between Portage la Prairie and Headingley have been built over time by governments and private individuals, and are described in more detail in section 2.3.2. It is also important to note that the overflows, which used to occur to Lake Manitoba, originating southwest of Portage la Prairie, were closed off by a man-made embankment built in 1936 (Morris, 1955).

2.1.3 Lake Manitoba

Lake Manitoba is the third largest lake in Manitoba, the thirteenth largest lake in North America (Last, 1984), and the 33rd largest lake in the world. It covers a surface area of approximately 4,700 km^2 (1,810 mi^2) and has approximately 915 km (569 mi) of shoreline (The Lake Manitoba Regulation Review Advisory Committee, 2003). The lake is approximately 225 km (140 mi) long from north to south and is naturally divided into north and south basins at Lake Manitoba Narrows, which is roughly the midpoint of the lake. The south basin is broad and shallow with a silty lake bottom and with gently sloping shorelines, which are primarily sand and clay. In contrast, the north basin shoreline is more irregular and exposed bedrock is prominent along the shore and on the lake bed (The Lake Manitoba Regulation Review Advisory Committee, 2003).

The Lake Manitoba watershed of approximately 79,000 km^2 (30,500 mi^2) covers a large portion of western Manitoba and extends into eastern Saskatchewan (see Figure 1). The majority of the watershed drains first into Lake Winnipegosis, and then into the Waterhen River, the largest source of inflow into Lake Manitoba. The only other significant tributary of Lake Manitoba is the Whitemud River, which drains the lands east and southeast of Riding Mountain and flows into the southwest corner of Lake Manitoba.

The sole point of outflow from Lake Manitoba, under recorded water levels, is the Fairford River. From the lake, flows on the Fairford River reach Lake Pineimuta, then Lake St. Martin. The construction and operation of the Fairford River water control structure is detailed in section 2.3.4. This water control structure has served to regulate the water levels on Lake Manitoba since 1961, narrowing the range of high and low water events.

2.1.4 Lake St. Martin

As described above, Lake St. Martin is located downstream of Lake Manitoba and receives the bulk of its inflow from the Fairford River. The lake is made up of two shallow basins. The larger basin is located upstream and receives inflow from the Fairford River. The smaller basin is located to the northeast and connected by a narrow portion of the lake. The Dauphin River, which originates at the northeast corner of Lake St. Martin, is the sole natural outlet from Lake St. Martin. The Dauphin River flows downstream to enter Lake Winnipeg in Sturgeon Bay. There is an elevation change of 12 feet (3.65 m) between Lake Manitoba and Lake St Martin, and a further 85-foot (25.9 m) difference between Lake St. Martin and Lake Winnipeg. The Dauphin River has a limited outflow capacity, which can be further reduced during the winter, as the river is prone to developing frazil ice. The frazil ice can cause hanging ice dams, which further restrict flows.

The lake has a total surface area of approximately 345 km^2 (133 mi^2) with about 260 km (162 mi) of shoreline (The Manitoba Water Commission, 1978). The shoreline around Lake St. Martin is generally low, except for a gravel ridge located along the east shore of the south bay (The Lake Manitoba Regulation Review Advisory Committee, 2003). Early explorers in the area also noted that the area around Lake St. Martin and on the Dauphin River was “flat and swampy country” (Hind, 1860).

As described in section 2.3.4, the outflows from Lake Manitoba have been regulated since the Fairford River water control structure was constructed in 1961. Regulation has had a significant effect on Lake St. Martin. When Lake Manitoba is high, Lake St. Martin receives higher than natural inflows and when the Lake Manitoba is low, Lake St. Martin receives lower than natural inflows. It is important to note that the surface area and volume of water on Lake St. Martin is significantly less than that of Lake Manitoba, meaning that high inflows from Lake Manitoba result in large increases in water level on Lake St. Martin. The greater fluctuations in water levels combined with the low and swampy shorelines around Lake St. Martin has resulted in more frequent flooding on Lake St. Martin since regulation of Lake Manitoba began.

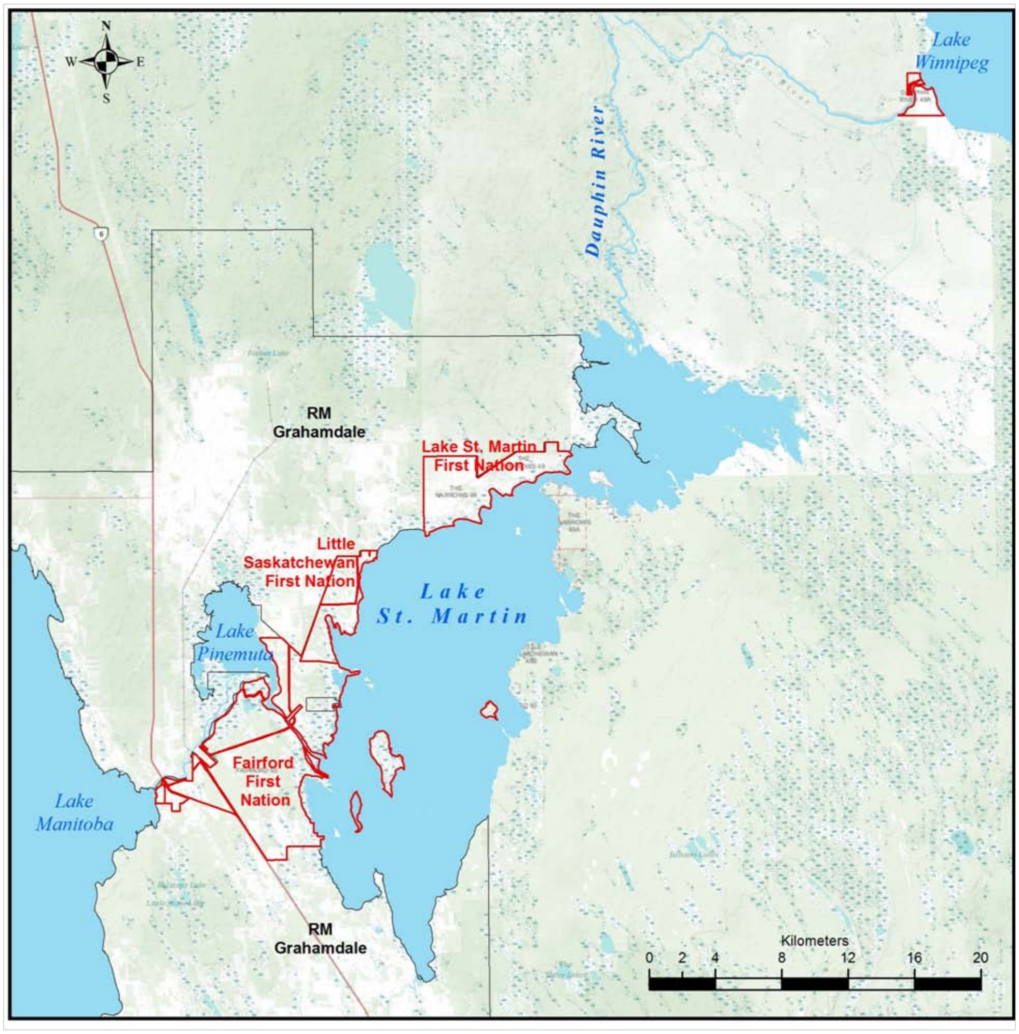

Figure 12: Fairford River, Lake St. Martin, and Dauphin River.

2.2 History of Flood Events

A review of historic flood events is important, as it illustrates the magnitude of past flood events and the impacts due to flooding. Depending on the timing of flood events relative to the construction of water control infrastructure, past flood events can also provide an improved understanding of the benefit that water control works and flood protection infrastructure provide in mitigating the impact of flood events.

2.2.1 1881-1882 Flood Event – linkage of the Assiniboine River and Lake Manitoba

Although the flood event that occurred in 1881-1882 happened before there were any recorded measurements of stream flow or lake levels, it is one of the most critical floods to examine in order to gain an appreciation of unregulated conditions and the linkages that exist between the Assiniboine River and Lake Manitoba.

Descriptions of the flood of 1882 exist in numerous sources. In fact, most indications are that both Lake Manitoba and the Assiniboine River were actually under flood conditions in the summer and fall of 1881 with renewed flooding occurring during the spring freshet of 1882 (Archives of Manitoba, Sessional Papers, GR 1565, Committee Report of the Manitoba Legislative Assembly, 1884). Unfortunately, little to no record of measured stages or discharge exists to be able to quantify the actual magnitude of the flood. As part of its 1952 Report on Conservation and Flood Control on the Assiniboine River, the Prairie Farm Rehabilitation Administration used observations of peak river stages to attempt to calculate peak discharges.

Table 1: Comparison of estimated 1882 peak flows and 2011 peak flows on the Assiniboine River.

	1882 Estimated Peak Flow	**2011 Peak Flow**	
		Recorded	**Unregulated**
Brandon	43,000 cfs (1,220 cms)	36,700 cfs (1,040 cms)	45,100 cfs (1,280 cms)
Portage la Prairie	Not available	53,100 cfs (1,500 cms)	64, 200 cfs (1,820 cms)
Headingley	32,000 cfs (906 cms)	19,200 cfs (544 cms)	Not available

Note: 1882 peak flows were estimated by the Prairie Farm Rehabilitation Administration (Prairie Farm Rehabilitation Administration, 1952b)

Although agricultural settlement in the area between Portage la Prairie and Winnipeg was still developing in 1882, the extent of damages was significant enough that the Manitoba Legislative Assembly struck a committee in 1884 to study the 1882 overflow of the Assiniboine River and Lake Manitoba. The committee heard testimony from experts such as engineers and officials from the Dominion Land Survey as well as from farmers and landowners who experienced, and were affected by, the flood event. According to accounts from a number of individuals, the flood actually began in 1881 when the Assiniboine River overflowed its banks and water levels peaked as late as June 30, 1881, at Poplar Point (Archives of Manitoba, Sessional Papers, GR 1565, Committee Report of the Manitoba Legislative Assembly, 1884). By all accounts the flood on the Assiniboine River in 1882 was even higher than that of 1881. Daily accounts from the Manitoba Free Press, precursor to the modern Winnipeg Free Press, from late April to mid-May 1882 chronicled the event on the Assiniboine River through the effect that the flood and overflow water had on railway infrastructure. The newspaper also chronicled some damage to farms and other consequences of the overflows. Some of the highlights from the Manitoba Free Press are included below and the full text is available through the Winnipeg Free Press Archives (http://archives.winnipegfreepress.com/Default.aspx).

> West of Red River the C.P.R. track is in a bad condition. At the Air Line Junction there are washouts of about 20 feet each, which have been blocked up. About three miles west of Winnipeg West, the water is running over the track and has washed out a little. Three quarters of a mile west of Portage la Prairie there is a bad washout.... A report was current yesterday that the Assiniboine had broken loose this side of the Portage, but a reference to our telegraphic

columns shows that the only trouble so far is at Sandy Point, a few miles west of the Portage, the water having overrun the farms in that vicinity. The rise in the Red River at this point yesterday was very slight (Manitoba Free Press, April 25, 1882).

From the Previous Day. The Portage la Prairie station agent telegraphed Tuesday night that the water had lowered two and a half feet in the Assiniboine there since morning, but that there was still a jam, which the town authorities had decided to blast. Between Portage la Prairie three feet of water was flowing across the track at several points, and considerable lengths of it had been washed away. Nothing can be done to repair the damage til the water gets off the track (Manitoba Free Press, April 27, 1882).

West of Red River the air line to Portage la Prairie is still mostly under water. As soon as this lowers a large force will be put on and the track raised out of flood's way. The comparatively small amount of work done on the air line has got it fairly into running shape. Ballast is being put in a lot of weak points and waterways are being cut. About three days more work will enable trains to make about 15 miles an hour. The washout about a mile west of Portage la Prairie having been fixed up the construction train pushed on towards Brandon, but has been ordered back, the track just west of the Portage being again badly washed (Manitoba Free Press, May 2, 1882).

Between Winnipeg and Portage la Prairie the old track by way of Stony Mountain is fast being got into better shape, a large quantity of ballast being put on the weaker spots. Owing to a fall in the Assiniboine the water running north across the track between Portage la Prairie and Burnside started to recede southward Monday night and made another bad washout, which will be fixed up by this morning.... A dispatch from Portage la Prairie, received at a (*illegible*) hour last night, said the water had again risen considerably in the Assiniboine and that a number of bad washouts had occurred on the C.P.R. between Portage la Prairie and Burnside. This is likely to continue the interruption of traffic for several days longer (Manitoba Free Press, May 3, 1882).

A DESPATCH from Portage la Prairie last night stated that the water had risen about ten feet above the usual level, but, had fallen ten inches yesterday. Another despatch, from Brandon was received to the effect that the water had fallen about one foot during the day. These facts, in conjunction with the additional fact that the water at this point had only risen about an inch: and a half during the day up to seven o'clock last evening, and that it was steadily sinking at Emerson, give reasonable ground for hope, that we may (*illegible*) witness a subsidence of the waters (Manitoba Free Press, May 5, 1882).

Superintendent Egan has returned to Winnipeg after a week's hard fight with washouts west of Portage la Prairie. He reports the line fixed through to Brandon so as to admit of the passage of trains. Between Portage la Prairie and Burnside there were three bad washouts, which have been piled and cribbed. The water has lowered two feet since Tuesday but is still running from

> the Assiniboine towards Lake Manitoba.... Between Winnipeg and Portage la Prairie the old main line is in fair condition and good time is being made on it. As soon as the water recedes from the air line a large force will be put on and it will be raised out of floods' way. At all points on the main line where washouts have occurred it is intended to put in trestle bridges, to avoid a recurrence of the difficulty (Manitoba Free Press, May 8, 1882).

Lake Manitoba was also very high during this period, likely the highest it has been in recorded history, and there are a number of accounts that, in the fall of 1881, water from Lake Manitoba began to overflow from the southeast corner of the lake, possibly down the Portage Creek, with the flows reaching the Assiniboine River. According to testimony given by Councillor Maxwell Wilton of High Bluff to a special committee of the Manitoba Legislature established to investigate the flood of 1882, the overflow from Lake Manitoba to the Assiniboine actually began in the fall of 1881: "The waters first came in from Lake Manitoba in the fall of 1881 gradually increased during the winter and finally reached the highest point about June in 1882" (Archives of Manitoba, Sessional Papers, GR 1565, Committee Report of the Manitoba Legislative Assembly, 1884). Although it may be difficult to believe that Lake Manitoba could rise high enough to flow back to the Assiniboine River, this event was further confirmed by Warren Upham in his 1890 *Report of Exploration of the Glacial Lake Agassiz in Manitoba:*

> Near the same time Lake Manitoba also reach its highest stage, about eight feet above its lowest level, rising until it overflowed southward across the east part of T. 13, R. 6, and thence eastward through the southern row of sections in T13, R. 5, falling ten feet in fifteen miles to Long Lake, through which old channel of the Assiniboine its waters were discharged into this river twenty miles east of Portage la Prairie (Upham, 1890, p. 24).

The overflow from Lake Manitoba joined with the overflow from the Assiniboine River in the vicinity of Long Lake and these combined overflow waters on the north side of the river eventually found their way back into the Assiniboine River in the vicinity of Headingley, though not before they caused significant damage to farms and crops in the area. According to Mr. John Garton, a farmer of Poplar Point, the overflows in 1881 flooded two thirds of the country south of the highway in the Parish of High Bluff, half the Parish of Poplar Point and the whole of the Parish of Baie St. Paul. A Councillor Wilton stated that, in High Bluff, the flood waters in 1882 averaged a foot in depth and were about two miles wide, and Mr. Robert Tait Warner of St. James gave evidence that the greater part of the Parishes of St. Francois Xavier and Headingley were under water and that the flood water in his neighbourhood reached a depth of up to 6 feet (Archives of Manitoba, Sessional Papers, GR 1565, Committee Report of the Manitoba Legislative Assembly, 1884).

There are also numerous accounts that the Assiniboine River overflowed its banks to the south, with the overflow waters finding their way to the Elm and La Salle Rivers and to swamps in the vicinity of Headingley, causing these streams to overflow and also causing considerable damage to the country south of the Assiniboine. Evidence provided by Mr. Dryden, Reeve of the Municipality of McDonald indicates that about half the land in his municipality was under water up to four feet deep and that the overflows from the La Salle River (fed by overflows from the Assiniboine) flowed by coulees into the Red

River with sufficient water to float a steamboat and that the overflows reached within four miles of the town of Morris (Archives of Manitoba, Sessional Papers, GR 1565, Committee Report of the Manitoba Legislative Assembly, 1884).

During the 1881-82 flood event, there were a number of accounts that document overflow from the Assiniboine River, although overflow from the Assiniboine River to Lake Manitoba was not given as much attention, possibly because it did not cause as much damage to agricultural production as the overflows further downstream which affected larger areas of cultivated land. Two of the best accounts of the overflow during the 1882 flood event are provided by William Murdoch in his 1884 report to the Minister of Public Works about the 1882 flood event, and by Warren Upham in his 1890 *Report of Exploration of the Glacial Lake Agassiz in Manitoba*.

From William Murdoch's *Measures to Restrain flooding along the Assiniboine River: Engineer's Report to the Minister of Public Works*, dated 8 April 1884:

> ... On Monday, the 17th of September, I started a small party to make the necessary measurements, under Chas Dancer, C.E., beginning at the Hudson's Bay Company's fort, which is where the first wash-out occurs, and which overflows yearly, causing great damage to valuable farms between the point of overflow and the Whitemud River, where the flood water finds its way into Lake Manitoba.
>
> Two years ago it washed out the heaviest bank on the Westbourne and North-Western Railway, causing a great deal of damage through the entire distance.
>
> The next low place is at Ogletree's farm, a mile below this point, which overflowed to some extent last year, but the principal wash-out occurs two miles below this point at what is known as Smith's saw mill, where some sheet piling has been put in which is altogether too low and ineffective in construction and extent. This is one of the principal points, and for a mile or more down the river, ought to be dealt with at once, together with three or four old drains which have been cut into the river, the bottoms of these are now on a level with low water; the consequence of which is that ordinary high water flows through them in the spring of the year and floods the country adjacent to such an extent that it has formed for itself channels where rolling land occurs washing it out on Evan's lot at the back of High Bluff, one hundred feet wide and fifteen feet deep; leaving from eight to thirteen feet of water in the cut, and cutting up and destroying whole farms and turning them into lakes, beginning on lot 65 High Bluff, running east to northeast two hundred feet wide in places and two miles long, leaving eight to ten feet of clear water without an outlet. At this point the country was overflowed to depth of six feet, and a distance of four miles from the river where the C.P.R. had a long piece of embankment washed away rendering the main highway impassable for fifteen to twenty miles, and unless the overflow from the river is stopped in the course of another year, a new channel from Portage la Prairie to the Baie St. Paul is inevitable for the Assiniboine River, and you can judge the severity of the flood the fact that all the houses along the river have been deserted. The action of the

water must have been terrific and appalling to the people, many cases close to their houses the earth being moved in huge masses and pit holes excavating huge rifts coming from different directions until they met in the grand wash-out a mile away from the river bank on high ground. The above describes the wash-outs on the north side of the Assiniboine River, and consequent effect on the country adjacent. (Archives of Manitoba, Sessional Papers, GR 1565, Report to the Minister of Public Works, 1884).

From Warren Upham's *Report of Exploration of the Glacial Lake Agassiz in Manitoba,* published in 1890 for the Geological and Natural History Survey of Canada:

> The highest floods of the Assiniboine at Portage la Prairie and along a considerable distance eastward rise only twelve to fifteen feet above its lowest stage, but they attain a height only a few feet below the highest portions of the adjoining country, much of which is submerged. At this extreme height, which the river reached and maintained from the 3rd to the 15th of May, 1882, the only time of such high water since 1860 or 1861, it overflowed near the former site of the fort of the Hudson's Bay Company two miles southwest of Portage la Prairie, and a portion of its flood passed north in shallow, winding water-courses to Lake Manitoba, making a descent of about forty feet in the distance of fifteen miles between the river and the lake (Upham, 1890, pp. 23-24).

Another account of overflows to Lake Manitoba during the flood of 1882 is provided in a letter to the editor of the Winnipeg Tribune from Mr. Henry J. Woodside, printed May 3, 1923. Mr. Woodside was a businessman, writer, journalist and photographer who worked with the Canadian Pacific Railway while they were constructing railways in Western Canada and from 1880-1898 he ran a number of businesses in Portage la Prairie.

> Western Floods
> To the Editor of The Tribune:
> Sir–People who are not acquainted with conditions in mid-Manitoba need not worry over the floods reported from there. These have usually recurred at about twenty year periods, and do little damage. The whole centre of the province was once the bed of Lake Agassiz, which accounts for its very rich soil. The banks of the Assiniboine River, a navigable stream, are low from Portage la Prairie eastward; the dense and valuable hardwood forests which once lined them for miles on each side have been cleared away. The Pigeon Lake country is merely an enlargement or overflow of the Assiniboine at the lowest level of land west of the Red River. It is a good grazing country with some farms, and in autumn is the home of myriads of fat wild ducks and geese.
>
> At Poplar Point, 18 miles east of Portage (which is 56 miles west of Winnipeg), the land rises westward over twenty miles, where it runs into the line north and south of sand hills, which was

> the ancient beach of Agassiz. Beyond that again, but above floods extends the rich flat plain toward Carberry and Brandon, cut by the valley of the Assiniboine and Souris rivers.
>
> At the latter city it is only the low bushy land along the river valley that becomes flooded, and that inhabitants move out temporarily. In 1882, when Brandon was founded at Grand Valley, two miles east of the present site, not long after and during the spring floods, seven feet of water was flowing through the streets of the balloon town. The hint was taken and the C.P.R. saw that the new city rose on the high and beautiful south bank of the Assiniboine.
>
> Prior to the early eighties, the Whitemud River country, south-west of, and the land south of Lake Manitoba were struggling each year with floods. "Bob" Watson, M.P. (now senator) (sic) secured government aid to canal the Waterhen River between Lakes Manitoba and Winnipeg, and with the assistance of provincial aid redeemed tens of thousands of acres of the richest soil in Manitoba for valuable crops.
>
> The famous Portage plains do not flood except in some slight depressions, and that temporarily. Just west of the city there is the deep bed of a former river running from the Assiniboine northward about 14 miles to Lake Manitoba. In 1882, when the main stream was in flood, I saw a river seven feet deep flowing rapidly across country to Lake Manitoba. On the Assiniboine a big stern wheel steamer loaded down with immigrants and agricultural machinery, was sweeping up the brimming river, the passengers undismayed, to find prosperous homes in the Brandon, Souris, Qu'Appelle and Pelly districts… (Winnipeg Tribune, May 3, 1923)

The significance of overflows from the Assiniboine River to Lake Manitoba will be explored in greater detail in section 5.0.

2.2.2 Other Assiniboine River Floods

1902

There is evidence that a significant flood event occurred on the Assiniboine River in 1902. However, there is not sufficient evidence available to help determine the magnitude or duration of the event. In its 1952 report, the Prairie Farm Rehabilitation Administration stated that this flood was caused by heavy rains in the latter part of June. The PFRA went on to use a reference from the Brandon Times of May 12, 1904 which stated that the "The flood of 1904 is 25 inches above the 1902 flood and 34 inches below the 1882 flood" to calculate a level of 1,178.3 feet (359.146 m) and a discharge of 24,700 cfs (700 cms) at Brandon, slightly higher than the peak flow of 1923 (Prairie Farm Rehabilitation Administration, 1952b).

1904

The flood event of 1904 appears to have been the highest that occurred since 1882 and, unlike that of 1902, it was associated with the spring freshet rather than summer rains. In its 1952 report, the Prairie Farm Rehabilitation Administration used the same reference from The Brandon Times to calculate a gauge height of 1,180.4 feet (340.888 m) and a discharge of 32,300 cfs (915 cms) at Brandon. A profile from the 1921 Manitoba Drainage Commission Report was used to estimate a peak gauge elevation of 774.5 feet (236.068 m) and a discharge of 27,800 cfs (787 cms) at Headingley (Prairie Farm Rehabilitation Administration, 1952b).

1922

The spring flood on the Assiniboine River was the largest runoff recorded since record-keeping began in 1912, and according to many accounts was the worst experienced since 1882 (Attwood, 1923). Atwood's report attributed the cause of the flood to significant precipitation in the fall of 1921 which saturated the soils and storage basins prior to freeze-up followed by significant snow and rain events in April of 1922; the long duration of the flood (the flooded area between Portage la Prairie and Headingley was underwater for four to five weeks) was attributed to heavy rains on the upper portion of the watershed in the first half of May (Attwood, 1923). In this year, the peak discharge at Brandon was recorded as 21,300 cfs (603 cms), and the peak discharge at Headingley was 19,300 cfs (547 cms). At Portage la Prairie, the river rose up 5.6 feet (1.71 m) above its normal level and the flow was recorded as 21,200 cfs (600 cms). It maintained these high levels for approximately seven days between May 9-15. The anomaly of the lower discharge further downstream was explained by the loss of water due to overflows – in the vicinity of Portage la Prairie the river overflowed its banks to the north, reaching Lake Manitoba and to the south reaching the La Salle River, while east of Portage la Prairie the river overflowed its north bank flooding twenty five miles of land to a width of two or three miles (Morris, 1955).

At this time, some diking of the river had been undertaken by private landowners and governments and the efforts to raise and maintain these dikes were successful in protecting lands on the south side of the river, east of Poplar Point (Attwood, 1923). With most of the overflow occurring to the north of the river, the end result was an estimated 10,100 hectares (25,000 acres) of land flooded between Portage and Headingley and the main Winnipeg-Portage highway being destroyed at many places; in some cases officials decided to blow sections of the road to allow flood waters to pass without destroying the entire length of road (Attwood, 1923).

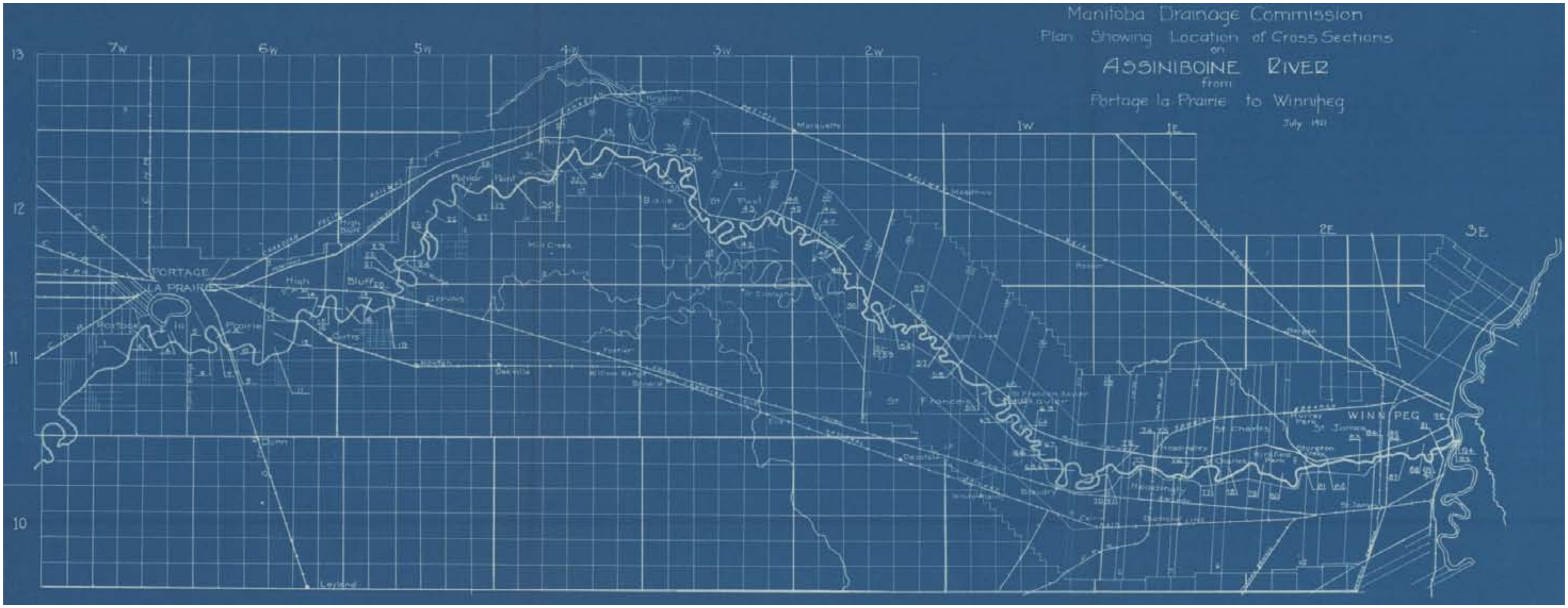

Figure 13: Map of the Assiniboine River between Portage la Prairie and Winnipeg (Manitoba Drainage Commission, 1921)

Figure 14: Photograph from 1922 showing the overflows from the Assiniboine River overtaking the Winnipeg-Portage highway – two miles east of Poplar Point (Attwood, 1923).

Figure 15: Photograph from 1922 showing blasting of the Winnipeg-Portage highway to allow flood waters to pass without destroying the entire length of road (Attwood, 1923).

Figure 16: Photograph from 1922. A hole was blasted in the Winnipeg-Portage highway two miles east of Poplar Point to pass waters north and prevent destruction of the entire road (Attwood, 1923).

Figure 17: Photograph from 1922, looking north from Winnipeg-Portage highway to Raeburn, from point two miles east of Poplar Point (Attwood, 1923).

Figure 18: Photograph from 1922 showing water flowing north under a bridge on the Winnipeg-Portage highway that was reported to be normally dry (Attwood, 1923).

1923

The flood in 1923 had two distinct peaks. The first peak occurred on April 21, caused by ice jams on the lower Assiniboine River that produced the highest peak levels at Portage la Prairie recorded to that time at over 858 feet (261.518 m) (see Figure 19). After the ice cleared, the second peak was slightly higher than that of 1922 although it occurred for a shorter period. It is reported that overland flow from the Assiniboine River occurred both to Lake Manitoba and to the La Salle River and that there was significant storage of water on the land, some of which eventually returned to the Assiniboine further downstream (Morris, 1955). The total amount of land flooded in 1923 has been estimated at approximately 70,900 hectares (175,000 acres) but a large part of this was due to melting snow and rain lying on saturated fields and being unable to run off because of blocked drainage ditches. The damage due to the flooding in this year was at least equal to that caused by the flood of 1922 (Morris, 1955).

1927

As shown in the hydrograph in Figure 19, in 1927 the Assiniboine River again experienced high flows although the waters did not reach the same height that they did in 1922 or 1923. The river peaked at Portage la Prairie at 851.3 feet (259.476 m) on May 13, although an earlier ice affected peak of 852.4 feet (259.812 m) was experienced on April 16. It is recorded that the dikes successfully prevented flooding on the south side of the river but that the river overflowed at a number of points on the north side of the river between High Bluff and Pigeon Lake, flooding an area to a maximum width of about one mile (Craig, 1927). Most of the water that overflowed to the north found its way back to the river, but the effect of the overflows was to reduce the peak discharge from 20,400 cfs (578 cms)at Portage la Prairie to 18,300 cfs (518 cms) at Headingley. There is no account of whether or not the river overflowed to Lake Manitoba in this year.

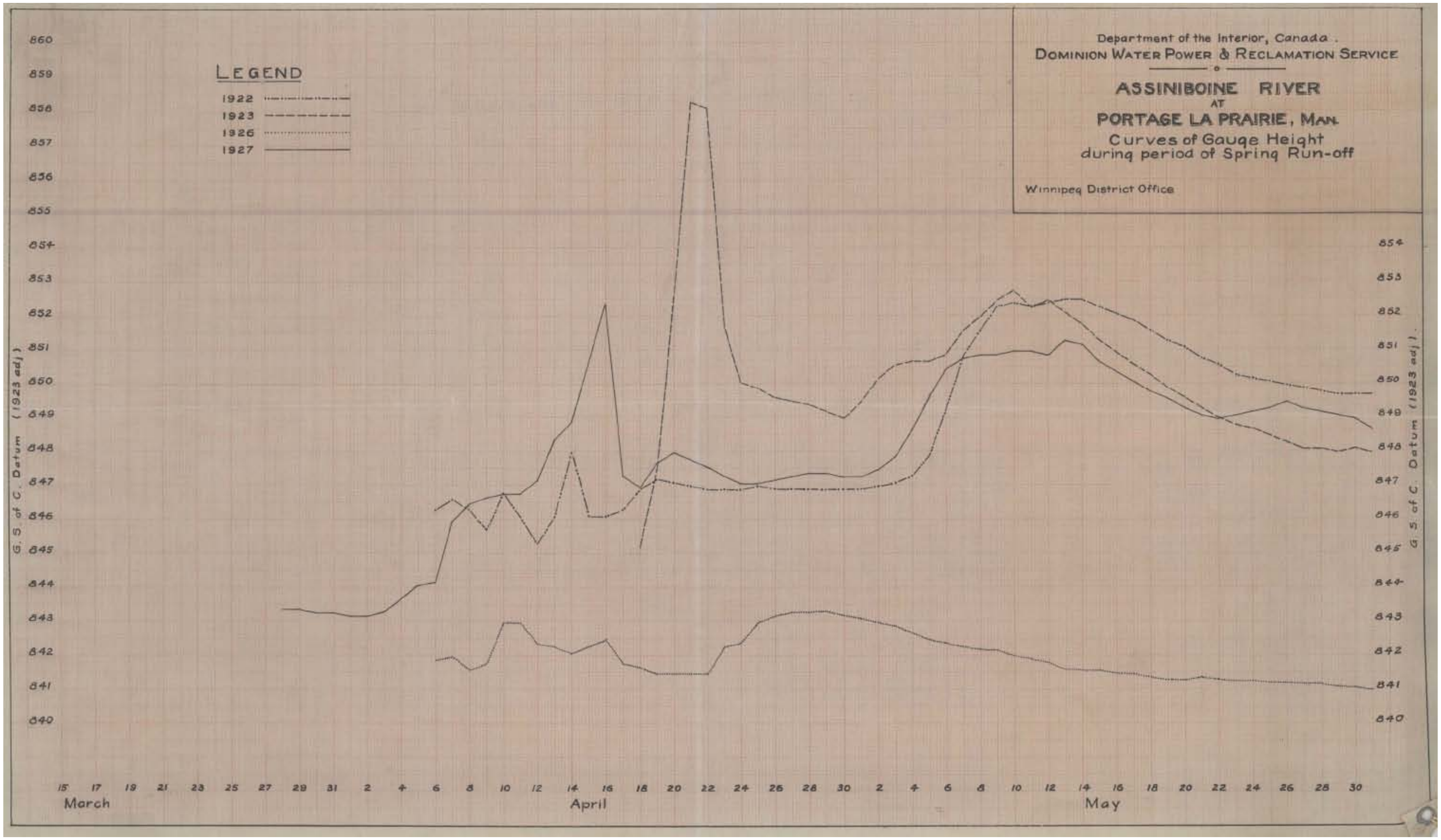

Figure 19: A hydrograph from a 1927 report showing gauge height at Portage la Prairie during spring runoff in 1922, 1923, 1926 and 1927 (Craig, 1927).

1955

The flood of 1955 was a significant flood event and coincided with a period of high water on Lake Manitoba which is discussed below. After the break-up of ice on the river, an ice jam caused the water level at Portage la Prairie to peak at 858.6 feet (261.701 m) Overflows to the south which reached the La Salle River were recorded but no overflow to Lake Manitoba was reported (Morris, 1955). This is likely due to the fact that the natural overflow channel to Lake Manitoba had been closed by construction of an embankment in 1936 which has prevented any flow to Lake Manitoba since that time (Morris, 1955). The open water peak, which occurred later in May, would reach 22,200 cfs (629 cms) at Portage la Prairie (see Figure 20) and only 17,000 cfs (481 cms) at Headingley, owing to the loss and storage of large volumes of water to the north and south of the river.

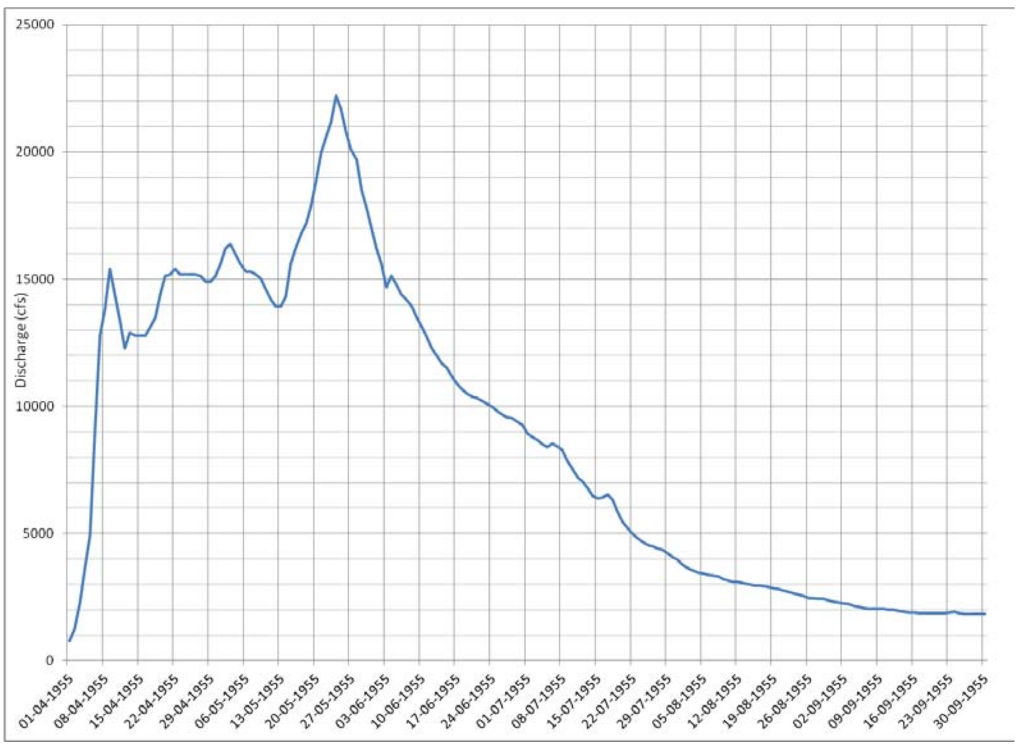

Figure 20: Daily discharge at Portage la Prairie, April - Sept 1955.

During the 1955 flood event, water overflowed the banks of the Assiniboine River to both the north and south as shown in Figure 21. The overflows to the south of the river were particularly acute, with one break-out point widening to 1,400 feet (426 m) in length and allowing up to 25 percent of the Assiniboine’s discharge to flow south, flooding a large area and allowing a portion of the overflow to reach the La Salle River (Morris, 1955).

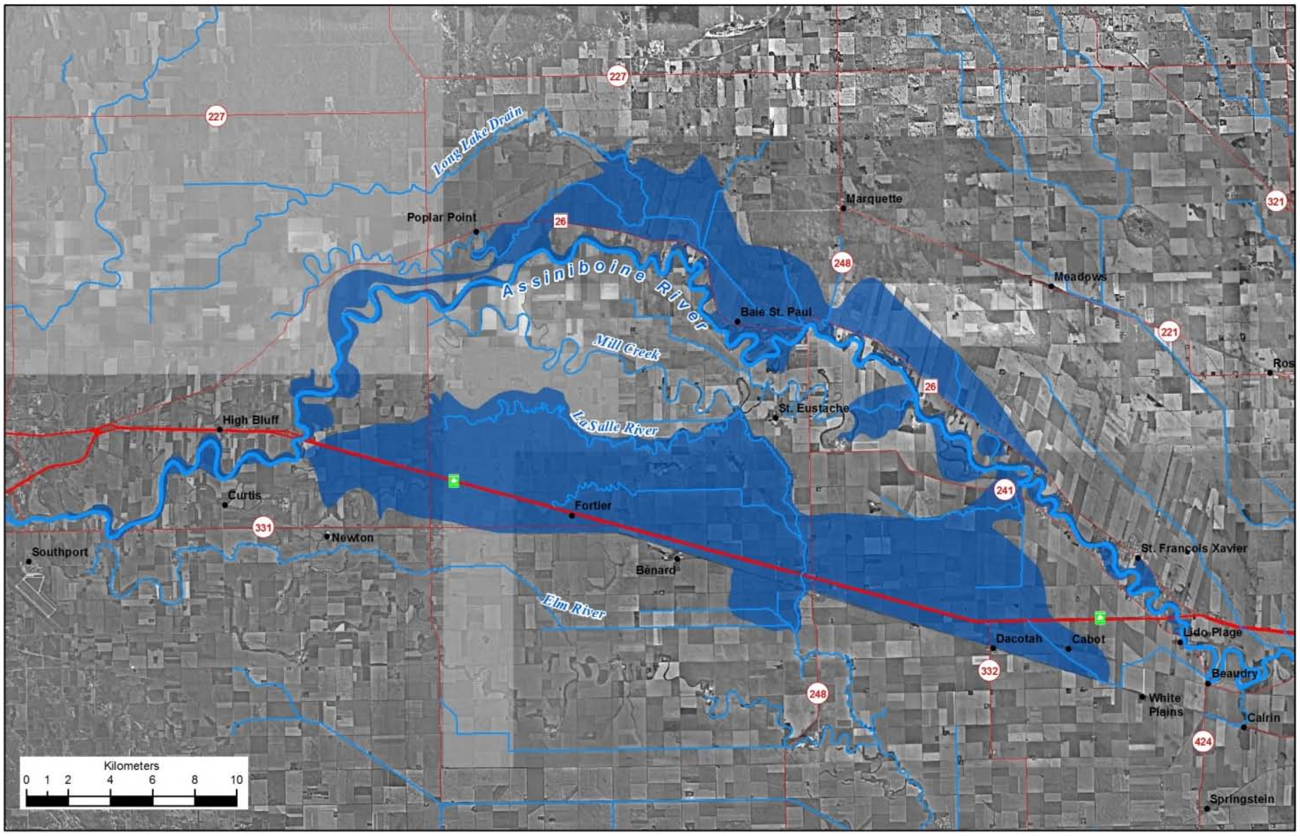

Figure 21: The extent of flooding on the lower Assiniboine River in 1955.

1976

The flood of 1976 was, until 2011, the largest flood event on the Assiniboine River in living memory. This flood developed as a consequence of a larger than normal snowpack (300 to 400 percent of normal snow-water equivalent in the Souris Basin and 200 to 300 percent of normal in the Assiniboine Basin), a very sudden snowmelt, high soil moisture levels, and frost conditions preceding break-up. This resulted in high runoff on the Assiniboine River and extremely high flows on the Souris River (Long, 1976). The contributions from the upper portion of the Assiniboine basin in 1976 was significant in absolute terms but the flood event was dominated by conditions in the Souris River basin which alone produced discharge larger than had been recorded on the Assiniboine River prior to 1974 (Rannie, 2001).

Flow on the Souris River peaked at 26,200 cfs (742 cms) at Wawanesa; the high water levels and fast-flowing water caused extensive damage to communities, farms and infrastructure, and also caused severe erosion. The Assiniboine River was in flood stage in its upper reaches, but downstream of the point where the river joined the Assiniboine River, the flow was even higher, reaching a peak flow of approximately 49,000 cfs (1390 cms) above Portage la Prairie. The Portage Diversion was used above its design capacity in 1976, diverting a peak of up to 26,000 cfs (736 cms) to Lake Manitoba, and with flows at or near capacity for a period of seven days in late April. The Assiniboine River dikes between Portage la Prairie and Winnipeg were reinforced and a peak flow of approximately 23,600 cfs (668 cms) was recorded at Southport and a peak flow of 22,000 cfs (623 cms) was recorded at Baie St. Paul. The use of the Portage Diversion combined with work to reinforce the Assiniboine dikes prevented major flooding from occurring between Portage la Prairie and Winnipeg.

<u>1995</u>

The flood of 1995 was one of the most significant floods on the Assiniboine River in recent years. Heavy rains in the summer and fall of 1994 and the resultant saturated soils were the preconditions that contributed to spring flooding. High runoff in the upstream portion of the Assiniboine River basin in late April 1995, particularly between Russell and Kamsack, resulted in the Shellmouth Reservoir filling rapidly. On April 24, the recorded flows at Kamsack were nearly twice as high as the previous record peak flows, which occurred in 1976 (see Figure 22). During the 1995 flood event the Shellmouth Reservoir reached its peak recorded water level on May 3 at 1,415 feet (431.292 m); in contrast, the 1976 recorded peak was 1,409.31feet (429.558 m). It was concluded at the time that the peak water levels in the Russell area would have exceeded records set in 1922, were it not for the operation of the Shellmouth Dam and Reservoir.

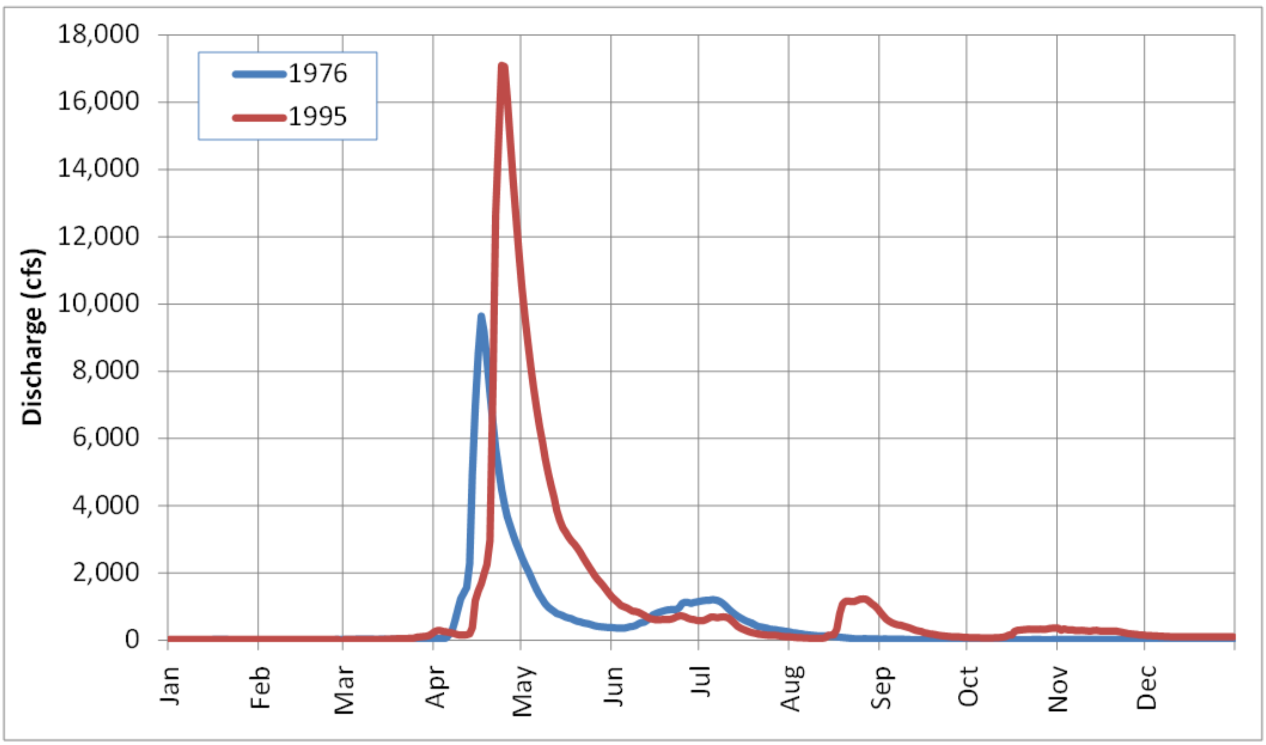

Figure 22: Hydrograph showing recorded flows on the Assiniboine River at Kamsack in 1976 and 1995.

In 1995 the Portage Diversion was operated for a total of 76 days from March 25 to June 9, to reduce flows downstream of Portage la Prairie. During this time a total volume of approximately 1,114,900 acre-feet (1,375,200 dam^3) flowed through the diversion into Lake Manitoba.

In conclusion, the historical evidence indicates that the Assiniboine River was likely in flood stages in 1881, 1882, 1902 and 1904 prior to the beginning of official records, and since official records have been kept, floods were recorded in 1913, 1916, 1922, 1923, 1927, 1948, 1954, 1955, 1974, 1976, and 1995

(Prairie Farm Rehabilitation Administration, 1952b) and (Morris, 1955). There is also evidence of large floods on the Assiniboine River in 1826, 1852 and 1861 (Rannie, 2001) although there is a paucity of information on these events.

2.2.3 Lake Manitoba Flood History

Pre-1915

It has long been recognized that water levels on Lake Manitoba are subject to the weather conditions in its larger basin, with wetter periods producing high lake levels and dry periods producing low lake levels. The earliest known period of high water was 1826. After this, until 1852, the water is said to have been low. The following is a list of observed periods of high and low water levels on Lake Manitoba taken from a letter written in 1914:

1826	High water
1852	High water
1858	High water
1874-5	High water
1881-2	Very high water
1888-9	Very low water
1897	High water
1901	Very low water
1902	Very high water
1908	High water
1915	Fairly high water

(Letter from L.R. Veligny, April 1914 printed in (Library and Archives Canada, Arthur Meighen Fonds, MG26-I, Vol. 43, Microfilm Reel C-3453,Dunn, T. H., 1915).

As discussed in section 2.2.1 above, Lake Manitoba experienced significant flooding in 1881-82. By some estimates the land around the south basin of the lake was flooded for a distance ranging from half a mile to six miles (Archives of Manitoba, Sessional Papers, GR 1565, Committee Report of the Manitoba Legislative Assembly, 1884). Although no measurements of the water level were taken during this period, there is evidence that suggests that the lake level during this flood event was higher than what was reached in 2011. It is well documented that the water level on Lake Manitoba in 1881-82 was so high that the lake began to overflow to the south, with the overflows travelling via the Long Lake system to join the Assiniboine River in the vicinity of Baie St. Paul. It has been estimated that overflows from Lake Manitoba to the Assiniboine River would require a water level of approximately 817 feet (249 m) (Last, 1984). Furthermore, a measurement of 14,835 cfs (420 cms) outflow from Lake Manitoba through the Fairford River was taken in 1881 (Library and Archives Canada, Arthur Meighen Fonds, MG26-I, Vol. 43, Microfilm Reel C-3453,Dunn, T. H., 1915). When this discharge value is compared to the rating curve for unregulated flows on the Fairford River, it would have taken a lake level of 817.5 feet (249.174 m) to produce that outflow. Finally, there is also a statement by Upham that during 1881-82 Lake Manitoba rose approximately eight feet above its lowest level. The lowest recorded levels on Lake Manitoba are at approximately 810 feet, so it is possible that the lake rose to nearly 818 feet during this flood event.

1954-56 Flood

Following a period of low lake levels in the 1930s and 1940s, Lake Manitoba experienced high water levels above 813 feet from mid-1953 to mid-1959, with the worst flooding occurring from 1954-1956 (see Figure 23). The water level on Lake Manitoba peaked in June, 1955, at approximately 816.6 feet (248.900 m), recorded at Delta (Lakes Winnipeg and Manitoba Board, 1958a). The flooding on Lake Manitoba in this period was largely due to prolonged high inflows on the Waterhen River, particularly during 1954 and 1955 (see Figure 24). Of note, water levels on Lake Manitoba remained above 814 feet (248.107 m) from mid-1954 until the end of 1957, in spite of the fact that inflows from the Waterhen River were lower in 1956 and 1957. The prolonged flooding on Lake Manitoba, even after the inflows returned to a more normal range, was due to the limited natural outflow capacity of the Fairford River.

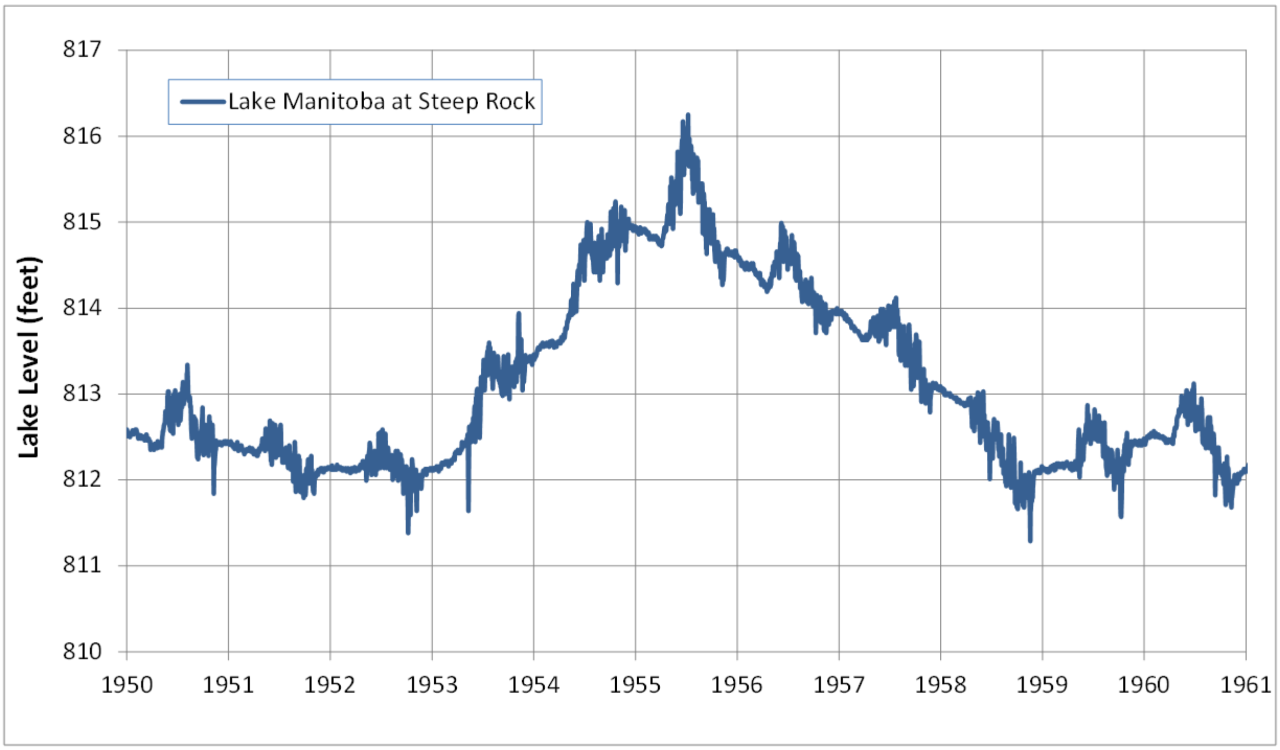

Figure 23: Recorded Lake Manitoba water levels at Steep Rock from 1950 to 1961.

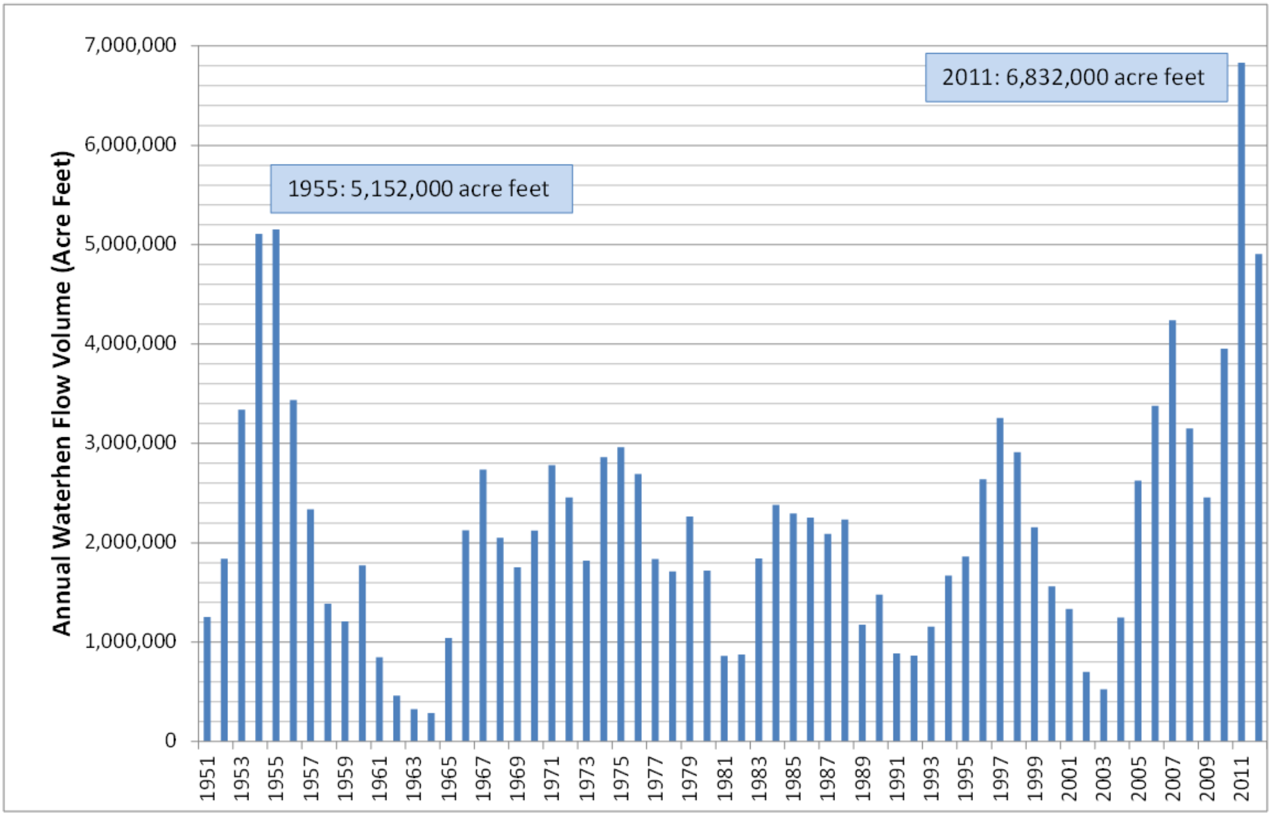

Figure 24: Annual flow volumes on the Waterhen River 1951-2012.

During the flood of the mid-1950s, farmers around the lake were generally the most affected, experiencing production losses as large tracts of land were flooded and meadows and pasture land reverted to marsh; in addition, cottage owners were flooded out, and fishermen and trappers complained of losses in production (Lakes Winnipeg and Manitoba Board, 1958a). For example, from 1954 to 1956 it was estimated that approximately 155,000 acres (62,800 hectares) of land were flooded, resulting in approximately $1.6 million of agricultural production losses in 1958 dollars (Lakes Winnipeg and Manitoba Board, 1958).

2.2.4 Lake St. Martin Flood History

Prior to the construction of the Fairford River water control structure, water levels on Lake Manitoba and Lake St. Martin exhibited a positive relationship, where the water levels on the two lakes would generally rise and fall together over the long term. For example, high inflows to Lake Manitoba would result in high lake levels which would in turn result in high outflows (inflows to Lake St. Martin). As a result, prior to 1961, flood years on Lake Manitoba would be common between Lake Manitoba and Lake St. Martin. As discussed in section 2.3.4, regulation of Lake Manitoba changed this relationship between water levels on the two lakes, meaning that flood conditions on one lake were no longer indicative of flooding on the other lake. In general though, since regulation began in 1961, if Lake Manitoba experienced flooding, Lake St. Martin also experienced flooding, although there are also some years when Lake Manitoba may have remained below flood stage while Lake St. Martin was above flood stage due to the high outflows from Lake Manitoba. In general, Lake St. Martin experiences a greater fluctuation in water levels and generally experiences higher water levels more frequently than it did before construction of the Fairford River water control structure.

There is little documentation of flood damages around Lake St. Martin during historic flood events. There are three First Nation communities located on Lake St. Martin and they have suffered the greatest effects of flooding on the lake. In general though, the area around Lake St. Martin is less inhabited and less intensively used than the land around Lake Manitoba, and flood events have not been subject to the same level of documentation and study. In short, damage did occur during past flood events, but historically less effort was expended to quantify this damage, as compared with other areas. This makes it more difficult to understand past flooding events, or the damages that were caused, from the vantage point of the present day.

2.3 Water Control Infrastructure

There are many water control works in place in southern Manitoba (see Figure 25). This section of the report provides background information on each of the major structures affecting flows and water levels in the Assiniboine River and Lake Manitoba basins, as well as information on the upgrades and some of the operational measures that were undertaken during, and in preparation for, the 2011 flood. Detailed descriptions of the operation of the major provincial flood control infrastructure are included in section 4.0 under the description of the 2011 flood event in each basin. Many of these, such as the Red River Floodway, Portage Diversion and Shellmouth Dam, were built in response to the devastating flood of 1950, which flooded the Red River Valley and the City of Winnipeg. Construction of the Red River Floodway was completed in 1968, and the Portage Diversion and Shellmouth Reservoir were completed in 1970 and 1972, respectively. The Assiniboine River dikes were built up over time by individuals and different government agencies in response to flood risks.

2.3.1 Shellmouth Dam

The Shellmouth Dam was built in a deep, wide portion of the Assiniboine Valley located approximately 24 km (15 miles) northwest of Russell. The reservoir created by the dam is approximately 56 km (35 miles) long and is commonly known as Lake of the Prairies. Construction of the dam began in 1964 and was completed in 1972 at a cost of $10.8 million. The structure includes a reinforced concrete, horseshoe-shaped conduit that allows a controlled release of water from the reservoir. During flood events, a portion of floodwater is stored in the reservoir. When reservoir levels are very high, uncontrolled flows can spill over the concrete chute spillway.

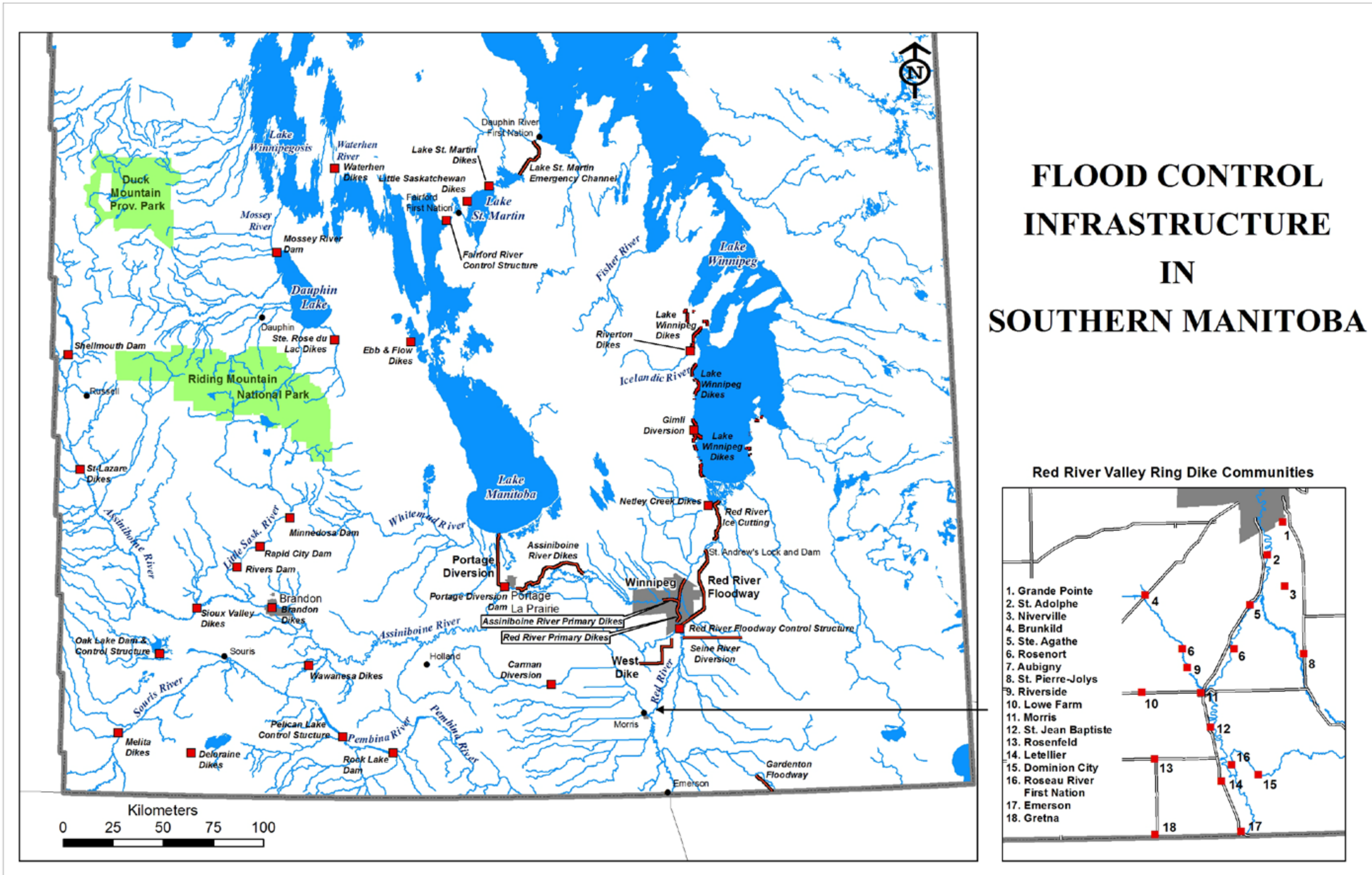

Figure 25: Map of flood control infrastructure in southern Manitoba.

Figure 26: An aerial view of the Shellmouth Dam looking upstream. The outlet for the conduit is on the right hand side of the photo and the spillway is on the left hand side of the photo.

The Shellmouth Dam was built to provide flood protection for the city of Winnipeg and to provide a stable water supply on the Assiniboine River. The secondary benefits from the dam included flood protection for the cities of Brandon and Portage, as well as other communities on the Assiniboine River. Since the dam was constructed, additional considerations such as instream flow needs and ecosystem requirements on both the river and the reservoir, as well as recreational interests on the Shellmouth Reservoir are included in the management regime for the structure.

Canada and Manitoba have jointly committed to a $14.0 million project to look at improvements to the dam, including installing gates on the concrete spillway. These gates would allow higher reservoir levels, providing improved flood protection and a larger potential water supply for domestic, commercial and irrigation use.

2.3.2 Assiniboine River Dikes

As described above, when the Assiniboine River descends through its alluvial fan, the river channel has a limited capacity in this reach, and high flows can result in widespread flooding once the water overtops the channel and spreads out across the relatively flat prairie. Unlike most infrastructure that is discussed in this section of the report, the Assiniboine River dikes were not built as a single project that was completed at one point in time. Instead, the dikes were built over a number of decades by a combination of different governments and private landowners.

Not long after rural settlement of Manitoba began in the late 19th century, flooding on the lower Assiniboine River damaged the communities and farms of early settlers. There is evidence that individual landowners began building dikes to protect their property as early as the late nineteenth century. The federal Department of Public Works first became involved in the construction of dikes on the Assiniboine River in 1913, and by 1940, nearly 116 km (72 miles) of dikes had been constructed (Stunden Bower, 2010). Responsibility for the Assiniboine dikes was transferred from the Department of Public Works to the Prairie Farm Rehabilitation Administration (PFRA) in 1950. Records from the time indicate that the dikes had not been built to a consistent flood protection level, but instead, were often built to local high water marks and at varying widths (Riesen, 1958). Between 1950 and 1958, PFRA undertook to raise and reinforce the dikes to provide a consistent design standard of 22,500 cfs (637 cms) channel capacity on the river (Riesen, 1958). In 1996, the federal government turned ownership and maintenance responsibility for the Assiniboine River dikes over to the provincial government. Following the 1997 flood, 18 sites on the Assiniboine River dikes were repaired, from 1997 to 2005, at a total cost of approximately $5 to $6 million.

The Assiniboine River dikes are built on each side of the river, presently consisting of approximately 77 km (48 miles) on the north bank and 71 km (44 miles) on the south bank of the river (a total of 148 km or 92 miles of dikes), starting just east of Portage la Prairie and extending downstream east of Baie St. Paul (see Figure 27). The dikes effectively increase the capacity of the Assiniboine River channel and, in conjunction with the Shellmouth Dam and the Portage Diversion, act to contain high flows on the Assiniboine River, thus preventing the river from overflowing its banks. The overflows on the north side of the river near Portage la Prairie would flow to Lake Manitoba. Overflows occurring to the north further downstream would enter the Long Lake system where they would cover a large area of land, with a portion of the Long Lake overflows re-entering the river between Baie St. Paul and Headingley. The dikes also prevent overflows to the south where they would enter the La Salle River watershed and flow overland as well as through creeks and paleochannels into the La Salle River before joining the Red River upstream of Winnipeg. Thus, the dikes act to protect farmland, farms and residences as well as the communities of Elie, Sanford, Starbuck and La Salle, on the La Salle River. A consequence of the dikes preventing the overflows that would have occurred under unregulated conditions is that higher flows occur on the Assiniboine River downstream (Prairie Farm Rehabilitation Administration, 1952c). In the past, some individuals recommended against constructing dikes on the river for fear of passing a greater portion of Assiniboine River flood flows down to Winnipeg (Attwood, 1923). This is because a portion of the overflows would have been lost to other watersheds, or gone into storage on the landscape. Although some of the overflows would have reached Winnipeg by rejoining the Assiniboine River, or by way of the La Salle River, the overall effect of the overflows from the Assiniboine River would have been to reduce flows downstream.

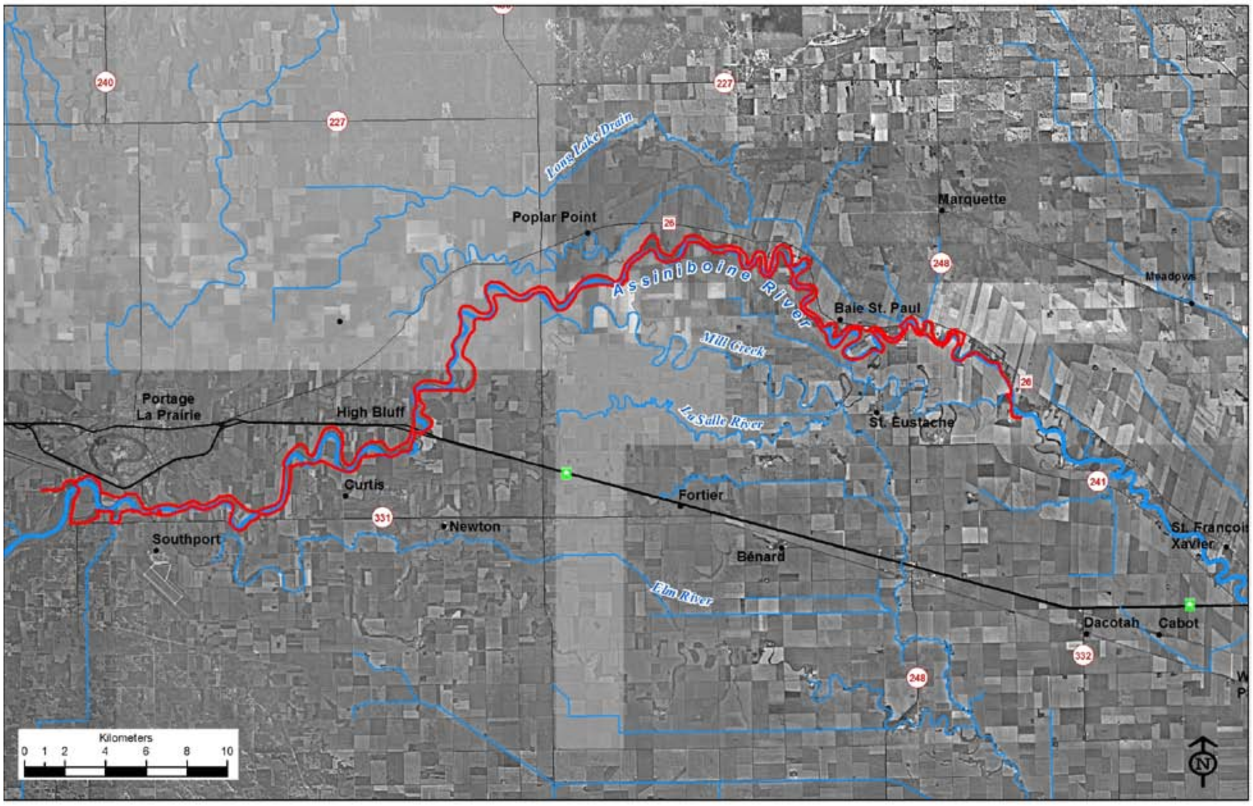

Figure 27: Provincial dikes (in red) along the Assiniboine River.

East of the provincial dikes, dikes have also been constructed along the river. These dikes are not provincial infrastructure but instead are privately owned. The private dikes are sometimes referred to as the CaSH dikes, named after the municipalities of Cartier, St. Francois Xavier and Headingley, where the dikes are located. It is significant to note that the CaSH dikes were also built by the federal government. The ownership and maintenance of these downstream dikes was left to the individual landowners rather than remaining with government. The reason for this apparent inconsistency has to do with the nature of the flood protection benefit that the dikes provide. The provincial dikes located between Portage la Prairie and just east of Baie St. Paul act to prevent overflows that would flood many communities in the La Salle River watershed, as well as potentially raising water levels in the City of Winnipeg. Downstream of that reach, any overflows that occurred were expected to affect local homes, businesses and agricultural land, but were not expected to reach the La Salle watershed. Thus, the dikes in the upstream reach were retained as publicly owned infrastructure because they were intended to provide a regional flood protection benefit, while the dikes further downstream were intended to provide a local flood protection benefit to land on or near the river.

It is generally accepted that the natural capacity of the Assiniboine River channel downstream of Portage la Prairie prior to construction of dikes was approximately 12,000 to 15,000 cfs (340 to 425 cms) (Mudry, MacKay, & Austford, 1981), although by some estimates, the original capacity of the Assiniboine River was less than 10,000 cfs (283 cms) (Prairie Farm Rehabilitation Administration, 1961). The construction of the Assiniboine River dikes increased the capacity of the Assiniboine River from Portage la Prairie downstream to just east of Baie St. Paul to approximately 22,500 cfs (637 cms). However, the experiences of the 1976 and 2011 floods showed that this design capacity could be achieved only under certain circumstances. Such circumstances included when dikes were still largely frozen so they had increased stability and minimal seepage; when high flow duration was relatively short, minimizing any seepage problems; and when emergency raising and reinforcement in some areas was undertaken.

In February 2011, Manitoba Infrastructure and Transportation raised and reinforced the Assiniboine River dikes as early flood forecasts indicated the potential for significant flooding on the Assiniboine River. Manitoba Infrastructure and Transportation hired engineering consultants to model the 1976 flows, and the Assiniboine River dikes were raised to provide two feet of freeboard on top of the levels reached in 1976. Approximately 80 km (50 miles) of dikes between Portage la Prairie and Winnipeg were raised in one month, moving 450,000 m^3 of earth. However, during the 2011 flood, the Assiniboine River dikes could not safely withstand the magnitude of flows seen during the 1976 flood. This was because of the later timing and long duration of the high flows in 2011. The dikes had remained largely frozen in 1976, but in 2011 the dikes were fully thawed and seepage and permeability problems were significant. The question of potential deposition in the river channel was explored, but the rating curve at Baie St. Paul was found to be similar between 2011 and previous flood years.

Flows on the Assiniboine River were increased gradually (in increments of 1,000 cfs (28.3 cms)) until they reached 18,000 cfs (510 cms) on May 2. Flows on the Assiniboine River were increased to 19,000 cfs (538 cms) on May 10, in anticipation of the first peak at Portage la Prairie, but by the evening of May 11, it was reported that the dikes on the Assiniboine River could not safely withstand the higher flows. The concern wasn’t that the dikes would be overtopped, as freeboard remained on the dikes (see Figure 28). The concern was that the water pressure on the relatively permeable dikes at flows above 18,000 cfs (510 cms) would have caused significant amounts of water to seep through or below the dikes, causing dike instability and potentially leading to a catastrophic, uncontrolled dike failure. Because of the magnitude of the impacts of an uncontrolled dike failure on communities and homes downstream of Portage la Prairie, flows on the river were reduced to 18,000 cfs (510 cms) by the morning of May 12. It should be noted that the Assiniboine River capacity in Winnipeg is well over 19,000 cfs (538 cms), so no significant issues would arise in Winnipeg if the dikes handled the same flows as in 1976.

Figure 28: Photograph of the Assiniboine River and dikes in the vicinity of Baie St. Paul, taken on May 15, 2011. Note that there is freeboard remaining on the dikes (they are not in danger of being overtopped).

2.3.3 Portage Diversion

The Portage Diversion is a 29 km (18 mile) long channel that diverts water from the Assiniboine River into Lake Manitoba. The diversion was designed to convey up to 25,000 cfs (708 cms) from the Assiniboine River in order to provide flood protection to Winnipeg, the areas along the Assiniboine River below Portage la Prairie, and along the Red River north of Winnipeg. The Portage Diversion was constructed from 1965 to 1970 at a cost of $20.5 million. The diversion project includes the diversion channel and dikes adjacent to the channel, two drop structures within the channel and one at the outlet of the channel into Lake Manitoba (to dissipate energy and manage water velocities). It also includes a realignment of part of the Assiniboine River main channel, a control structure at the entrance of the diversion channel, a river control structure within the Assiniboine River just downstream of the diversion channel and a small reservoir upstream of the river control structure. The last five kilometres of the diversion passes through Delta Marsh and this portion of the diversion channel has a lower capacity of only 15,000 cfs (425 cms). Any flows in excess of 15,000 cfs (425 cms) spill into the western section of Delta Marsh through a lower section of the west dike, known as the ‘fail-safe’ (Mudry, MacKay, & Austford, 1981).

Figure 29: An aerial photograph of the Portage Diversion during a flood event; the year is unknown. The Portage Reservoir is visible on the left edge of the photo, the diversion channel continues northward into the background of the photo, and the Assiniboine River flows off the right hand edge of the photo. Of note, a portion of the Blind (or Fort la Reine) paleochannel is visible downstream of the control structure on the river, running north from the highway into the background.

When a diversion from the Assiniboine River was being considered in the 1950s, a number of different configurations and sizes of diversion channel were investigated (see Figure 30). This included looking at different locations and configurations for the diversion channel; three different capacities of diversion channels, 10,000 cfs (283 cms), 25,000 cfs (708 cms), and 40,000 cfs (1,130 cms) were also considered (Prairie Farm Rehabilitation Administration, 1952d). The most obvious option for a diversion route was to use the Fort la Reine natural overflow channel, located just west of Portage la Prairie. Variations on this route, including a version with meander loops cut off and a constructed channel that ran straight north to Lake Manitoba, were also considered (see Figure 31). Diversion options downstream of Portage la Prairie were also considered, as they would have required fewer railway and highway bridges to be constructed across the diversion channel; however, if located east of the city the channel would not have provided flood protection to Portage la Prairie. One eastern option started at an old meander loop and ran to the Portage Creek; a second eastern option started even further downstream at High Bluff and ran to the Portage Creek. In the end, the Portage Diversion and its related infrastructure were constructed just west of the Fort la Reine channel options using a constructed channel to run straight north to Lake Manitoba.

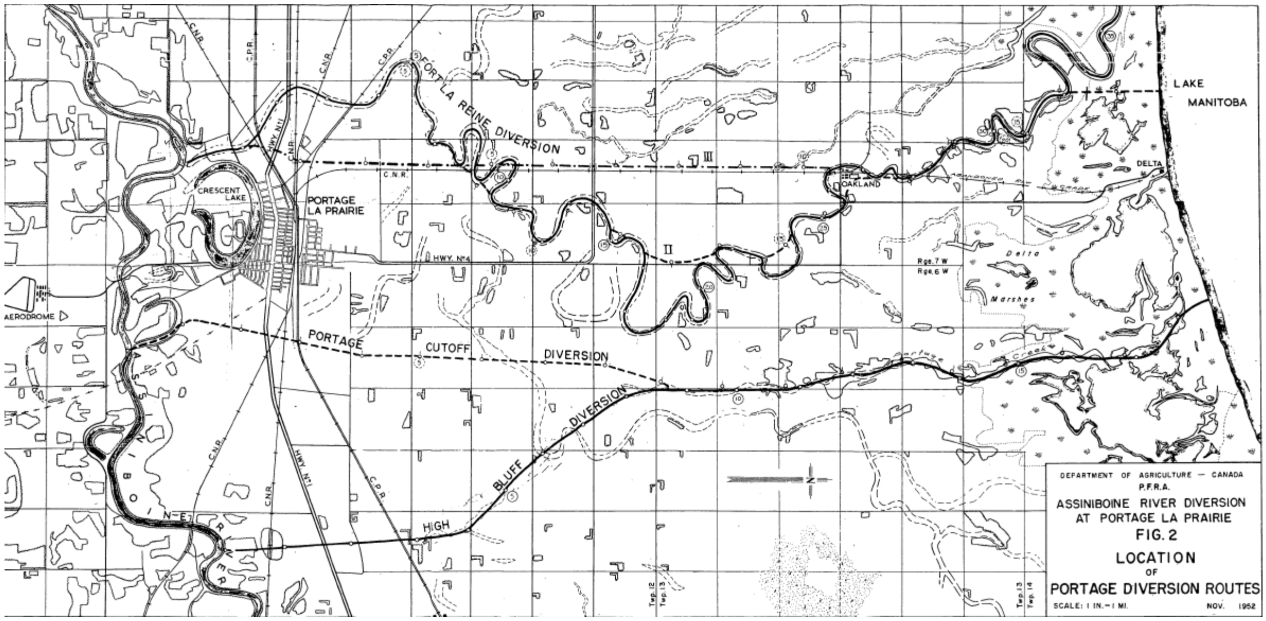

Figure 30: Map showing the routes considered for a diversion from the Assiniboine River to Lake Manitoba (Prairie Farm Rehabilitation Administration, 1952d)

The objectives guiding the operation of the Portage Diversion are listed below. These objectives are included in the Portage Diversion's operating guidelines (see Appendix B: Operating Guidelines for the Portage Diversion).

1. To provide maximum benefits to the City of Winnipeg and areas along the Assiniboine River downstream of Portage la Prairie.
2. To minimize ice jams forming along the Assiniboine River.
3. Not to increase the water level in Lake Manitoba beyond the maximum regulated level of 812.87 feet (247.76m), if possible.
4. Prevent overtopping of the failsafe section in the Portage Diversion, if possible.
   (Manitoba Water Resources Branch, 1984)

Early in the design of the Portage Diversion it was recognized that the diversion of flows to Lake Manitoba would raise water levels on the Lake and could effectively shift flooding from one area to another. Initially, three approaches to offset any effect from the Portage Diversion on Lake Manitoba were considered: negotiating flood easements on land around the lake, construction of dikes around the lake, and improvement of the outlet of Lake Manitoba (Prairie Farm Rehabilitation Administration, 1952d). Improving the outlet of Lake Manitoba was selected as the best option; the Fairford River water control structure is detailed below in section 2.3.4.

In 2011, the capacity of the Portage Diversion was temporarily increased to a design capacity of 34,000 cfs (963 cms) as it became clear that the forecasted Assiniboine River flows exceeded the combined flow capacity of the Assiniboine River Channel and the design capacity of the Portage Diversion. The operation of the Portage Diversion in 2011 is detailed in section 4.1.2.

2.3.4 Fairford River water control structure

The Fairford River is the natural outlet from Lake Manitoba, flowing into Lake Pineimuta and then on to Lake St. Martin; outflows from Lake St. Martin are conveyed by the Dauphin River to Lake Winnipeg. Construction of the Fairford River water control structure (FRWCS) was completed in 1961, consisting of a concrete stop-log control structure as well as excavation and enlargement of the natural river channel at the mouth of the channel from Lake Manitoba. The extent of excavation of the natural channel is shown in Figure 31. The excavation work was conducted not only on the river but also on the bed of Lake Manitoba itself, creating a deeper channel leading up to the river. The nature of these improvements has enabled regulation of Lake Manitoba within a narrower range of water levels. When the stop-logs are placed in the structure so as to restrict outflow from Lake Manitoba, the water level on the lake is raised during dry periods. Conversely, the enhanced channel provides a greater than natural outflow capacity from Lake Manitoba, preventing or reducing flooding on the lake. For example, when water levels are high or significant inflows are predicted, all of the stop-logs can be removed from the structure to increase outflows from Lake Manitoba to help lower the lake before, during and after periods of high inflow. The enhancement of the natural outflow channel increased potential outflows from Lake Manitoba by over three times its natural capacity when the lake is at 813 feet (247.802 m) or below, and by 1.5 times the natural capacity when the lake is at 817 feet (249.022 m) (see Figure 32).

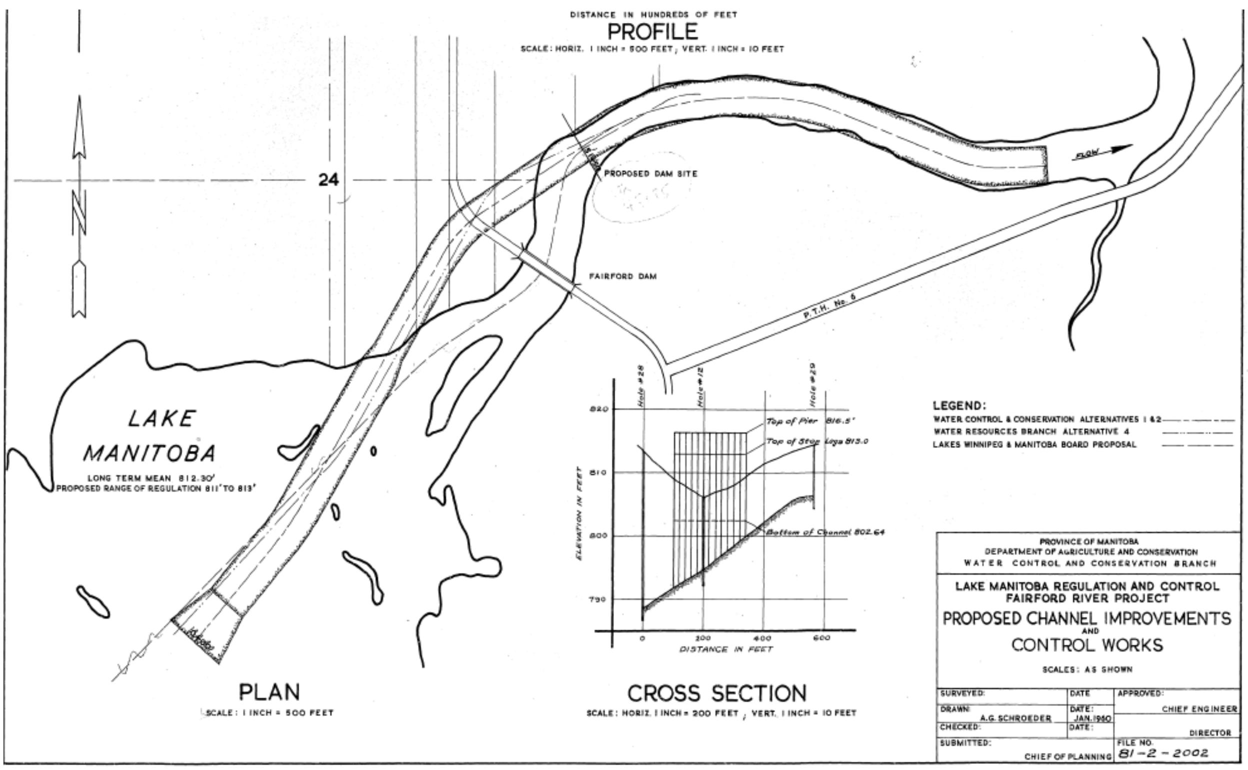

Figure 31: Plans from 1960 for the channel excavation portion of the Fairford River water control structure project (Province of Manitoba, Water Control and Conservation Branch, File # 81-2-2002). Note that the excavation included a new channel as well as deepening the approach to the channel within the lake itself.

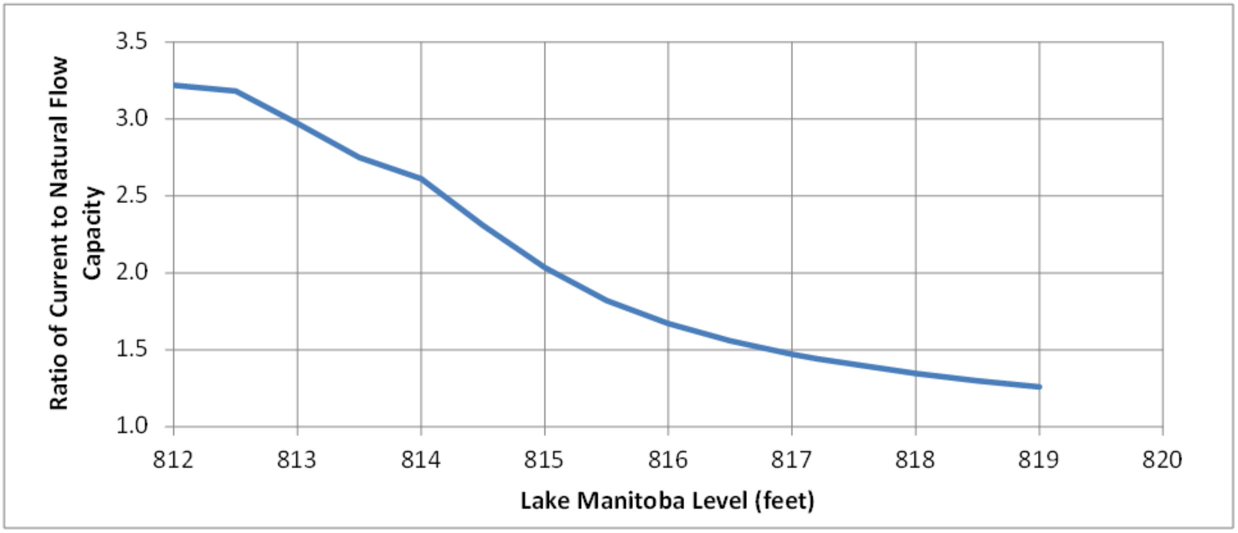

Figure 32: Ratio of the enhanced outflow capacity through the Fairford River water control structure compared to unregulated outflow capacity at different lake levels.

The Fairford River water control structure was built to allow for regulation of the levels on Lake Manitoba, resulting in a narrower fluctuation of lake levels, meaning lower high levels and higher low levels (see Figure 33). The timing for construction of the FRWCS was driven largely by pressures to lower levels on Lake Manitoba following a prolonged period of flooding during the 1950s. This continued a trend on Lake Manitoba, whereby actions to regulate the lake level were often taken in response to prolonged flood or drought events. For example, following flooding and high water in the late nineteenth century, in the late 1890s the federal Department of Public Works constructed a 200 feet (61.0 m) wide and 1500 feet (457 m) long canal between the lake and the Fairford River for the purpose of improving the outflow from the lake and providing flood relief to settlers around the lake. It is generally accepted that this early project failed to provide the intended flood relief (Library and Archives Canada, Arthur Meighen Fonds, MG26-I, Vol. 43, Microfilm Reel C-3453,Dunn, T. H., 1915). Later, in response to several dry years in the late 1920s and early 1930s, in 1934 the provincial government built a concrete control structure on the Fairford River which could be operated to reduce outflows from Lake Manitoba. The operation of this original structure helped to raise Lake Manitoba levels during dry periods but didn't allow for increased outflow from the lake.

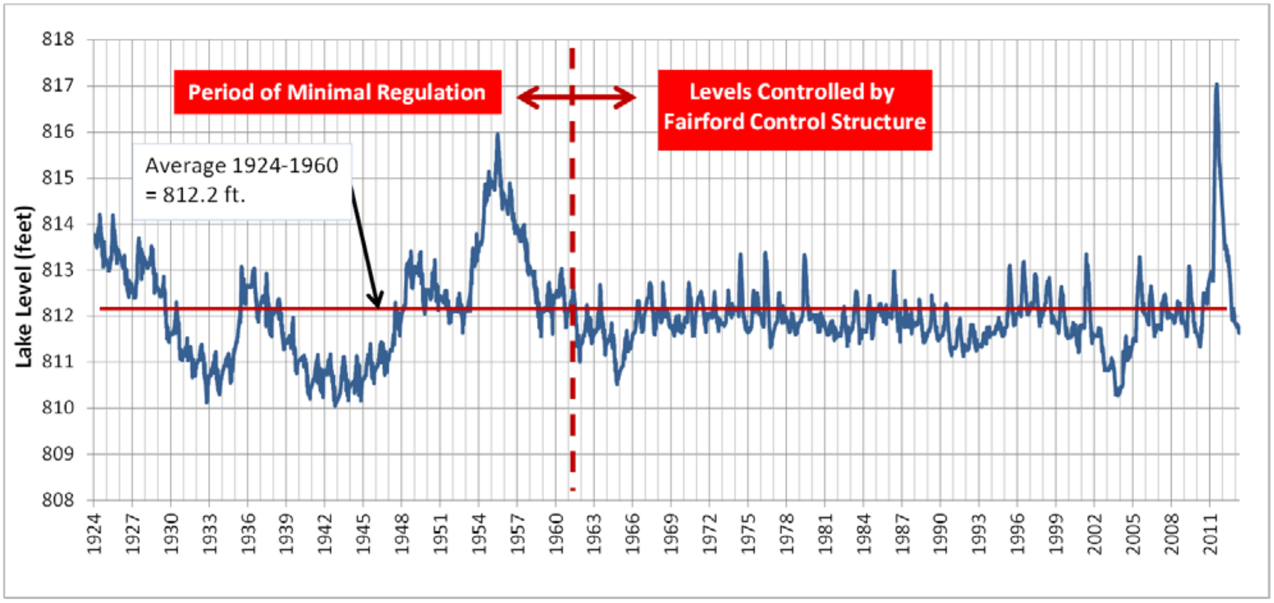

Figure 33: Recorded Lake Manitoba levels, 1924 to present.

Although the Fairford River water control structure was built a decade before the Portage Diversion was completed, the structure was designed so as to handle the increased volume of water on Lake Manitoba that the Portage Diversion was projected to contribute. However, the channel improvements and increased outflow capacity of the Fairford River water control structure project were not intended to match the actual capacity of the Portage Diversion. Instead, the increased outflow capacity of the FRWCS was designed to allow Lake Manitoba to be maintained within a target range of 811 to 813[1] feet (247.193 to 247.802 m) based on the total volumes of inflow expected, including the projected inflows from the Portage Diversion (Kuiper, 1958). The projections of inflow volumes undertaken at the time the structure was designed were based on recorded inflows and climate (ex: precipitation and evaporation) at that time, and on the projected inflows from the planned Portage Diversion based on the recorded history of flows on the Assiniboine River. The greatly increased outlet capacity of the FRWCS allows for the levels on Lake Manitoba to be brought down relatively quickly after the occurrence of a high lake level event. Prior to 2011, the control structure was effective in managing the lake levels within the desirable range for the vast majority of that period.

Up to 2011, Lake Manitoba has been regulated through operation of the FRWCS in accordance with the recommendations of the Lake Manitoba Regulation Review Advisory Committee. The recommendations stipulate that Lake Manitoba should be allowed to fluctuate naturally in the range of 810.5 to 812.5 feet (247.040 to 247.650 m) with the FRWCS operated only if the Lake were to deviate from this range. Since 2005, the FRWCS has remained fully open nearly continuously, allowing for maximum possible outflow, due to ongoing high water levels on Lake Manitoba. Figure 34 below shows the water levels on Lake Manitoba and the operation of the FRWCS in the six years prior to the 2011 flood. The temporary reductions in outflow, which are visible as dips in the red line, were necessary to help control the

[1] A datum change in the early 1960s meant that the desirable range remained constant but was instead measured as 810.8 to 812.8 ft.

formation of frazil ice on the Dauphin River, into which Lake St. Martin flows. Frazil ice formation lends itself to ice jams which can quickly cause local flooding and also reduce the outflow from Lake St. Martin, raising levels on the lake. One consequence of this ice jam phenomenon is that Provincial Road 513, the sole point of access to Dauphin River First Nation and the community of Dauphin River, has had to be closed on numerous occasions in recent years, due to flooding which is caused by frazil ice jams.

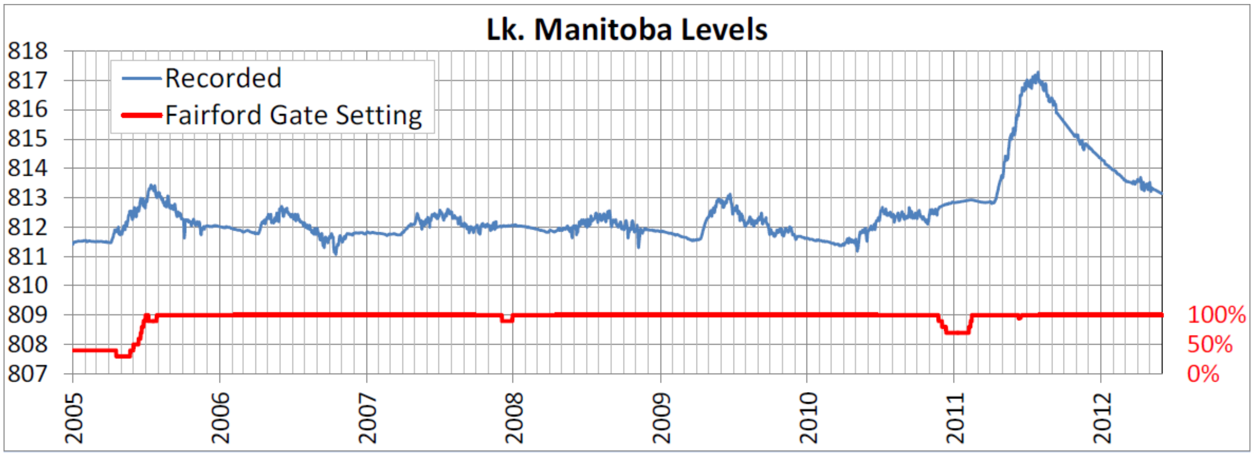

Figure 34: Recorded Lake Manitoba levels and Fairford River water control structure gate settings

As a consequence of the construction and operation of the Fairford River water control structure, Lake St. Martin, which is located downstream of Lake Manitoba, experiences greater extremes in lake levels. Whereas under unregulated conditions, the two lakes would rise and fall together, the regulation of Lake Manitoba has meant that Lake St. Martin now experiences higher inflows (outflows from Lake Manitoba) during high water periods and lower lake levels due to reduced inflow (outflow from Lake Manitoba) during dry periods.

2.3.5 Souris River Dams

The headwaters of the Souris River are in south central Saskatchewan. From there the river flows southeast into North Dakota before heading back north into Manitoba. There are a number of large dams located on the Souris River in its upstream reaches, such as the Rafferty and Alameda Dams in southern Saskatchewan and the Lake Darling Dam in North Dakota. The Rafferty and Alameda Dams were built in the late 1980s to mid-1990s to provide water supply for the area and flood control to communities downstream on the Souris River. The Lake Darling Dam on the Souris River was built in 1936 for water storage and conservation as part of a national wildlife refuge. However, during flood conditions, operational control of the dam is turned over to the United States Army Corps of Engineers. During large flood events such as 2011, these dams are operated so as to reduce flows, and thus provide flood protection downstream.

2.3.6 Cut-offs and straightening of the Assiniboine River

As the accounts of historic flood events in section 2.2.2 above show, ice jams are a relatively frequent feature on the Assiniboine River, owing largely to the meandering nature of the river in this reach.

Governments and early settlers recognized that the sharp curves in the river contributed to ice jamming and, as a result, some of the earliest flood protection work done on the Assiniboine River was to make cuts between the nearest points of the river at meanders, in order to straighten the river and eliminate some of the sharper bends where ice jams had occurred or were likely to occur. A PFRA report from 1952 noted that the cut-offs in the river bends had been successful in reducing the numbers of ice jams and lessening erosion on river bends, and that further cut-offs were advisable to improve the situation (Prairie Farm Rehabilitation Administration, 1952c). This human alteration of the river, in addition to helping to prevent some ice jams, has also resulted in changes to the morphology and flow patterns of the river, although the effects are not computed in this report.

3.0 Regulated and Unregulated Flooding

This chapter of the report provides an overview of artificial flooding and reviews the effect that each of the water control structures had on the regulated level of the Assiniboine River, Lake Manitoba, and Lake St. Martin.

3.1 Definitions: Artificial Flooding, Regulated and Unregulated Water Levels

In this report, the term **unregulated**, in relation to water levels, refers to the calculated levels that would have occurred in the absence of all flood control infrastructure, including the Portage Diversion, Fairford River water control structure, Assiniboine River dikes, Shellmouth Dam, and the dams on the Souris River located upstream in Saskatchewan and North Dakota. **Regulated** refers to the levels that occurred and were recorded and thus includes the operation of the aforementioned flood control infrastructure. Artificial flooding occurs when regulated water levels (recorded water levels) exceed unregulated water levels. In other words, artificial flooding occurs when operation of flood control infrastructure causes water levels on a water body to be higher than they would have been if none of the flood control infrastructure was present.

The term **natural** refers to conditions that existed prior to the above mentioned flood control works and also prior to man-made modification of the landscape. Natural would entail considering the landscape and hydrologic conditions without flood control infrastructure, as well as without other landscape changes such as roads and drainage works, and also without alteration of land cover and natural vegetation. Natural conditions cannot be accurately modelled, since it is impossible to fully understand and quantify the hydrologic impacts of the multitude of changes that human development across the landscape has resulted in. For example, drainage infrastructure, associated with agricultural, urban and suburban development, and transportation infrastructure, has altered the amounts and rates of runoff due to precipitation events and snowmelt. These effects are too complex to model accurately at the scale of the entire Assiniboine and Lake Manitoba basins.

Presently, there are two pieces of legislation in Manitoba that define artificial flooding. In 2008, the Manitoba government amended *The Water Resources Administration Act* to define artificial flooding and establish compensation for damages due to artificial flooding caused by the operation of designated water control works. The Shellmouth Dam is presently the only water control work designated under the Act. *The Red River Floodway Act* also deals with artificial flooding, but it is concerned with operation of the Red River Floodway and is not applicable to an examination of Lake Manitoba or the Assiniboine River. Although this legislation does not apply to Lake Manitoba, the definitions used in this report are consistent with those used in this legislation. More information and the legislation and associated regulations are available on the provincial government website.

3.2 Landscape Changes

Water control infrastructure has a significant effect on flows. However, there are other human alterations to the landscape that also affect both the timing and magnitude of flows on streams and water levels on lakes. For example, the conversion of Manitoba's landscape from native prairie to annual agricultural production has changed the patterns and rates of runoff, infiltration and evapotranspiration across most of Manitoba's landscape. Perhaps the most significant change, however, has been the improvement of drainage across the province, including in-field drainage improvements, construction of ditches and drains, and draining and filling of wetlands. The improvement of drainage has played an important part in facilitating the settlement and development of Manitoba, but it is generally accepted that the faster removal of water from the landscape results in greater volumes of runoff and higher peak flows on streams. This effect can be significant for small floods, but is generally insignificant for large floods.

3.3 Effect of Flood Control Works on the Assiniboine River and Lake Manitoba

Determining whether or not artificial flooding occurred on a given water body requires calculation of the unregulated water level that would have occurred in the absence of all flood control infrastructure. In the case of Lake Manitoba, the Portage Diversion artificially adds flows to Lake Manitoba, while the Fairford River water control structure at the outlet of Lake Manitoba acts to increase the outflow capacity from the Lake, dikes on the Assiniboine River act to keep more water in the river channel (some of which would have otherwise overflowed into Lake Manitoba), and the Shellmouth Dam acts to reduce peak flows on the Assiniboine River during flood events (thereby reducing potential overflows downstream). The dams located on the Souris River upstream of Manitoba also act to reduce peak flows on the lower Assiniboine River. While these dams are located in other jurisdictions and operated by other authorities, they played a role in reducing peak flows on the Souris River, and consequentially on the Assiniboine River, during the 2011 flood event. An accurate calculation of the unregulated level on Lake Manitoba must discount the influence that all of these pieces of infrastructure have on lake levels. Table 2 below provides a summary of the effect that each of the water control works have on both the Assiniboine River and Lake Manitoba. Sections 3.4 and 3.5 below provide an explanation of how the unregulated levels are calculated, while the results of the computation of unregulated levels on the Assiniboine River and Lake Manitoba in 2011 are detailed in Section 5.0.

Table 2: Summary of effects of flood control works.

	Effect on Assiniboine River Peak Flows	Effect on Lake Manitoba Water Levels
Shellmouth Dam	Decrease	Decrease (reduce potential overflows of Assiniboine River)
Portage Diversion	Decrease	Increase
Assiniboine River Dikes	Increase	Decrease (reduce potential overflows of Assiniboine River)
Fairford River water control structure	___	Decrease
Souris River Dams (Rafferty and Alameda Dams in Saskatchewan and Lake Darling Dam in North Dakota)	Decrease	Decrease (reduce potential overflows of Assiniboine River)

Note: operation of the Shellmouth Dam and dams on the Souris River will generally decrease the peak flow on these rivers while slightly raising flows later, as the flood waters recede. This effect is included in the calculation of unregulated levels documented in this report.

3.4 Computation of Unregulated Assiniboine River Flows

In order to compute the unregulated flows on the Assiniboine River, one must remove the effect of the water control structures outlined in Table 2 above. On rivers, water control structures have an effect, not only at the location of the structure, but also extending downstream. In this report, the unregulated river flows were computed up to the Portage Reservoir using standard flow routing techniques (described below). Below the reservoir the situation becomes more complex, largely due to the potential for overflows from the Assiniboine River, where the river becomes unconfined on the alluvial fan. Thus hydrodynamic modelling was undertaken to estimate unregulated flows and overflows below the Portage Reservoir. The results of the computation of unregulated flows on the Assiniboine River in 2011 are discussed in section 5.1. The hydrodynamic modelling and estimation of overflows is discussed further in section 5.2.

The Shellmouth Dam and the dams on the Souris River act to reduce the peak flows on the Assiniboine River by holding back a portion of the flows on those rivers. The difference between the recorded outflow from a dam and the calculated outflow that would have occurred, if the dam were not in place, is known as a holdout. Unregulated flows downstream from a dam must be computed, since operation of the dam affects flow at all points downstream. The calculation of the effect on unregulated Assiniboine River flows from the Shellmouth Dam and the dams on the Souris River was done using two different methods, described below.

For the Shellmouth Dam, unregulated flows at the dam site were considered to be equal to the actual inflows into the Reservoir, including over-reservoir precipitation. The rationale for this approach is that, if the dam was not in place, the flows that would be observed on the river at this location would be made up of the flows on the main river, plus the flows that any tributaries would have contributed to the river in the reservoir reach, plus the runoff from any local precipitation. Unregulated flows at sites downstream from the dam were computed by using Muskingum routing, a technique used to model the movement of water down the river. The unregulated flows at the site of Shellmouth Dam were routed to the location of the Portage Reservoir, incorporating the addition of runoff from tributaries while moving downstream.

For the dams on the Souris River, the holdouts (reduction in flows) from the dams were first calculated by the United States Army Corps of Engineers at Minot. Manitoba technical staff calculated the expected travel time from Minot to the Portage Reservoir. The holdouts at Minot were then lagged by the observed travel time and added to the Assiniboine River flows to estimate the daily flows that would have occurred in the absence of water control structures on both the Assiniboine and Souris Rivers. For example, if a holdout value of 500 cfs (14.2 cms) was computed for May 1st, 2011, and the travel time to the Portage Reservoir was ten days, then the May 11 unregulated flow at the Portage Diversion was increased by 500 cfs (14.2 cms) to account for the holdout on the Souris River dams.

3.5 Computation of Unregulated Water Levels on Lake Manitoba

The unregulated water levels on Lake Manitoba were calculated using water balance methodology, which is based on the principle of Conservation of Mass. The difference in volume between the total inflows to the lake over a defined period, minus the total outflows over that same period, is equal to the change in volume in the lake. The principle is shown in Figure 35. If the total inflow exceeds the total outflow, the lake level rises by an amount equal to the volume difference. If the total inflow is less than the outflow, then the lake level drops. The challenge in using this approach is determining the unregulated inflows and outflows, many of which must be computed based on regulated inflows and outflows.

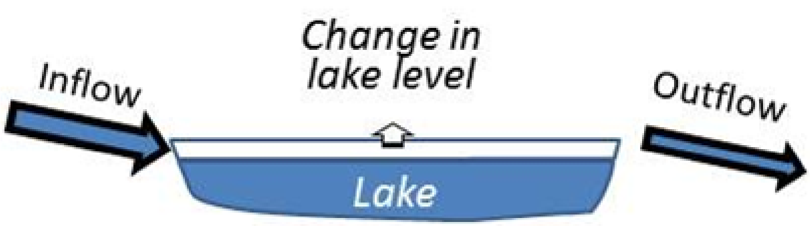

Figure 35: Lake water balance.

Any computation in lake levels must be done iteratively, on a day-by-day basis, starting on the day that regulation began and going forward to the date of interest. This is a critical consideration when calculating unregulated water levels, because water level is a continuous value. In other words, the end of day water level on day one is the start of day water level on day two. Thus, computation of the unregulated water level cannot begin in the middle of a period of regulation, as this would not account for changes to the water level that occurred prior to that date. Instead, the water level must be computed so as to account for all inflows and outflows that have occurred since regulation was implemented.

3.5.1 Measured Lake Levels – Recorded and Average

The water level on Lake Manitoba is measured continuously at two locations; at Steep Rock near the north end of the lake and at Westbourne at the southwest corner of the lake. The recorded lake levels can differ considerably between the two stations, and from day to day, because of wind effects. To compute the changes in lake volume, the average lake level is required. The average lake level (also known as the wind-effect eliminated water level) is computed by averaging the recorded levels at both monitoring stations over a five-day period. This procedure smoothes out most of the wind effects on the lake levels. Figure 36 shows the daily recorded levels at Steep Rock and at Westbourne and the five-day average level.

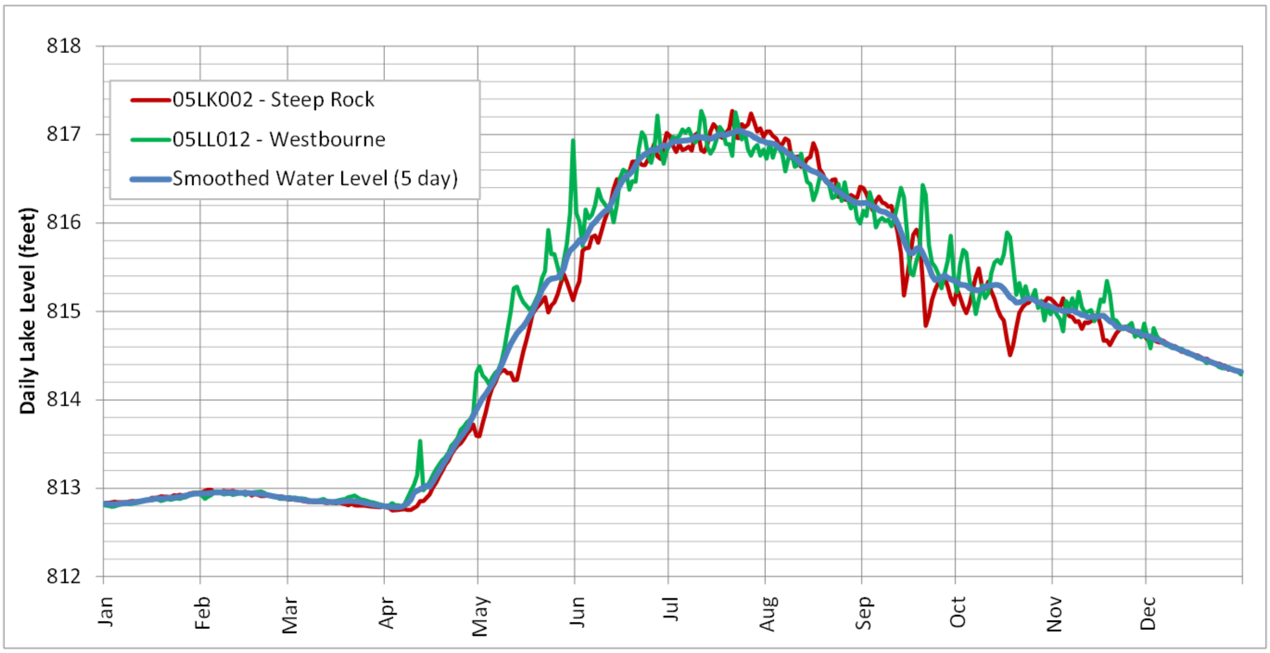

Figure 36: Daily water levels on Lake Manitoba in 2011.

3.5.2 Computation of Inflows and Outflows

The different inflows and outflows to Lake Manitoba under regulated and unregulated conditions are illustrated schematically in Figure 37. As outlined above, accurate determination of inflows and outflows to Lake Manitoba is critical to computing the unregulated lake level. Some of the inflows and outflows on the lake are known (they measure the same in the regulated and unregulated conditions), some can be computed or readily estimated from available data, while others must be computed using more complex methods (see Table 3).

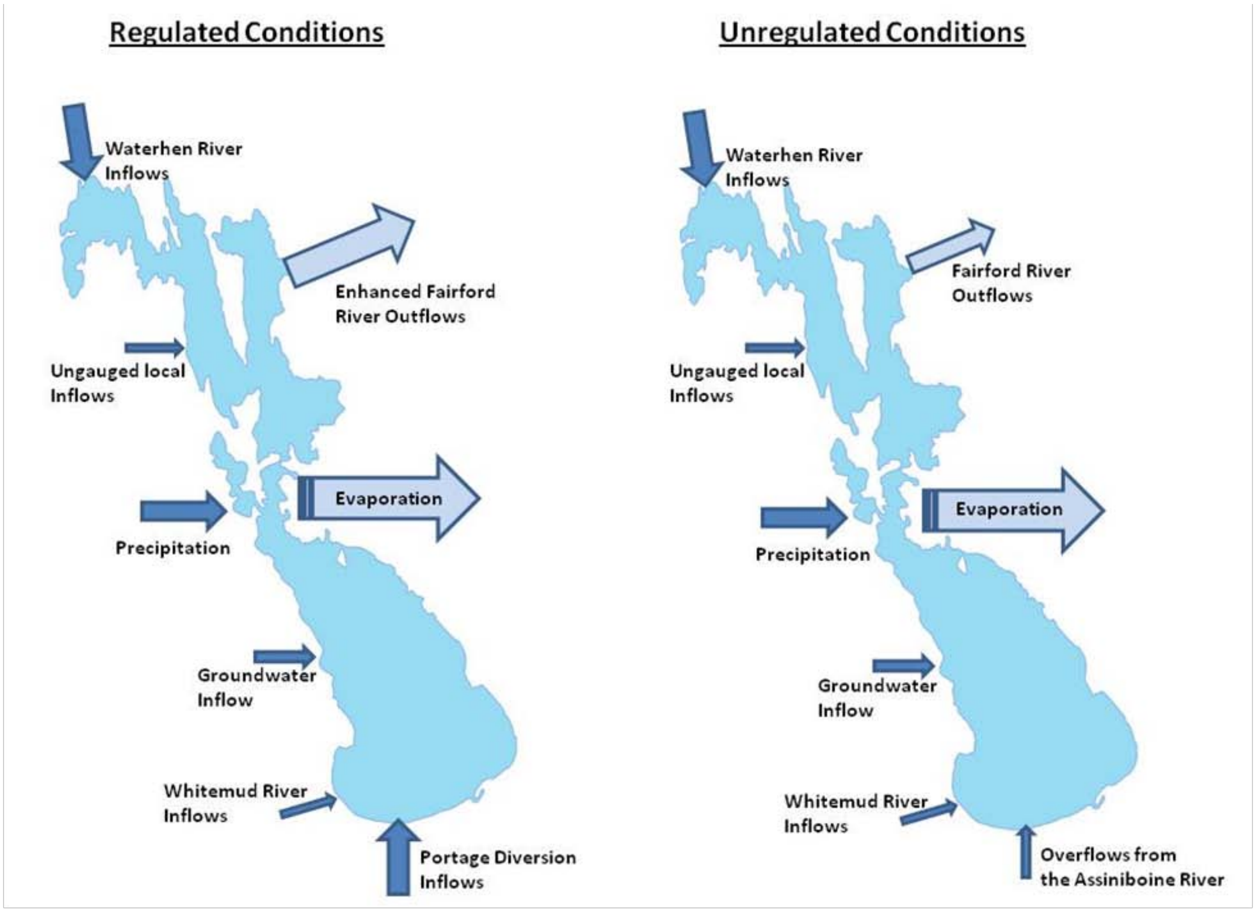

Figure 37: Schematic showing inflows into and outflows from Lake Manitoba under regulated and unregulated conditions.

The unregulated inflows to Lake Manitoba, outlined in Table 3 below, are detailed as follows. Inflows from the Waterhen and Whitemud Rivers are recorded; these inflows are the same between regulated and unregulated conditions. There are a number of inflows including rainfall, local runoff, ungauged stream flow and groundwater inflow, which are not measured and which are difficult to compute or estimate accurately. Rain falling directly on the lake is an important inflow, but varies over the lake, and daily rainfall estimates based on recorded rainfall at nearby weather stations are not necessarily representative of rainfall over the lake. Runoff from the surrounding land is difficult to estimate accurately. Inflow from groundwater, although slow, may also be significant, given the size of the lake. Since these inflow values were unknown, they needed to be calculated so that they could be used as inputs in computation of the unregulated lake level.

Table 3: Balance of Lake Manitoba inflows and outflows.

Regulated Condition			
Inflows		**Outflows**	
Waterhen River	Measured	Enhanced Fairford River	Measured
Whitemud River	Measured	Evaporation	Calculated
Local Inflows	Calculated	Possible overflow to Assiniboine River (above 817.2’)	Assume zero because none observed
Precipitation	Calculated		
Groundwater inflow	Calculated		
Portage Diversion	Measured		
Unregulated Condition			
Inflows		**Outflows**	
Waterhen River	Measured	Natural Fairford River	Calculated
Whitemud River	Measured	Evaporation	Calculated
Local Inflows	Calculated	Possible overflow to Assiniboine River (above 817.2’)	Unknown – assumed to be zero
Precipitation	Calculated		
Groundwater inflow	Calculated		
Assiniboine River Overflows	Calculated from Hydrodynamic model		

To get around the problem of unknown and difficult to compute inflows, the net daily inflows to Lake Manitoba were computed for regulated conditions using the Inflow Available for Outflow (IAO) method. In short, the IAO method uses the known values of recorded daily change in water levels (Figure 36) and recorded outflows through Fairford River (see Figure 38) to compute the total inflow to the lake, which is made up of the recorded and unknown inflows (see Table 3). The total unknown inflows are then calculated by subtracting the known inflows from the total inflows. This computed IAO includes all inflows, recorded and unrecorded, as well as precipitation minus evaporation. This method provides an accurate estimate of the total daily inflows that occurred, under regulated conditions. These unknown inflows are generally assumed to be the same under unregulated conditions, with the exception of precipitation minus evaporation, because these values are affected by lake surface area. The method for dealing with effect of lake levels on the precipitation-evaporation balance under unregulated conditions is described in section 3.5.3 below.

Figure 38: 2011 Recorded Fairford River flows (recorded outflows from Lake Manitoba).

Finally, one potentially important inflow to the lake under unregulated conditions is overflow from the Assiniboine River to Lake Manitoba. This inflow value could not be reliably estimated because there is no quantified record of overflow to Lake Manitoba. For this reason, the unregulated flows on the Assiniboine River were analyzed and an estimation of the overflow to Lake Manitoba was obtained. The results from this analysis are presented in section 5.2.

There are two important unregulated outflows from Lake Manitoba. Evaporation is an important outflow, as in a typical year, more water is evaporated from the surface of Lake Manitoba than the total outflow volume on the Fairford River. Daily evaporation from the surface of the lake can be estimated, but has a high degree of uncertainty, thus evaporation was accounted for within the IAO method, detailed above.

For unregulated conditions, the outflow through the Fairford River water control structure is calculated using the rating curve developed from the outflow data prior to the construction of the FRWCS in 1961. Figure 39 shows the relationship between recorded daily levels and outflows for the period from 1955, when both lake level and Fairford River flows were recorded, until 1960 when construction started on the improved channel. Unfortunately there are no data below a lake level of 811.5 feet (247.345 m) during that period. The zero on the curve is based on the bottom of the natural channel. The cluster of plotted points to the left of the curve for lake levels between 811.7 feet (247.406 m) and 812.6 feet (247.681 m) shows the effect of the old control structure that was built in 1934 and used to reduce outflows during drier periods.

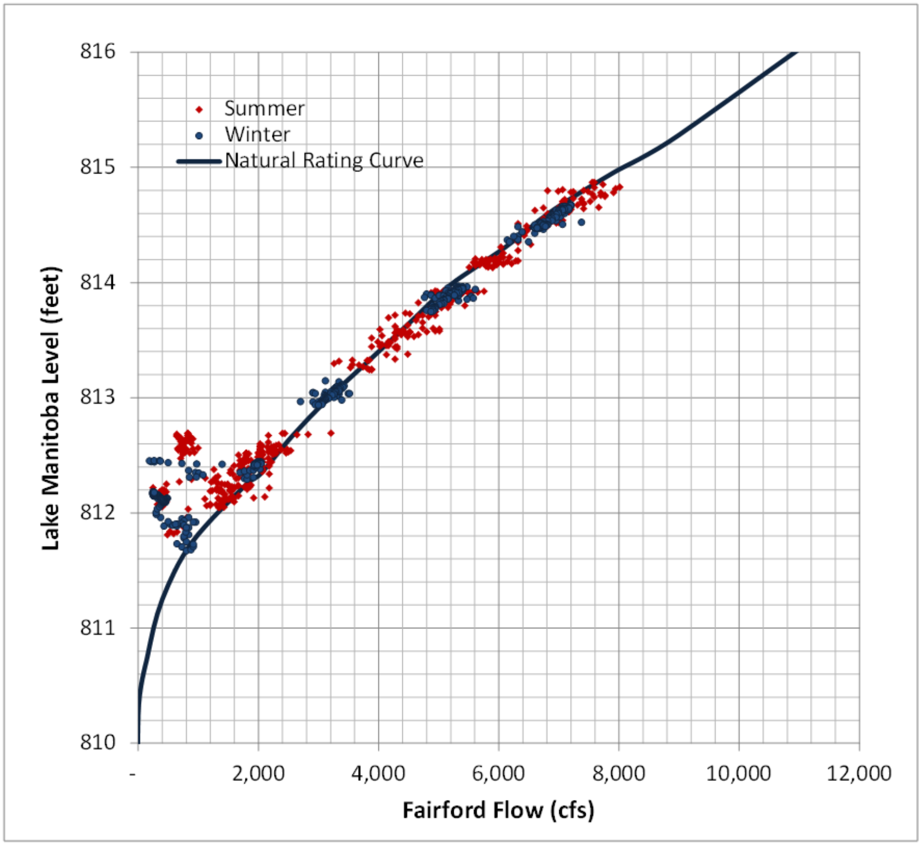

Figure 39: Lake Manitoba natural outflow rating curve.

Figure 39 also shows that under unregulated conditions there was no difference in the flow relationships between summer and winter. As an example of how to read Figure 39, if the level of Lake Manitoba were at 812.3 feet (247.589 m), the natural outflow would be approximately 2,000 cfs (56.6 cms).

3.5.3 Computation of Unregulated Lake Manitoba Levels

The computation of what daily water levels would have occurred on Lake Manitoba under unregulated conditions must start in 1961 before regulation of the lake began. The total inflows for each day are computed as described above. All recorded Portage Diversion flows must be subtracted from the total inflows to provide daily inflows that would have occurred under unregulated conditions. Then these daily inflows are routed through the Lake Manitoba natural outflow rating curve. For each day, the natural outflow is computed based on the start of day lake level. That volume is subtracted from the daily unregulated inflow volume computed without Portage Diversion flows. If the resulting volume is less than zero, then the lake level would drop. If the net volume is greater than zero, then the lake level would rise. The change in level is equal to the volume change divided by the lake's surface area at that lake level (see Figure 40). The resulting computed average level would be slightly different from the start of day lake level used in the original computation, so the natural outflow would be slightly different. The computation is reiterated, based on the computed average lake level, until there is no significant difference in outflow.

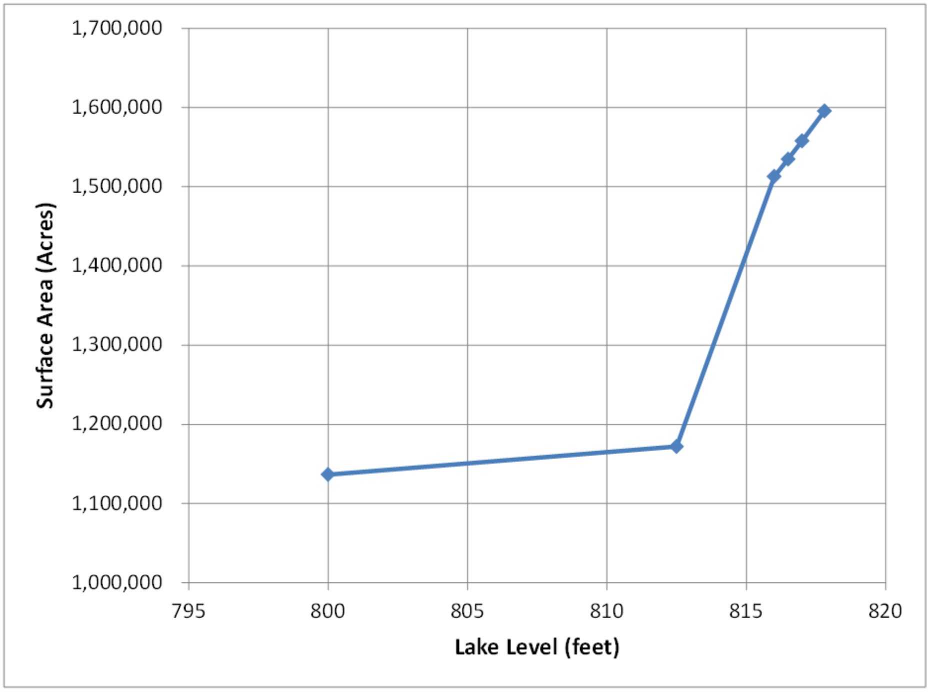

Figure 40: Lake Manitoba surface area curve.

The computed unregulated water levels were also fine-tuned to account for differences in precipitation and evaporation between regulated and unregulated water levels. As explained in section 3.5.2 above, the precipitation-evaporation balance was computed for regulated conditions. As the surface area of the lake changes, the volume added to the lake by direct precipitation and subtracted by evaporation from the water surface will change. In the iterative computation procedure, the net daily precipitation minus evaporation is multiplied by the change in surface area between the recorded level and the computed unregulated level. The above procedure was applied for each day, commencing January 1, 1961

The final input needed to compute the unregulated lake level is the addition of overflows from the Assiniboine River to Lake Manitoba that were estimated to have occurred under unregulated conditions (estimation of these overflows is described in section 5.2). Two unregulated levels were calculated for Lake Manitoba, one assuming that no overflows from the Assiniboine River occurred, and the second assuming overflows to the river based on a landscape that closely approximates conditions prior to European settlement and alteration of the landscape. The latter is referred to as pre-development conditions. As noted earlier, the term **unregulated levels** is used throughout this report to refer to the lake levels that would have occurred without the effect of flood control works. The term **unregulated: no overflows** is used to refer to unregulated lake levels if no Assiniboine River overflows occurred. The term **unregulated: pre-development overflows** is used to refer to unregulated lake levels calculated assuming Assiniboine River overflows that would have occurred in pre-development conditions. The purpose of computing the two unregulated levels was to determine the sensitivity of Lake Manitoba levels to overflows from the Assiniboine River. This is discussed further in section 6.3.

3.6 Computation of Unregulated Water Levels on Lake St. Martin

The procedure used for computing the unregulated levels on Lake St. Martin is similar to that used on Lake Manitoba. In the case of Lake St. Martin, the unregulated inflows are the computed unregulated Fairford River flows (the unregulated outflows calculated for Lake Manitoba). It is noteworthy that the IAO method was not used for calculation of levels on Lake St. Martin because the Fairford River inflows are so large that other inflows are relatively insignificant, and because the outflows through the Dauphin River are not known with the same degree of certainty as those on the Fairford River.

The outflows from Lake St. Martin are computed using the appropriate rating curve relating recorded Lake St. Martin levels to recorded Dauphin River flows. The rating curves for Lake St. Martin are shown in Figure 41. Three rating curves are necessary for the Dauphin River because the flow characteristics are very different depending on conditions. Outflow is restricted in most years in the winter period when an ice cover forms on the Dauphin River. Furthermore, if winter flows exceed about 5,000 cfs (142 cms), frazil ice starts to form in the river, which eventually would form an ice dam. An ice dam would severely restrict Dauphin River flows. Therefore, in simulating unregulated flows, a different relationship is required for the summer and winter periods, as well as for conditions with frazil ice formation. For example, if the level of Lake St. Martin is at 800 feet (243.840 m), the Dauphin River will pass 5,000 cfs (142 cms) in the open water period, but only 3,500 cfs (99.1 cms) in the winter. With fully developed frazil ice in the Dauphin River the capacity would only be around 1,000 cfs (28.3 cms) for a lake level of 800 feet (243.840 m).

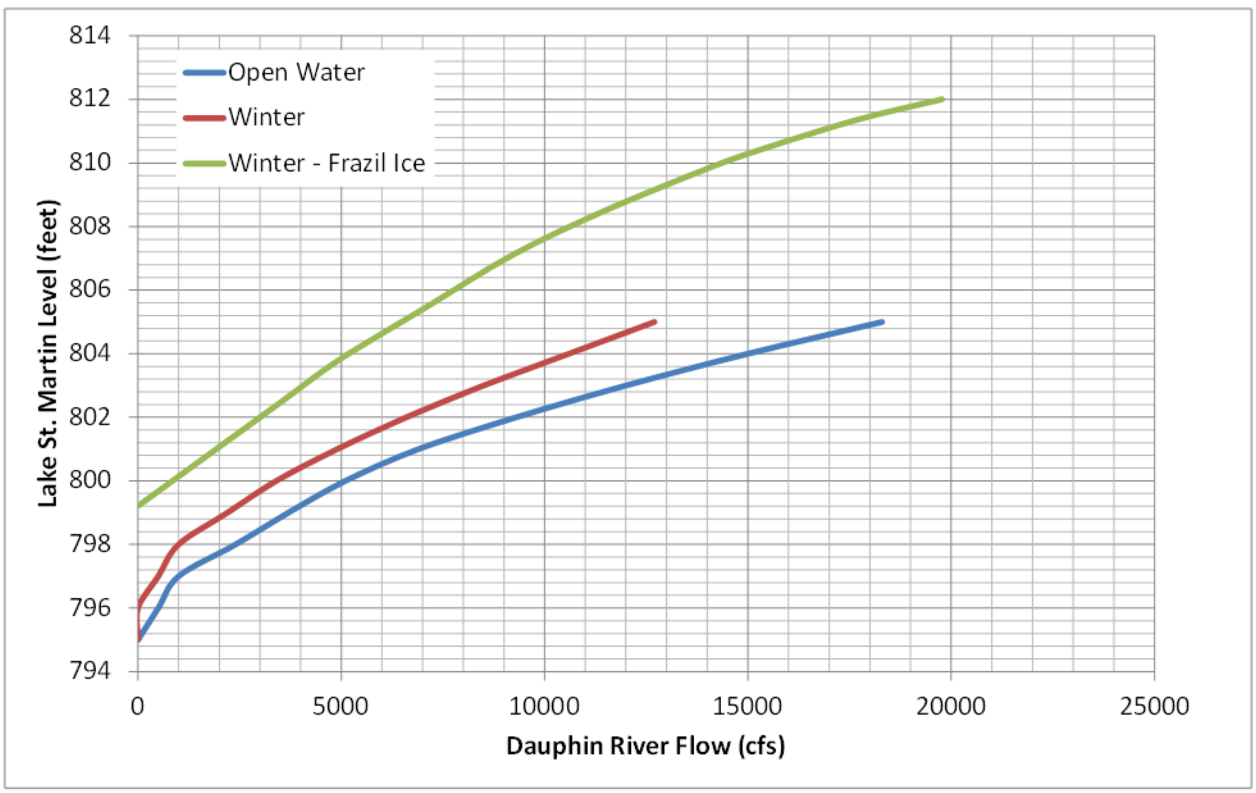

Figure 41: Lake St. Martin outflow rating curves.

In the fall of 2011, the Lake St. Martin Emergency Outlet Channel (LSMEOC) was opened. The construction and operation of this water control structure is discussed in detail in section 4.3.1. During the period that it was operating, the LSMEOC significantly increased the outflow capacity from Lake St. Martin. In order to compute the unregulated water levels on Lake St. Martin, the effect of this increased outflow must also be removed from the regulated conditions.

Using the daily computed unregulated Fairford River flows as inflow to the lake and the rating curves to compute the outflow, the difference between the daily inflow and outflow is divided by the surface area of the lake at that lake level to determine the change in lake level over that day. Similar to Lake Manitoba, this computation process is repeated for each day going back to the beginning of regulation in order to compute the unregulated Lake St. Martin levels.

4.0 2011 Flood Event

The enormous geographic scope and magnitude of flooding that occurred in 2011 is best illustrated by looking at the peak flows on streams and peak water levels on lakes that occurred in 2011, compared to the peak flows and water levels that occurred prior to 2011. Table 4 lists 2011 peak flows on streams and peak water levels on lakes, and indicates the ranking of the 2011 flows and water levels relative to the previous record values. The earliest formal measurement of water levels began in the early 1890s or later, so the historic flood of 1882 and previous flood events are not part of the period of record.

4.1 Assiniboine River

In 2011, many portions of the Assiniboine River Basin experienced record or near-record flooding (see Table 4 above). Above normal soil moisture at freeze-up, above normal winter snow pack and spring and summer precipitation, including severe storm events, led to major flooding in much of the Assiniboine River Basin in both Manitoba and Saskatchewan. Antecedent soil moisture in the Assiniboine River Basin was 130 per cent of normal at the time of freeze up. Significant snowpack throughout the basin resulted in an average snow-water equivalent of 4.72 inches (120 millimetres), 150 percent of normal. Spring rainfall was well above average, and precipitation in May in the Manitoba portion of the Assiniboine River Basin was 200 to 300 per cent of normal. Rainfall amounts in the first portion of the summer were also very high. For example, average total rainfall between April and June in Brandon is 6.3 inches (160 millimetres), but in 2011 the total rainfall in the same period was 12.6 inches (320 millimetres).

The Assiniboine River crested at Russell on May 11 at 1,352.69 feet (412.300 m), at Miniota on May 6 at 1,247.39 feet (380.204 m) and at the Water Survey of Canada Gauge near Brandon on May 9 at 1,193.28 feet (363.712 m) (see Figure 42). Major storms in May and June within the Souris River basin caused high flows and multiple peaks on the Souris River. These peaks on the Souris River, in turn, created four separate peaks on the lower portion of the Assiniboine River (see Figure 43).

Table 4: Peak flows on waterways and peak lake levels.

Station Name/Location	2011 Daily Peak Flow (cms [1])	2011 Daily Peak Flow (cfs [2])	Return Period (Years) [3]	Ranking Of 2011 Peak Flow
Fairford River	646	22,800	380	Highest
Assiniboine River at Kamsack, Saskatchewan	369	13,000	36	2nd Highest
Assiniboine River at Russell (Unregulated)	539	19,000	67	4th Highest
Qu'Appelle River at Welby	345	12,200	110	Highest
Assiniboine River at Brandon (Unregulated)	1,280	45,100	250	Highest
Assiniboine River at Holland (Unregulated)	1,640	57,800	230	Highest
Assiniboine River at Portage (Unregulated)	1,690	59,600	220	Highest
Souris River at Westhope	821	29,000	220	Highest
Souris River at Melita	759	26,800	180	Highest
Souris River at Souris	798	28,200	145	Highest
Souris River at Wawanesa	788	27,800	130	Highest
Elgin Creek near Souris	72.2	2,550	44	Highest
Little Saskatchewan River at Minnedosa	85.7	3,020	40	2nd Highest
Oak Creek near Stockton	75.3	2,660	100	Highest
Pipestone Creek near Pipestone	126	4,400	52	2nd Highest
Plum Creek Near Souris	89.4	3,160	53	2nd Highest
Waterhen River near Waterhen	451	15,900	120	Highest
Whitemud River at Keyes	115	4,060	13	5th Highest
Wind Effect Eliminated Peak Water Levels On Lakes				
Dauphin Lake	262.35	860.7	75	Highest
Lake Manitoba (Since Regulation)	249.04	817.1	400	Highest
Lake St. Martin (Since Regulation)	245.51	805.5	250	Highest
Lake Winnipegosis	254.50	835.0	125	Highest

Note: all peak flows and peak water levels in Table 4 are regulated peaks, unless otherwise noted. For Holland and Portage la Prairie, the effects of holdouts from dams on the Souris River were not included in the unregulated calculations. These stations would have higher unregulated peak flows if these holdouts were included.
Note 1: "cms" stands for "cubic metres per second"
Note 2: "cfs" stands for "cubic feet per second"
Note 3: "return period (years)" refers to the average length of time (in years) that the 2011 peak value would be equalled or exceeded, on average, over the long term, based on recorded historical data. For example, for a flow with a 300 year return period there is a 0.3% (1/300) chance every year that this flow would be equalled or exceeded. However, 300 year flows could occur more than once in a 300 year period.

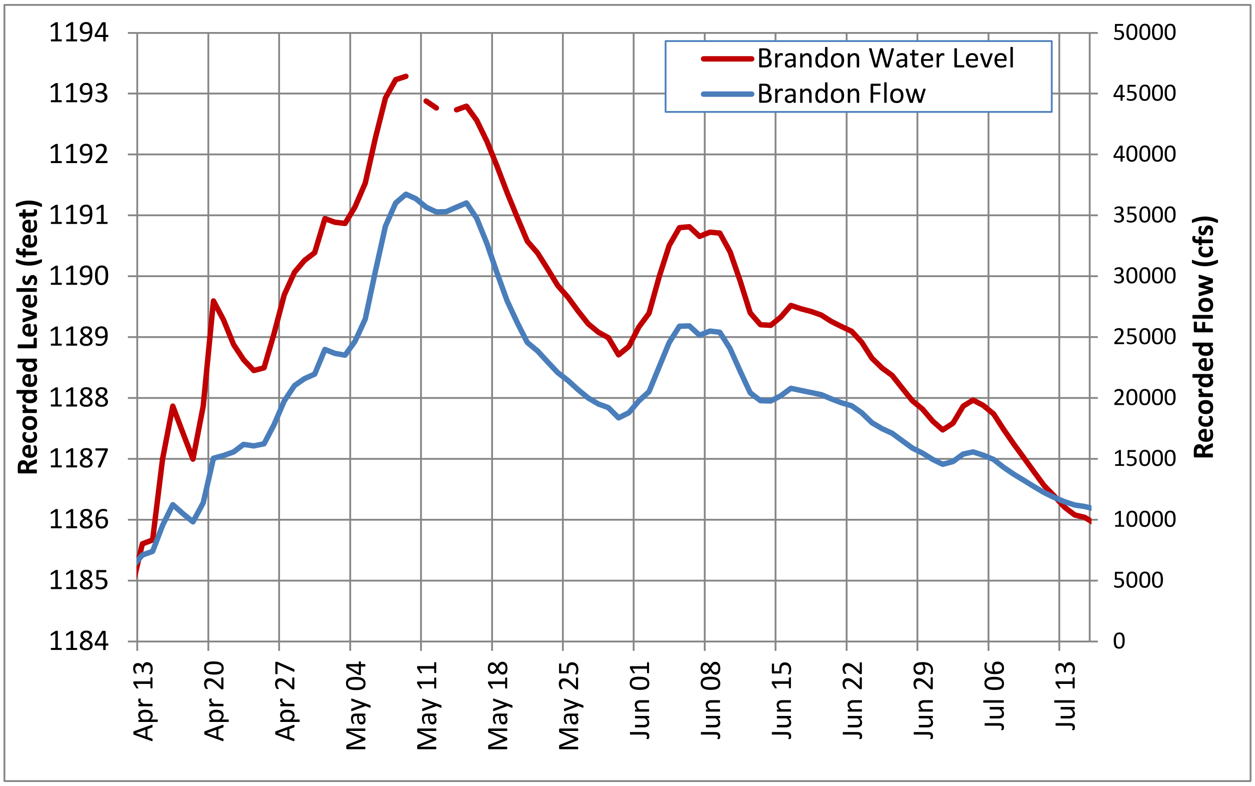

Figure 42: Recorded (regulated) water levels and flows on the Assiniboine River near Brandon.

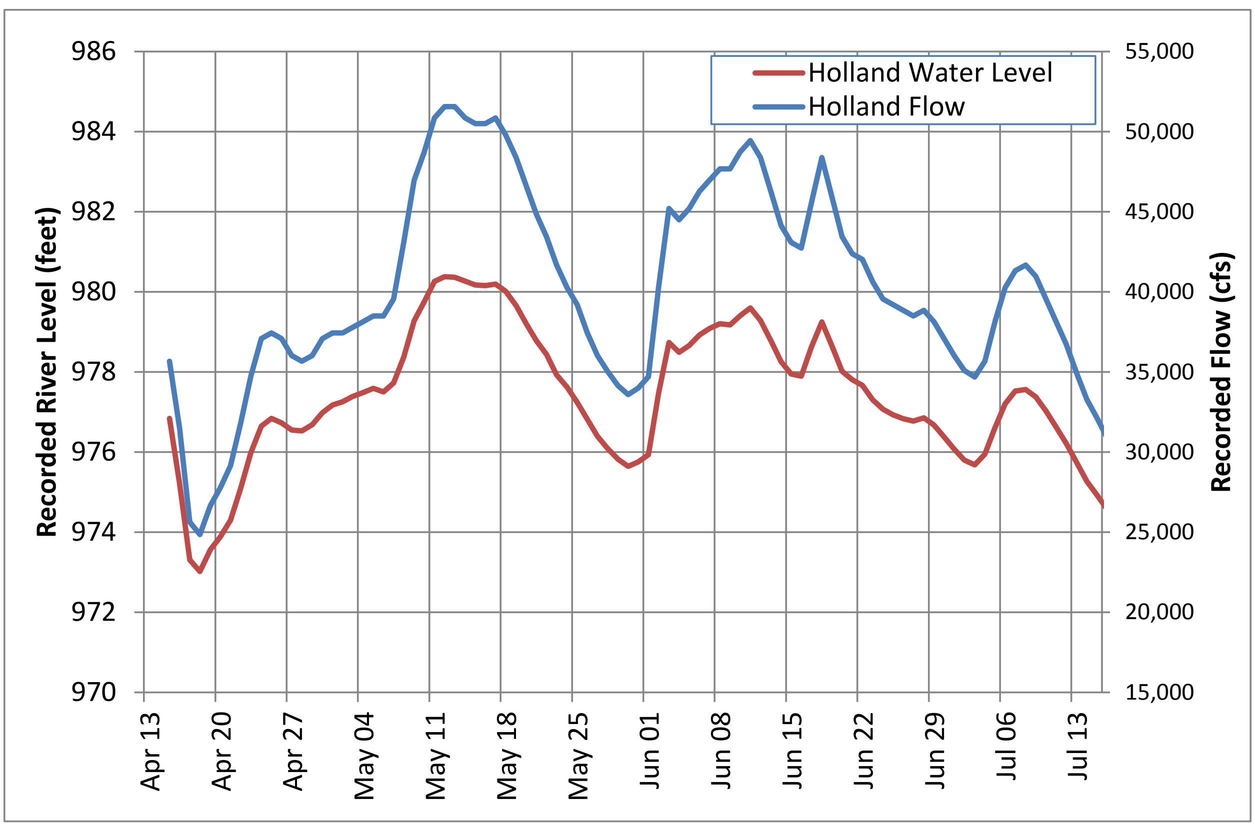

Figure 43: Recorded (regulated) water levels and flows on the Assiniboine River near Holland.

4.1.1 Shellmouth Dam and Reservoir

In anticipation of the spring's high run-off, the water level in the Shellmouth Reservoir was drawn down to 1,383.85 feet (421.797 m), a historic low for pre-spring levels. This operation increased the storage volume available in the reservoir for storing spring runoff waters and so helped reduce spring flows on the Assiniboine River downstream from the Shellmouth Dam. Prior to lowering the reservoir, the operating scenarios were reviewed and discussed with Shellmouth Dam Liaison Committee. The conduit controlling outflow from the dam was opened starting on October 3, 2010 and a flow of up to 3,000 cfs (85.0 cms) was maintained. It was gradually decreased to 1,600 cfs (45.3 cms) by the beginning of December.

Operation of the Shellmouth Dam provided a significant flood reduction benefit in the entire Assiniboine Valley at the peak of the flood (see Figure 44). Under unregulated conditions, the flow in the Assiniboine River immediately below the Dam would have peaked at approximately 20,800 cfs (589 cms) on April 21. The reservoir water level reached the spillway elevation (1,408.5 feet) and flows began over the spillway on April 28 and continued until June 7. The reservoir water level reached its peak on May 11 to 12 at 1,414.50 feet (431.140 m), with a corresponding total outflow of approximately 12,100 cfs (343 cms), 10,600 cfs (300 cms) of which was spillway flow. This means that the recorded peak flow on the Assiniboine River immediately downstream of the dam was 8,700 cfs (246 cms) below the unregulated peak due to operation of the Shellmouth Dam. In 2011, the operation of the Shellmouth Dam provided a reduction in the peak flows of the Assiniboine River at Portage la Prairie of 7,100 cfs (201 cms) (a 1.6 feet (0.488 m) reduction in flood stage).

The reservoir holding capacity when the water level is at the top of the spillway is 477,000 dam^3 (387,000 acre-feet). In an average year, the annual volume of flow on the Assiniboine River at Russell is about 475,000 dam^3 (385,000 acre-feet). In 2011, the volume of water that flowed into the Reservoir for the four month period of April through July was 1.64 million dam^3 (1.33 million acre-feet). Of this, 1.48 million dam^3 (1.2 million acre-feet) flowed into the reservoir in the three months of April through June.

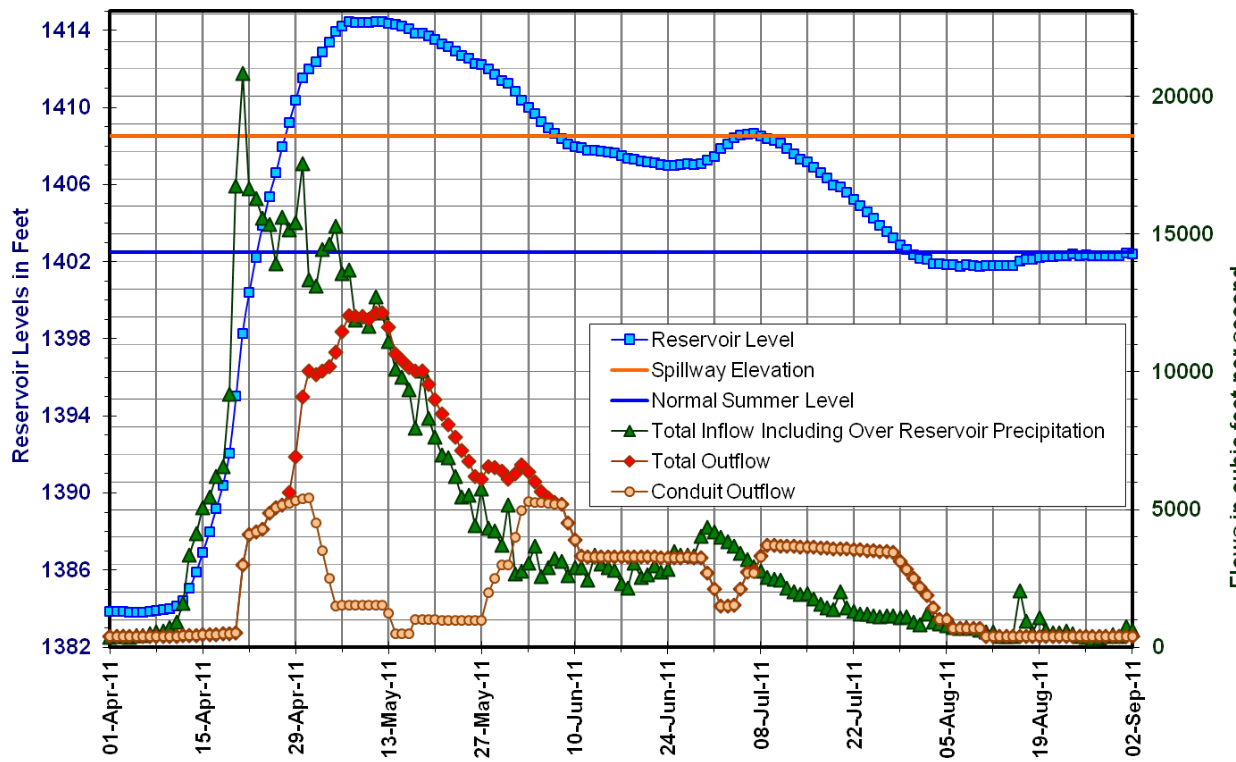

Figure 44: 2011 Shellmouth Reservoir water levels, inflows and outflows.

4.1.2 Operation of the Portage Diversion

Early in the spring runoff period, operation of the Portage Diversion is typically focused on operating to help manage ice conditions both upstream and downstream of the Portage Reservoir. The Portage Reservoir is typically maintained at a low level to provide as much storage as possible within the Reservoir to manage the large volume of ice expected from upstream. In high flow years such as 2011, ice jamming typically occurs in a number of locations upstream of the reservoir; when these jams release, large volumes of water and ice enter the reservoir in a short period of time. Additionally, relatively low flows are usually diverted down the Diversion Channel early in the spring runoff period to loosen any ice frozen in the channel, in preparation for higher flows expected later in the runoff period. Finally, once flows on the Assiniboine River begin to rise, the river control structure is typically operated to hold flows on the river downstream of the reservoir constant at approximately 5,000 cfs (142 cms) if possible, to minimize the risk of ice jamming on the river downstream of the Portage Reservoir.

In 2011, the Portage Diversion gates were first operated on April 1 to divert about 1,100 cfs (31.2 cms) down the diversion channel, with the objective of loosening any ice in the channel. Following the breakup of the ice cover upstream of the Portage Reservoir, flows into the reservoir spiked briefly at a peak of approximately 40,000 cfs (1,130 cms) on April 16. To minimize the flows on the Assiniboine River downstream of the reservoir, where winter ice was still in place, the diversion was used to its design capacity of 25,000 cfs (708 cms). With the high flows downstream on the Assiniboine River, a significant ice jam occurred upstream of the Baie St. Paul Bridge, located on PR 248. The jam caused elevated river water levels, which overtopped the Assiniboine River dike on the north side of the river. As the dike was being repaired, flows on the Assiniboine River were reduced so that water levels were lower on the dike. This allowed heavy equipment to complete the necessary repairs. As dike repairs were completed, flows on the Assiniboine River were increased gradually in increments of about 1,000 cfs (28.3 cms), reaching 18,000 cfs (510 cms) on May 2nd.

In early May the Assiniboine River flows at Portage la Prairie were forecasted to peak at approximately 50,000 cfs (1,420 cms). This was in excess of the safe capacity of the Assiniboine River channel downstream of the Portage Diversion (18,000 cfs (510 cms)) plus the design capacity of the Portage Diversion (25,000 cfs (708 cms)).

Assiniboine River below Portage	18,000 cfs (510 cms)
Portage Diversion	25,000 cfs (708 cms)
Assiniboine Total Capacity	43,000 cfs (1,218 cms)

In response to the projected flows in excess of existing capacity, work was undertaken to increase the capacity of the Portage Diversion and to ensure that the diversion could continue to operate even with very high flows and water levels. The enhanced Portage Diversion eventually conveyed flows of up to 34,700 cfs (983 cms). The work done to improve the Portage Diversion included:

- raising the south dike of the Portage Reservoir
- raising the diversion channel dikes on both sides by approximately three feet
- placing additional erosion protection around the drop structures in the channel
- adding rock on the diversion structures and around the bridges crossing the diversion channel to increase stability
- installing a gas generator to ensure the diversion gates could be operated if electrical power was affected by rising waters
- installing back-up hydraulic pumps to lift the bascule gates on the structure in the Assiniboine River because the mechanical room was flooded
- welding metal plates to the Assiniboine River control structure's control room floor and walls to allow the structure to remain operational once water levels in the reservoir exceeded the floor elevation

Flows on the Assiniboine River downstream of the diversion were increased to 19,000 cfs (538 cms) on May 10, in anticipation of the peak flow on the Assiniboine River arriving at the Portage Reservoir. By the evening of May 11, it was reported that the dikes on the Assiniboine River could not safely maintain the 19,000 cfs (538 cms) flow. Because of this vulnerability, flows on the river were reduced overnight, back to 18,000 cfs (510 cms) by the morning of May 12. One of the main concerns regarding high flows on the Assiniboine River downstream of the Portage Reservoir was a potential dike failure. Failure of the dikes would have resulted in an uncontrolled breach that could have caused catastrophic damage to homes, farms, or even entire communities. Complicating matters was the fact that the location, timing, and magnitude of a dike failure could not be predicted to allow for installation of temporary protection measures.

Figure 45: Photograph showing sandbags and filter cloth being used to shore up weak spots in the Assiniboine River dikes (photo from May 14, 2011).

On May 9, as a widespread rainstorm set in over much of southern Manitoba, the forecasted flows on the Assiniboine River were revised upwards to approximately 52,000 cfs (1,470 cms) by May 11 and 56,000 cfs (1,590 cms) by May 15. Since the forecast called for flows that exceeded the 52,000 cfs (1,470 cms) combined capacity of the enhanced Portage Diversion and the Assiniboine River channel downstream, it was identified that a controlled release from the Assiniboine River to the La Salle River watershed might be necessary to provide a controlled method of dealing with the excess flows. The Hoop and Holler site was selected for a controlled release point. The operation of the Hoop and Holler controlled release point is described in more detail in Section 4.1.3 below.

Flows down the Portage Diversion channel were increased steadily until peaking at approximately 34,700 cfs (983 cms) on May 14, approximately 10,000 cfs (283 cms) above design capacity (see Figure 46).

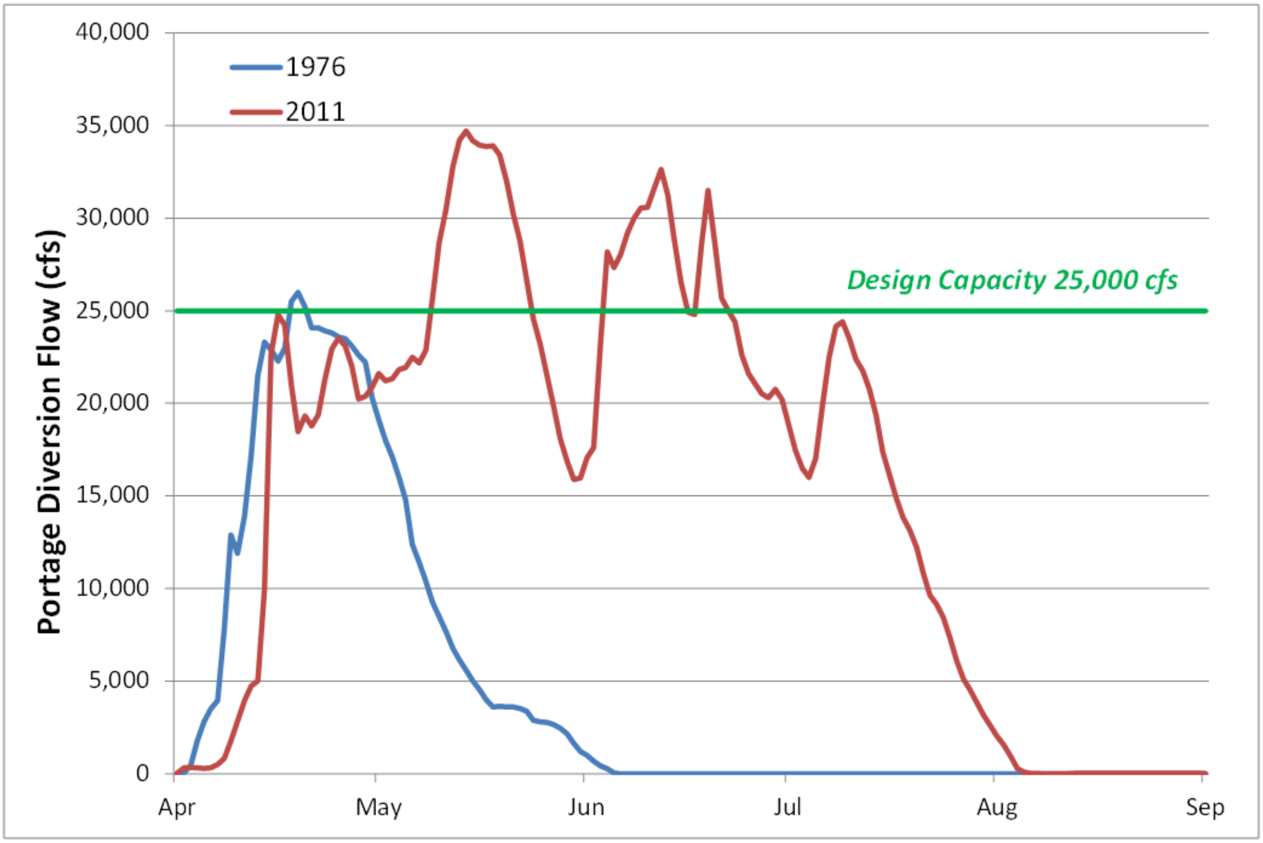

Figure 46: Recorded Portage Diversion flows in 1976 and 2011.

Portage Diversion channel flows above 30,000 cfs (850 cms) were maintained until May 21, when Assiniboine River inflows into the Portage Diversion Reservoir decreased. After May 30, inflows to the Reservoir rose to a second peak of approximately 50,100 cfs (1,420 cms) (on June 12). Inflows to the reservoir decreased for a short time, but heavy rain in the Wawanesa area caused a brief third peak of approximately 49,200 cfs (1,390 cms) on June 19. Then, inflow gradually decreased to approximately 34,000 cfs (963 cms) by July 4. Flood waters from the Souris River began to reach the Portage Reservoir and there was a fourth peak at about 42,100 cfs (1190 cms) on July 9. After this final peak, Assiniboine River flows upstream of Portage la Prairie decreased steadily. Figure 43 shows the discharge and water level on the Assiniboine River at Holland. Since Holland is located just upstream of the Portage Diversion, this figure provides a good indication of the inflows that occurred into the Portage Diversion Reservoir.

Flooding of farmland and residential yards occurred along portions of the Assiniboine River between Portage la Prairie and Winnipeg. However, many residential properties were adequately flood protected (see Figure 47).

Figure 47: Example of flooding along the Assiniboine River between Baie St. Paul and Headingley. Note that some homes are protected by temporary flood protection works.

Flows in the Assiniboine River downstream of the diversion were maintained at 18,000 cfs (510 cms) until July 11. Flows were then gradually reduced to 17,000 cfs (481 cms) to ease the hydraulic pressure on the Assiniboine River dikes. Flow on the Assiniboine River downstream of the diversion was then held constant at 17,000 cfs (481 cms) and the flow in the diversion channel was reduced until the diversion gates were lowered to their full-down position on August 5. After that date, Assiniboine River flows at Portage la Prairie continued to decline.

The flow of water down the Portage Diversion channel in 2011 was unprecedented. A record was set for the longest period of operation in one year at 126 days, diverting a record volume of 4.73 million acre-feet (5.83 million dam^3)[2] of water. By comparison, the 1976 flood was the next largest flood on record since the Portage Diversion was built. In that year the peak flow in the diversion reached 26,000 cfs (736 cms) and the total volume diverted to Lake Manitoba was 1.4 million acre-feet (1.72 million dam^3). A graph of annual diverted volume through the Portage Diversion is shown in Figure 48.

[2] dam^3 stands for cubic decametre, which is equal to 1,000 cubic metres; 1 dam^3 is equal to 0.81 acre-feet; 1 dam^3 of water would cover a square kilometre of land to a depth of 1mm.

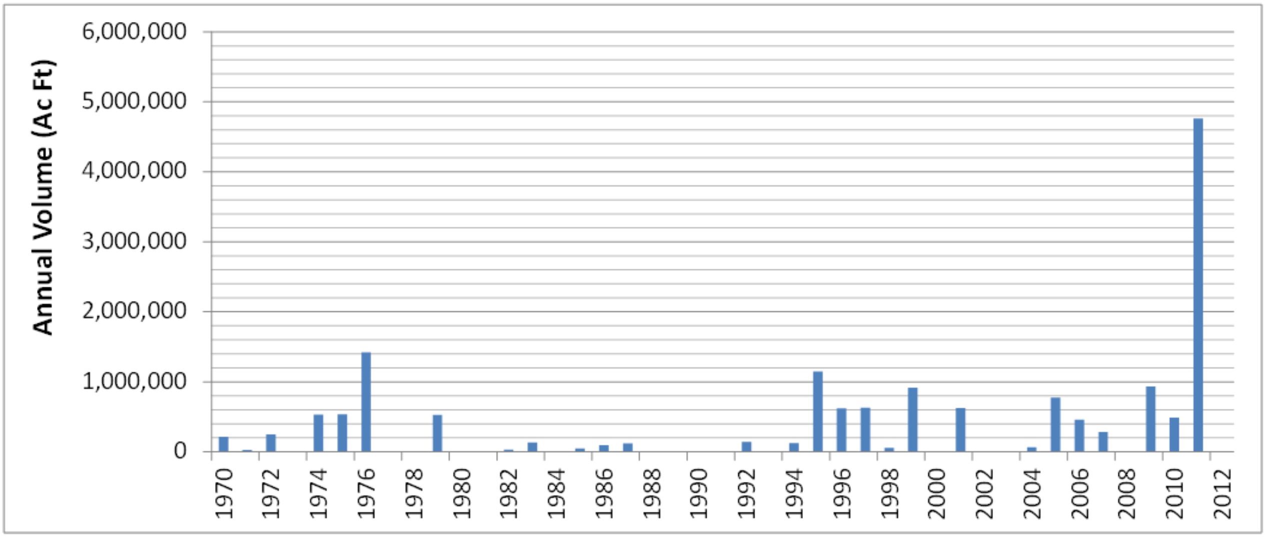

Figure 48: Annual volume of water diverted to Lake Manitoba by the Portage Diversion, 1970-2012.

4.1.3 Hoop and Holler Controlled Release

On May 8, due to an unstable weather system which was forecast to result in ¾ to 2 inches (20 to 50 mm) of rain across much of southern Manitoba, the peak flow on the Assiniboine River at the Portage Reservoir was projected to reach approximately 50,000 cfs (1,420 cms) in two to four days. On May 9, as the rainstorm developed, the projected Assiniboine River flows at the Portage Reservoir were further revised upwards to 52,000 cfs (1,470 cms) on or around May 11, and potentially as high as 56,000 cfs (1,590 cms) by May 15. As a result of these high forecasted flows, a provincial state of emergency was declared to deal with the imminent threat of flooding along the Assiniboine River in the rural municipalities of Portage la Prairie, Woodlands, Rosser, St. Francois Xavier, Headingly, Cartier, Macdonald and Grey.

The projected Assiniboine River flows at Portage la Prairie exceeded the combined capacity of the Assiniboine River channel and dikes downstream of Portage la Prairie plus the enhanced Portage Diversion channel. The enhanced Portage Diversion channel could not convey more than 34,000 cfs (963 cms) and flows greater than 18,000 cfs (510 cms) on the Assiniboine River downstream would lead to a very significant risk of an uncontrolled breach of the dikes which would result in flooding of many homes, farms and communities along the Assiniboine River and adjacent watersheds such as the La Salle River watershed. In response to this extreme situation, it was determined that it may become necessary to intentionally create a controlled breach in the Assiniboine River dikes in order to remove any flows in excess of 52,000 cfs (1,470 cms), the combined capacity of the Assiniboine River and the Portage Diversion.

Five sites were identified for a possible controlled release and assessed based on the flow patterns and the potential inundated area. Another factor in choosing the final site for a controlled release was to select a location where the Assiniboine River is known to have breached in the past. The Hoop and Holler Bend, located on an oxbow of the Assiniboine River, was selected as the site for the controlled release. The site was chosen as it offered a direct, effective overland flow path to the La Salle River system via Elm Creek. The site also provided for the ability to readily and effectively control flows, easy accessibility via roads, and the greatest degree of protection along the Assiniboine River. The site was located further upstream and so would reduce the flows against a greater length of the Assiniboine River dikes.

In the planning stages for a potential controlled release, the upper decile (unfavourable weather conditions) forecast was used to predict the peak flow, volume of flow, timing of the progress of the released waters and potential inundated area within the La Salle River watershed. To minimize the impact on homes, farms and businesses in the inundation zone, flood protection measures such as sandbag dikes and water-filled flood barriers were installed in the projected inundation zone. Based on the flow conditions and the forecast for the coming days, which projected a flow on the Assiniboine River upstream of Portage la Prairie of up to 56,000 cfs (1,590 cms), a controlled release of flows was deemed necessary at the Hoop and Holler site. The controlled breach was opened at 7:00 a.m. on May 14, releasing approximately 340 cfs (9.63 cms) into the La Salle River watershed. At that time, the Portage Diversion channel conveyed approximately 34,700 cfs (983 cms), and flow over the Portage Diversion's bascule gates was increased by the amount flowing through the controlled release site so that the Assiniboine River downstream of the controlled release site conveyed 18,000 cfs (510 cms). The water from the controlled release flowed overland across a relatively small portion of the predicted, maximum inundation zone before reaching the Elm River channel and flowing to the La Salle River.

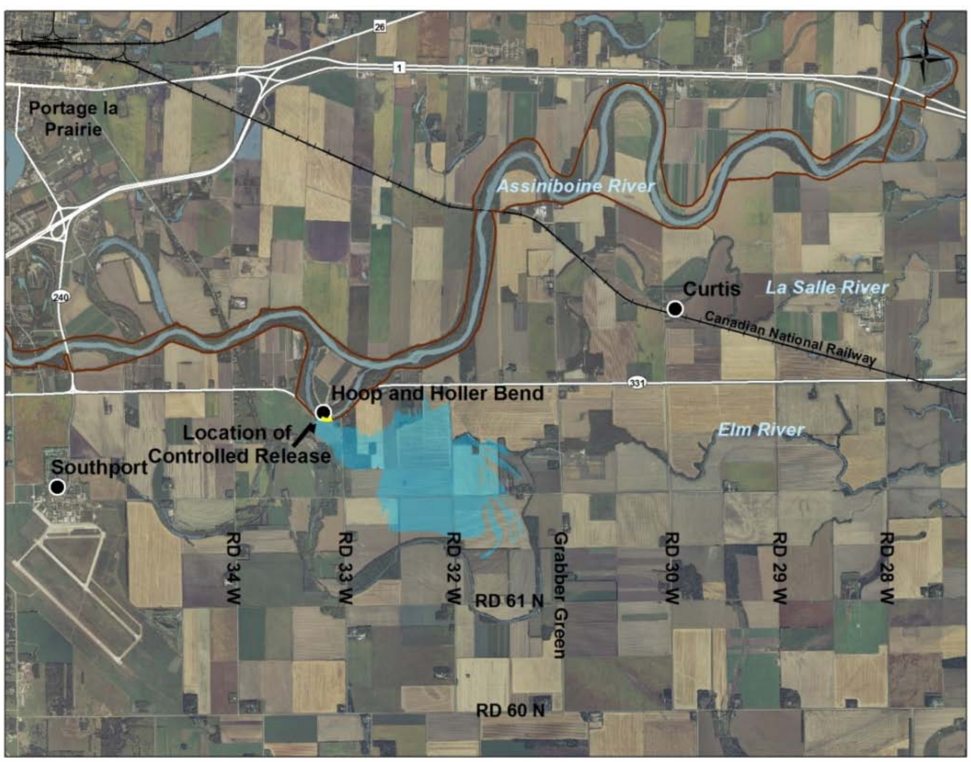

Figure 49: Hoop and Holler controlled release site and inundated area on May 20, 2011.

The work undertaken to increase the capacity of the Portage Diversion to 34,000 cfs (963 cms) from 25,000 cfs (708 cms) was critical in reducing the flows that were required to be diverted through the Hoop and Holler controlled release site. Maximum inflow into the Portage Reservoir reached approximately 53,100 cfs (1,500 cms) on May 14. Flows through the controlled release were maintained between 200 cfs and 400 cfs (5.66 cms and 11.3 cms), peaking at approximately 425 cfs (12.0 cms) on the afternoon of May 17. The Hoop and Holler controlled release was closed at noon on May 20. A total of 1.3 square miles (3.42 square kilometres) were inundated by floodwaters flowing through the controlled release (see Figure 49).

4.2 Lake Manitoba

The target range for water levels on Lake Manitoba in 2011 was 810.5 to 812.5 feet (247.040 to 247.650 m). Water levels on Lake Manitoba reached a record wind-eliminated peak in late July 2011, at 817.05 feet (249.037 m), more than 4.5 feet (1.4 m) higher than the top of the desirable range of water levels (see Figure 50). Lake Manitoba levels receded to 815 feet (248.413 m) by the end of October 2011, dropping at a rate of 0.4 feet (0.12 m) per month. The unprecedented high levels on Lake Manitoba were a result of numerous factors, described below.

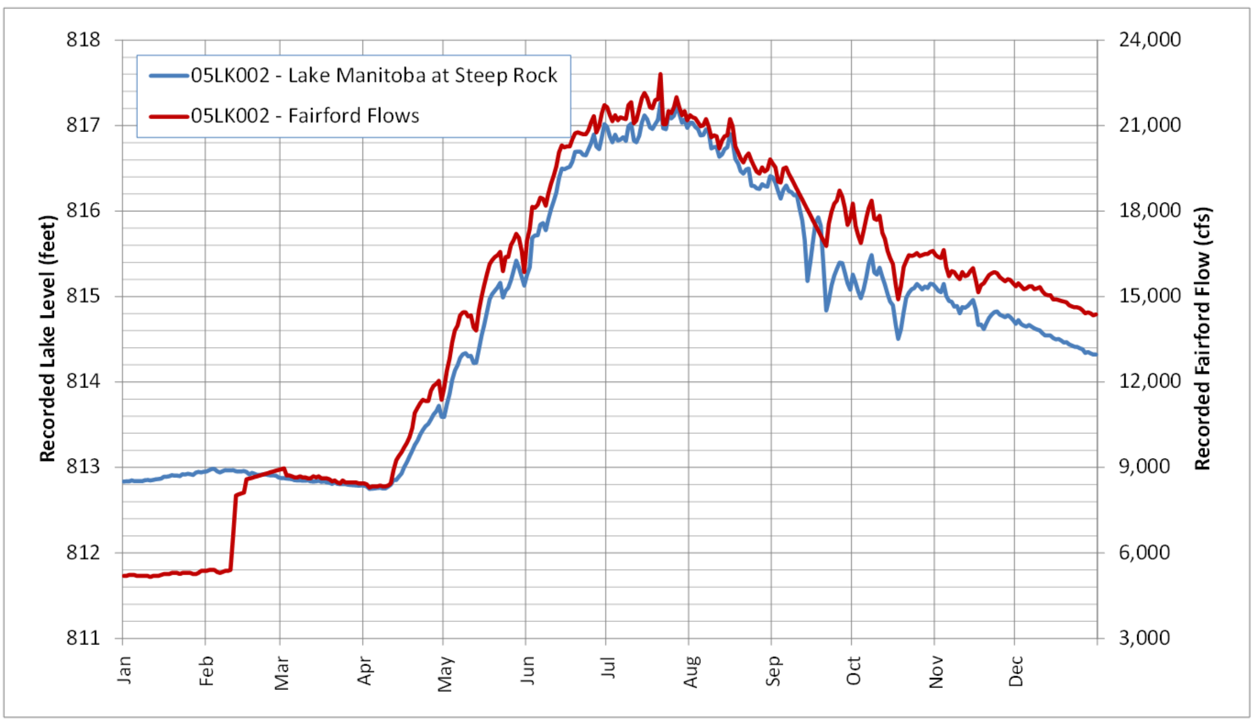

Figure 50: Recorded water levels on Lake Manitoba at Steep Rock and recorded outflows through the Fairford River water control structure in 2011.

High water levels on Lake Manitoba in 2010. Above average precipitation in the fall of 2010 led to high lake levels in 2010 and these high water levels contributed to the high lake levels in 2011. The Fairford River water control structure allowed for greater than natural outflows from the lake through most of 2010 but in spite of this additional outflow, prior to the spring freshet in 2011, the water level on Lake

Manitoba was at approximately 813 feet (247.802 m), already above the top of its desired operating range of 812.5 feet (247.650 m). The recorded level on Lake Manitoba was very high, but approximately 1.9 feet (0.58 m) below the unregulated level that would have occurred in the absence of provincial water control works (see Section 4.2.1).

Record high inflows from the Waterhen River in 2011. The Waterhen River conveys water from Lake Winnipegosis to Lake Manitoba. The Waterhen River is an uncontrolled river with flows that vary depending on lake levels on Lake Winnipegosis. The 2011 Lake Winnipegosis levels were some of the highest observed since record keeping began in 1913. Record high levels on Lake Winnipegosis resulted in high Waterhen River flows, which then contributed to high levels on Lake Manitoba. The total volume of inflow to Lake Manitoba from Lake Winnipegosis in 2011 was the highest ever recorded (see Figure 24).

Figure 51: Photograph illustrating damage to cottages in the Twin Lakes Beach area, on the southern shores of Lake Manitoba.

Above average precipitation and storms. In the spring and early summer of 2011 there was significantly higher than normal rainfall over the lake and the surrounding watershed. The storm between May 27 and June 1 was of particular significance. Many of the homes and properties on Lake Manitoba were damaged during the windstorm event that occurred on May 31 (see Figure 51 for an example of the property damage experienced as a result of that storm event). According to recorded wind data from a weather station at St Laurent, the six-hour average north-northwest wind on that date reached over 60 kilometres/hour (35 miles/hour) and hit a peak of 89.9 kilometres/hour (55.9 miles/hour). These strong, sustained winds forced the water into the south basin of the lake, raising lake levels in the south basin by over 3 feet (1 m) if wave effects are not considered. This is a phenomenon known as wind set-up (see

Figure 52 for an illustration of wind set-up at Westbourne; note that Westbourne was not the site of maximum wind set-up). On top of the wind set-up, the winds produced waves of 4-6 feet (1.2-1.8 m) in height. The effect of the wind and waves on this date produced the highest ever instantaneous water levels on the south and east shores of Lake Manitoba. The lake did climb to a higher wind-effect eliminated water level of 817.05 feet (249.037 m) later in early July of 2011. However, in much of the South basin, the instantaneous wind-affected levels experienced on May 31 remain the highest levels ever recorded on that part of the lake. Damages caused by the storm included destruction of and damage to homes and cottages, shoreline erosion, loss of access, water trapped behind shoreline dunes, environmental damage and damage to recreational properties.

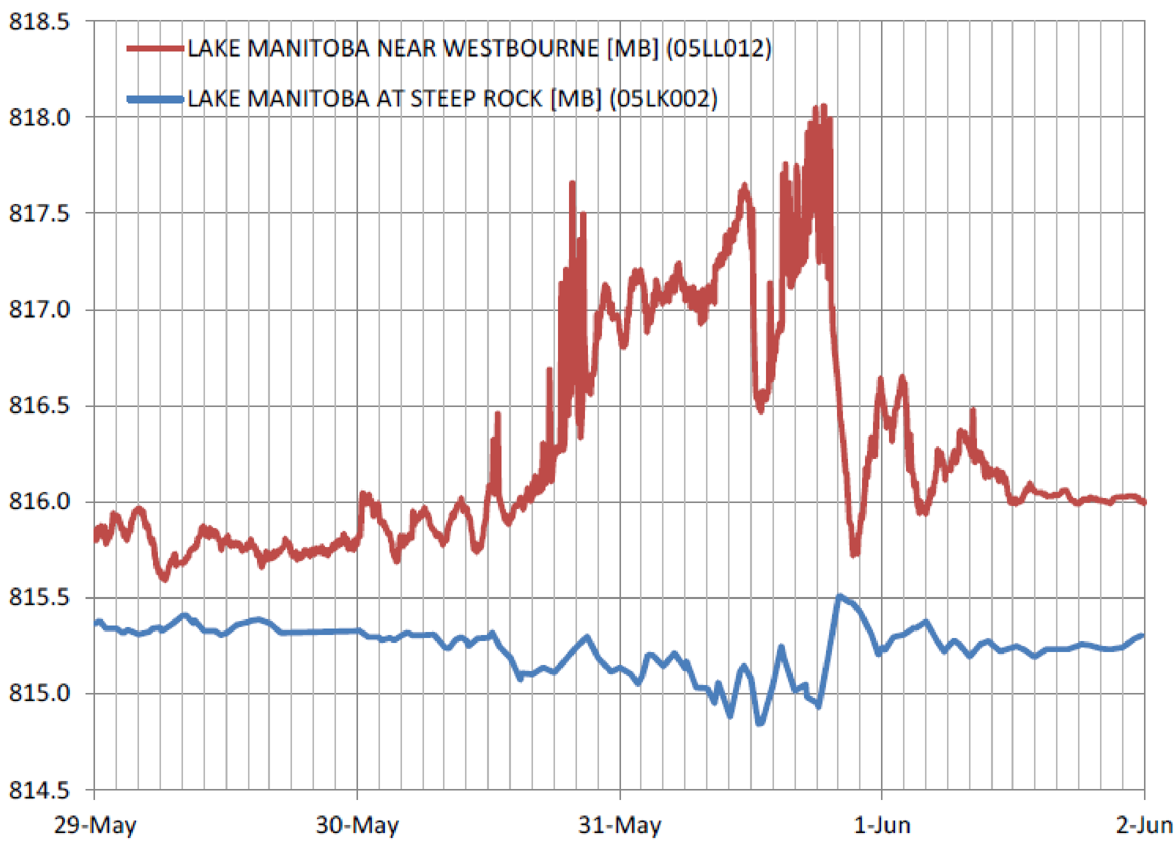

Figure 52: Water levels on Lake Manitoba at Steep Rock and Westbourne, illustrating the effect of wind set-up during the May 31, 2011 wind event. The strong, prolonged northwest wind forced water from the north basin of the lake to the south basin, raising water levels at Westbourne and causing the water levels at Steep Rock to fall. Note that Westbourne did not experience the highest wind set-up on the lake.

Use of the Portage Diversion. Due to the unprecedented high flows on the Assiniboine River, a large volume of water was diverted into Lake Manitoba via the Portage Diversion (see Figure 53). The diversion was in operation for 126 days. For 31 days, the diversion flow exceeded the diversion channel's design capacity of 25,000 cfs (708 cms). The Portage Diversion diverted a record volume of 4.73 million acre-feet (5.83 million dam^3) of water into Lake Manitoba during its operation in 2011. For comparison, during the 1976 flood event, which is the next largest on record, the peak flow in the

Diversion reached 26,000 cfs (736 cms) and the total volume of water diverted to Lake Manitoba was 1.4 million acre-feet (1.72 million dam^3). In order to minimize the volume of water diverted to Lake Manitoba, the Assiniboine River downstream of the diversion remained at maximum safe discharge until the Portage Diversion ceased operation. If the Portage Diversion did not exist, very significant overflows from the Assiniboine River would have occurred and a portion of those overflows would have reached Lake Manitoba (see section 5.2.2 for further discussion of overflows to Lake Manitoba).

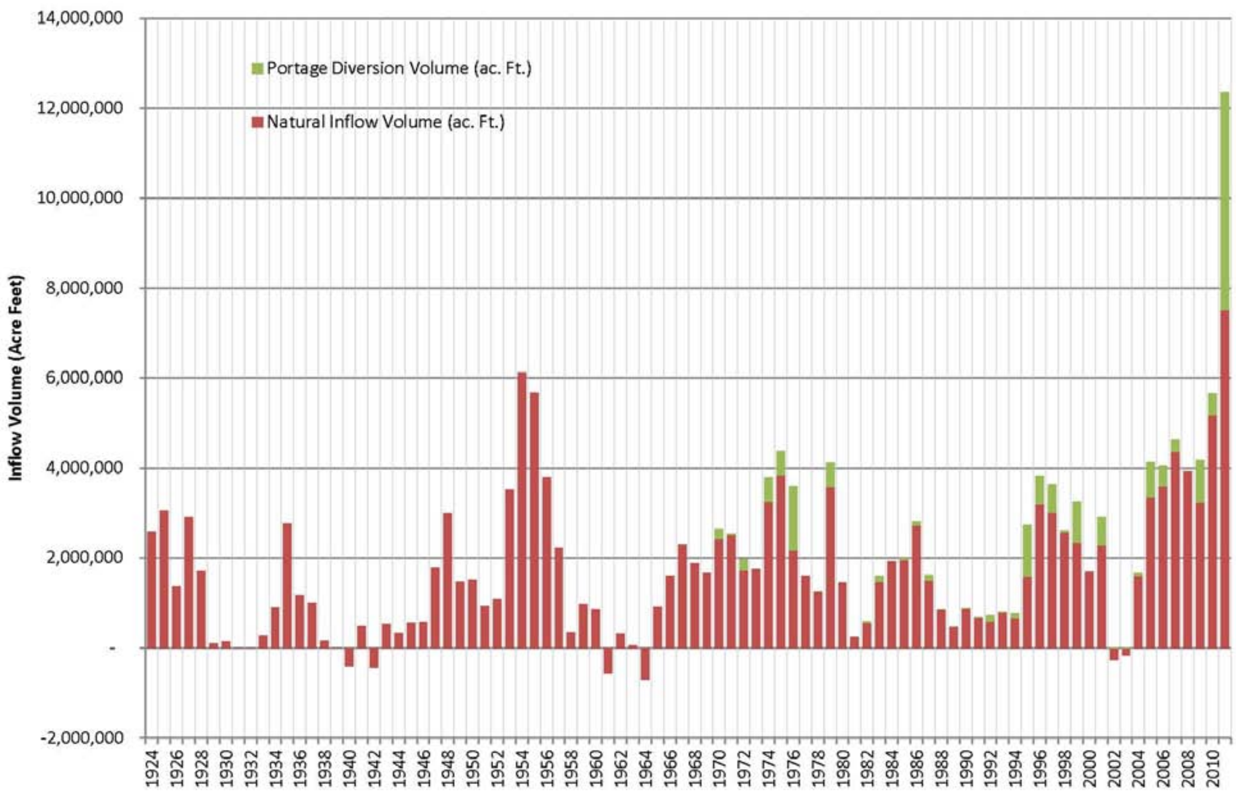

Figure 53: Annual inflows to Lake Manitoba, 1924-2011. Note that the natural inflow volume includes Waterhen River flows, all tributary inflows, plus the net difference in precipitation minus evaporation over the lake surface. Negative natural inflow values on the graph indicate that evaporation from the lake in that year exceeded all inflows to the lake including Waterhen flows, tributary inflows, and precipitation over the lake surface.

4.2.1 Operation of the Fairford River water control structure

Up until November 16, 2010 the Fairford River water control structure was operated to provide the maximum possible outflow in order to lower Lake Manitoba levels due to the high lake water levels and the high spring run-off potential. Beginning on November 16, near the time of freeze-up, outflows through the FRWCS were reduced to minimize the potential for frazil ice jams on the Dauphin River downstream of Lake St. Martin. Lake Manitoba outflows through the FRWCS were increased during the winter (February 11 to 16, 2011) once a stable ice cover was in place on the Dauphin River. From April 12 to 19, 2011, stop logs in the Control Structure were removed so that the discharge through the structure was at the maximum possible. Operation of the FRWCS allowed for greater than natural outflow from Lake Manitoba. Therefore, before spring runoff started, the Lake Manitoba water level was 812.8 feet (247.741 m), approximately 1.9 feet (0.58 m) below the unregulated level. During the entire 2011 flood event the FRWCS was operated so as to allow for maximum discharge out of Lake Manitoba. This additional outflow capacity provided a significant flood reduction benefit to Lake Manitoba. For example, in the calendar year 2011, the total outflow volume recorded through the FRWCS was 10,514,000 acre-feet (13,000,000 dam^3). The computed natural outflow volume through the Fairford River in the absence of the FRWCS would have been 7,014,000 acre-feet (8,650,000 dam^3). Of note, these values only show the benefit that the FRWCS provided during the flood event; they do not include the beneficial reduction in water levels provided before and after the flood event.

4.3 Lake St. Martin

Lake St Martin is susceptible to flooding because of the low lands surrounding the lake and the limited outflow capacity of the Dauphin River. Above average precipitation in 2010, high flows to Lake Manitoba from the Waterhen River and the Portage Diversion and the subsequent operation of the Fairford River water control structure to help lower Lake Manitoba, produced high inflows and caused levels on Lake St. Martin to reach the maximum desirable level of 801 feet (244.145 m) in January 2011. Lake St. Martin levels rose even further due to record high spring and summer flows on the Fairford River, raising the water to a maximum level of 805.5 feet (245.516 m) in July, approximately 2.0 feet (0.6 m) higher than the previous recorded maximum level. Shorelines and backshore areas around the lake were flooded and forced the evacuation of residents from a number of First Nation communities (see Figure 55 and Figure 54).

Figure 54: Lake St. Martin flooded shoreline and backshore area.

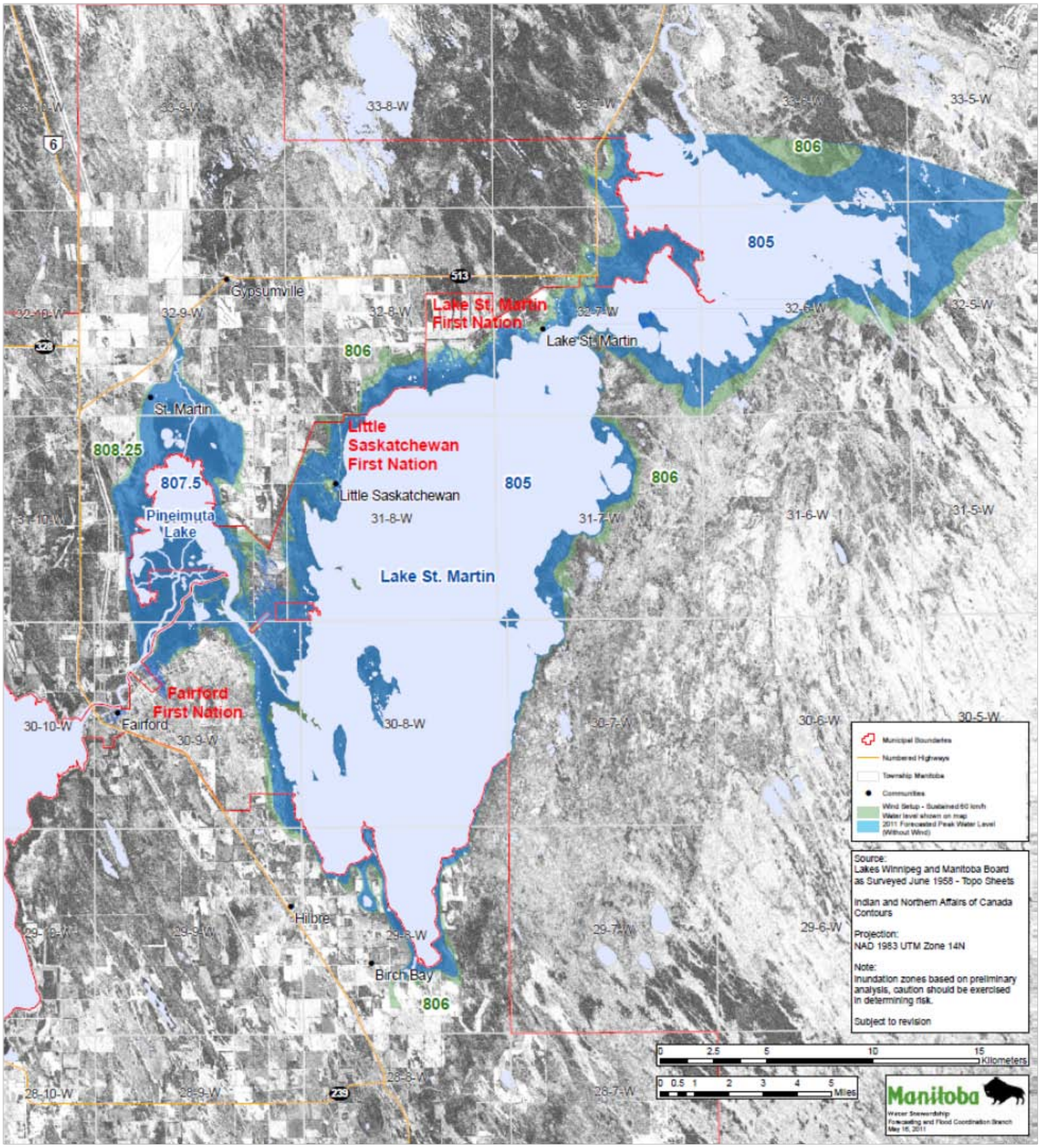

Figure 55: Forecasted flooded area around Lake St. Martin with a water level of 805 feet and wind set-up level of 806 feet.

4.3.1 Construction of the Lake St. Martin Emergency Outlet Channel

In the summer of 2011, while levels on Lake Manitoba and Lake St. Martin remained at or near the highest recorded levels, the Province of Manitoba commissioned two leading engineering firms to explore options to lower water levels on the two lakes on an emergency basis. In addition to the already high levels, an additional concern was that the Dauphin River has a tendency to form frazil ice, which can result in hanging ice dams; this can obstruct the channel and further reduce outflow. Modelling work performed by the consultants showed that under average weather conditions, if ice jams were to form and constrict outflow on the Dauphin River, the levels on Lake St. Martin could have risen as high as 809 feet (246.583 m) (see Figure 56). If Lake Manitoba outflows through the Fairford River water control structure were reduced to ease the flooding on Lake St. Martin, as was normally done during the winter until a solid ice cover forms on the Dauphin River, the water levels on Lake Manitoba would remain higher for a longer period of time.

In their report, the engineering firms modelled and assessed a number of different options and scenarios, including different outlets from Lake St. Martin, additional outlets from Lake Manitoba, and dams and diversions on the Assiniboine River. It was found that the most timely and cost-effective means to lower water levels on both Lake Manitoba and Lake St. Martin was to construct an emergency outlet from Lake St. Martin and to maximize the outflows through the Fairford River water control structure over the winter.

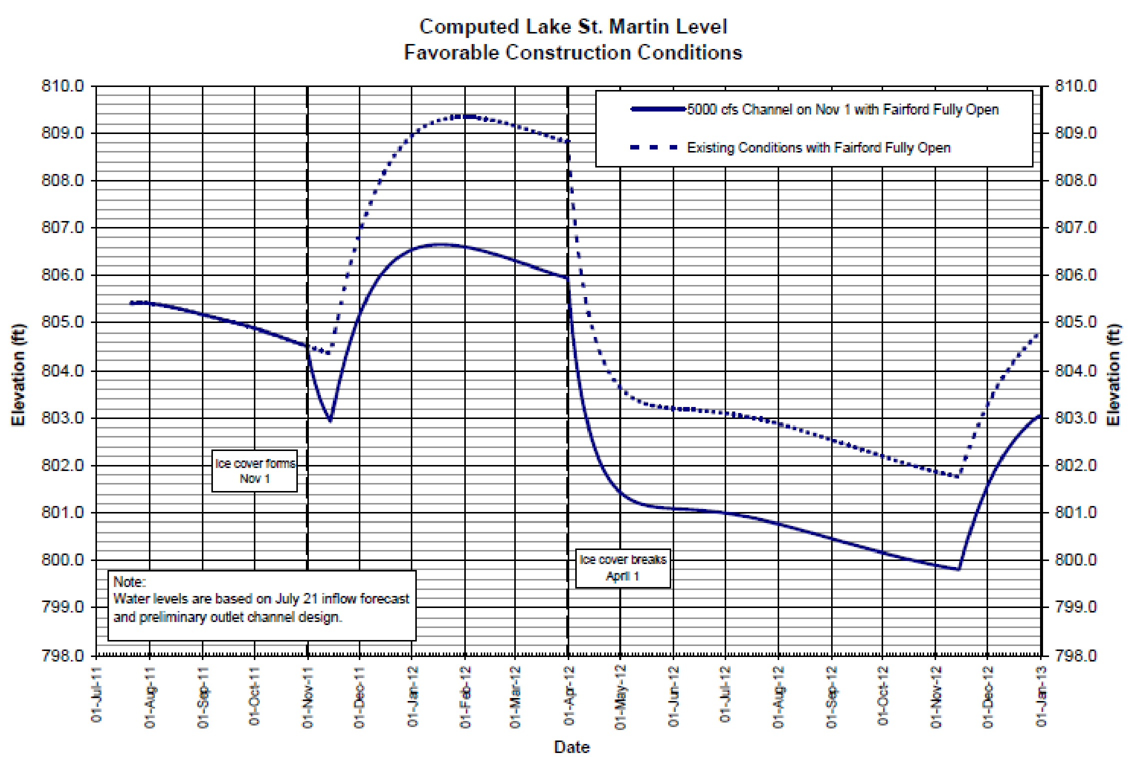

Figure 56: Lake St. Martin Levels with and without an emergency outlet channel through the winter of 2012, as modelled in the summer of 2011 (KGS Group and AECOM, 2011).

Construction of the channel began in late July, 2011 and the channel entered into operation as scheduled on November 1, 2011. Design and construction of the Lake St. Martin emergency channel was a huge project, undertaken in a remote area on short notice and on an emergency basis, during summer and fall when construction is more difficult in such a wet, marshy area. The Lake St. Martin emergency outlet channel was originally designed to be 60 m (197 ft) wide with a discharge capacity of 5,000 cfs

(142 cms) when Lake St. Martin was at a water level elevation of 801 feet (244.145 m). During construction, it became clear that it might not be possible to complete the channel as designed prior to winter and the risk of frazil ice formation. Therefore, it was decided to construct the channel at a slightly smaller size in order to ensure that the project could be completed before freeze-up. The channel was completed to a width of 45 m (148 ft) wide, and had an outflow capacity of 3,750 cfs (106 cms) when Lake St. Martin water level is at an elevation of 801 feet (244.145 m).

The 6.5-kilometre (4.0 mile) long channel was constructed from the east end of Lake St. Martin, running northeast to Big Buffalo Lake (see Figure 57). From there the water followed natural channels to Buffalo Creek, which discharges into the Dauphin River just upstream of where it runs into Lake Winnipeg. An additional channel, known as Reach 3, was constructed from Buffalo Creek eastward to Lake Winnipeg, to be used in case frazil ice buildup at the mouth of the Dauphin River obstructed outflows. Fortunately, mild weather during the winter of 2012 meant that frazil ice did not form and the emergency channel flows remained in the Buffalo Creek without need to open Reach 3.

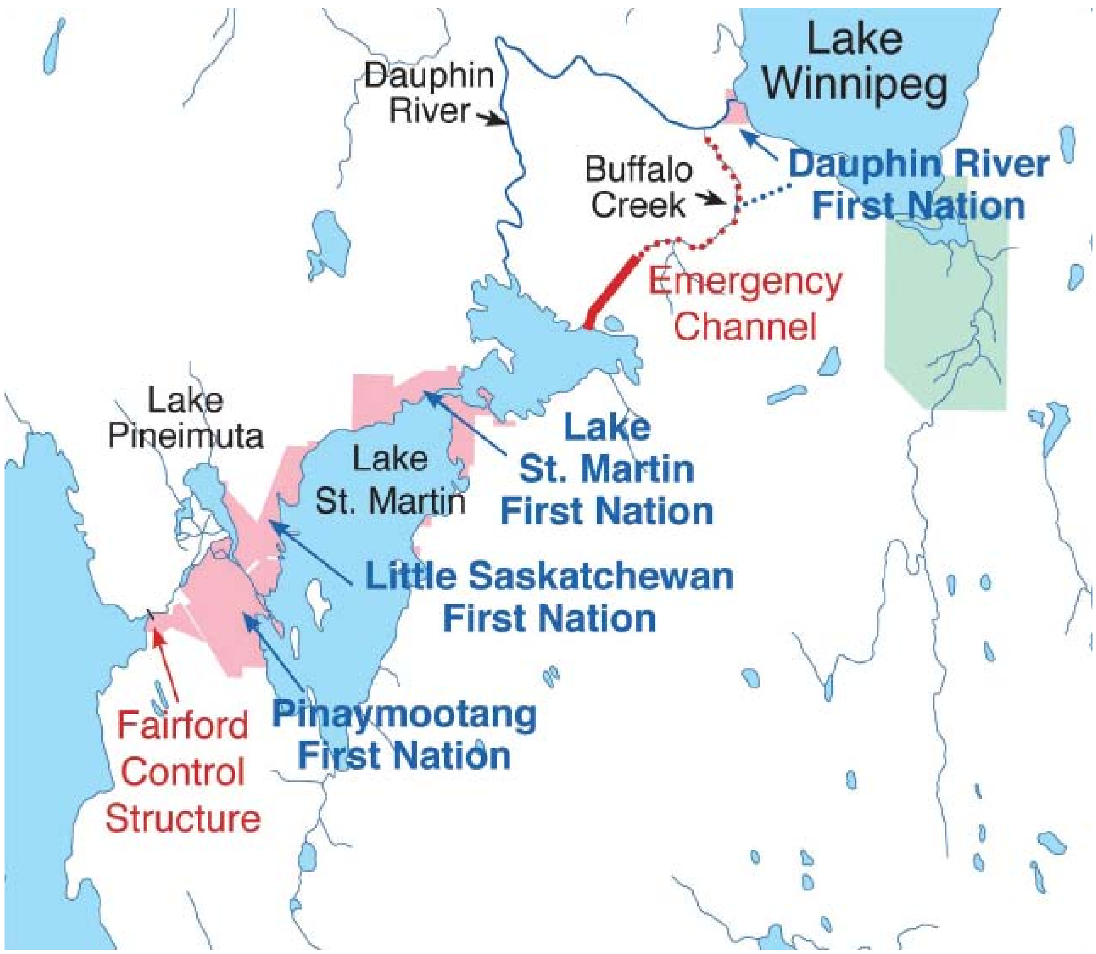

Figure 57: Map showing the Lake St. Martin emergency outlet channel and Buffalo Creek.

The emergency channel operated from November 1, 2011 until November 21, 2012. As discussed above, the winter of 2012 was very mild, and as a result, frazil ice did not develop on the Dauphin River. The Lake St. Martin emergency channel provided additional outflow capacity from Lake St. Martin and thus helped to reduce water levels on both Lake St. Martin and Lake Manitoba much faster than they would have dropped under unregulated conditions. The effect of the Lake St. Martin emergency channel is discussed further in section 5.5 below.

5.0 Analysis of the 2011 Flood Event

One of the objectives of this report is to examine whether Lake Manitoba was artificially high in 2011 due to operation of provincial water control works. Of course, the regulated water levels that occurred during the 2011 flood are known, as they were recorded. The water levels that would have occurred under unregulated conditions must be calculated to determine if at any time the lake was artificially high (above the unregulated water level). The procedure to calculate unregulated lake levels is outlined in section 3.5.

5.1 Unregulated Flows on the Assiniboine River in 2011

The unregulated flows on the Assiniboine River were calculated at the Portage Reservoir. This is an appropriate location at which to calculate unregulated flows, because it is upstream of the Portage Diversion as well as any known natural overflow point from the river. Therefore, the flows there allow for a relatively straightforward comparison between regulated and unregulated conditions. Computing the unregulated flow at this point also enabled hydrodynamic modelling of the overflows in the downstream reaches where the river has a history of overtopping its banks.

In short, the unregulated flows on the Assiniboine River were calculated on the following basis:

- The recorded flows were adjusted by removing the effects of holdouts from the Shellmouth Dam, lagged by Muskingum routing to the Portage Reservoir (a brief description of Muskingum routing is provided in section 3.4)
- The recorded flows were adjusted by removing the effect of holdouts from the dams on the Souris River, lagged by travel time to the Portage Reservoir.

The resulting flows on the Assiniboine River at the Portage Reservoir are shown graphically in the hydrograph in Figure 58, and the magnitude and timing of peak flows are summarized in Table 5 below.

Table 5: Summary of magnitude and timing of peak flows on Assiniboine River at the Portage Reservoir in 2011.

	Peak Flow at Portage la Prairie (Date)
Unregulated Flows without Shellmouth Dam or Souris River Dams	64,200 cfs (1,820 cms) (May 12, 2011)
Unregulated Flow without Shellmouth Dam	60,200 cfs (1,700 cms) (May 13, 2011)
Recorded Flows	53,100 cfs (1,500 cms) (May 13, 2011)

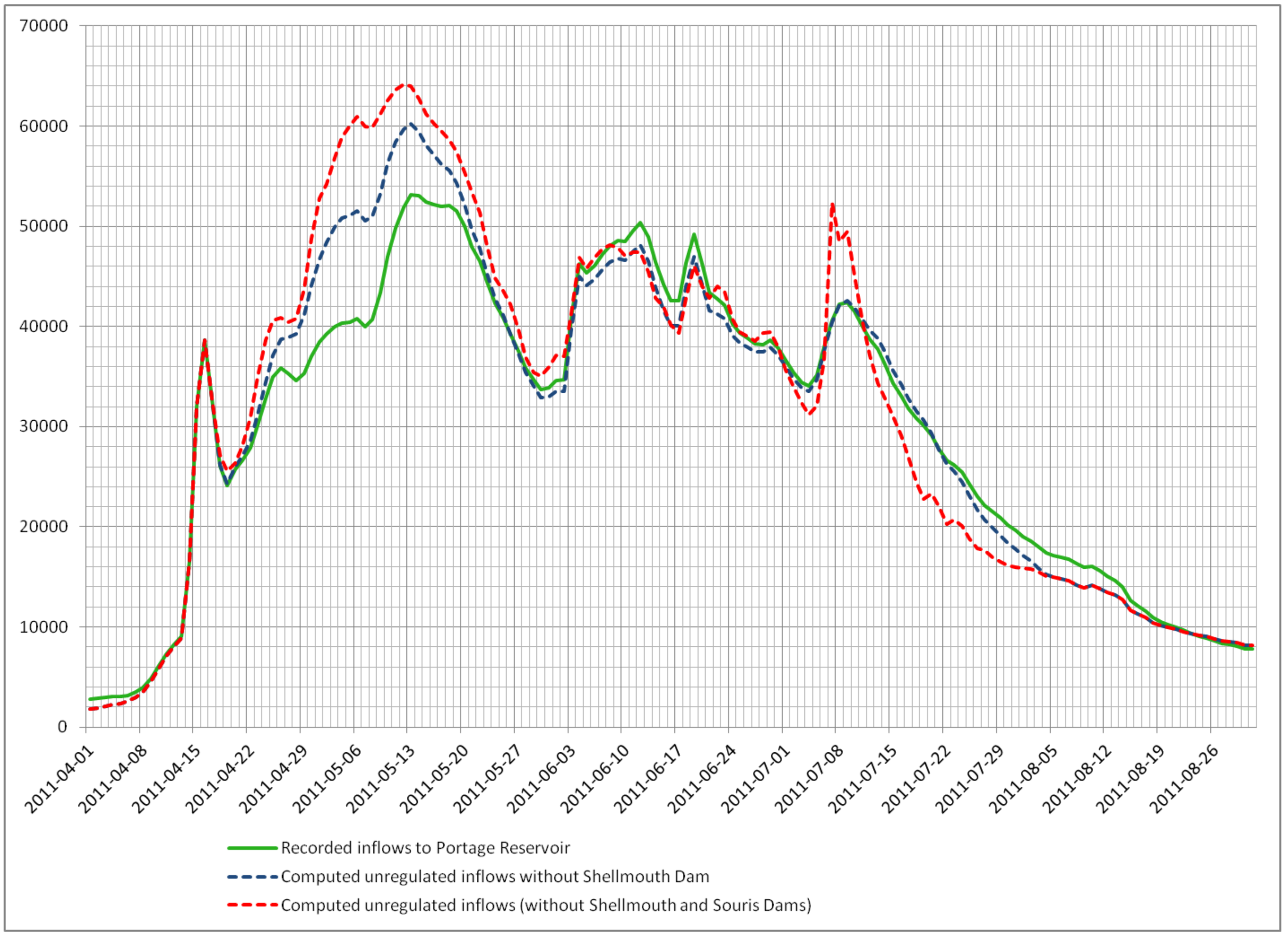

Figure 58: Recorded and unregulated flows on the Assiniboine River at the Portage Reservoir in 2011.

5.2 Estimation of Assiniboine Overflows

Under unregulated conditions, one of the inflows to Lake Manitoba that requires computation is the volume of water that would have overflowed from the Assiniboine River into Lake Manitoba. If the total volume of overflows was large, relative to the total volume of inflows into the Lake, those overflows could result in significantly higher unregulated water levels on the lake. However, if the volume of overflows was small, relative to the total volume of inflows, then the overflows would not be an important part of the water balance, which determines the unregulated level of Lake Manitoba.

Given the extremely high flows on the Assiniboine River in 2011, some amount of overflow from the Assiniboine River to Lake Manitoba would have occurred under unregulated conditions. This can be concluded from the fact that overflows to Lake Manitoba occurred during the floods of 1922 and 1923, prior to modern flood control infrastructure, when the peak flows at Portage la Prairie were less than 25,000 cfs (708 cms), a fraction of the 2011 peak flow of 64,200 cfs (1,820 cms) at Portage la Prairie.

Unfortunately, it is impossible to know with certainty exactly how much water would have overflowed under unregulated conditions in 2011. Overflows from the Assiniboine River to Lake Manitoba have not occurred since the 1920s, and although historic occurrences were documented, no measurement of the overflows could be found. As a result, it is not possible to use past overflow records to estimate the volume of overflows that would have occurred under unregulated conditions in 2011. Therefore, to estimate the overflows, the Hydrologic Forecasting Centre of Manitoba Infrastructure and Transportation created a hydrodynamic model of the Assiniboine River and adjacent overflow areas.

5.2.1 Description of Hydrodynamic Model

A hydrodynamic model is a computer model used to determine how water would move across a landscape by taking into account the topography of that landscape (the elevation and surface features of the landscape) and the flow that enters that landscape area from upstream. In determining how the water would flow, the model computes related information such as the direction and velocity of flows, and calculates a water surface profile (the elevation of the surface of the water above the ground). The model can also compute how much flow moved through a specific water course or a defined area of overland flow during the period of time that the model runs.

In order to develop the hydrodynamic model, a technical committee was assembled consisting of personnel from government, academia and the private sector. This included hydraulic and hydrologic engineers, as well members with expertise in geomorphology and geographic information systems (GIS). The committee reviewed technical data and historic records to develop input data and parameters for the model.

For the development of the model of the Assiniboine River overflow, the department used MIKE 21 FM, a well-known commercially available two-dimensional hydrodynamic software package developed by the Danish Hydraulic Institute (DHI). The model was developed to cover an area of approximately 1,900 km^2 (734 mi^2), shown in Figure 59. The model begins upstream at the location of the Portage Reservoir, near the apex of the alluvial fan, and continues east to include the area downstream to Baie St. Paul.

Topographic information is a key element in determining how the water would have flowed under unregulated conditions. This includes how the water flowed through channels, where overflows would have left the main channel and, once outside of the channel, how the overflows would have moved across the landscape or through paleochannels. Highly accurate light detection and ranging (LiDAR) surface elevation data was acquired in 2011 and 2012 (the stated tolerances of the data are vertical accuracy within 9 cm and horizontal accuracy within 75 cm). However, this topographic information is representative of the current landscape at the time the data was captured. In other words, the data is representative of regulated conditions, and not the pre-development conditions necessary to analyze unregulated overflow.

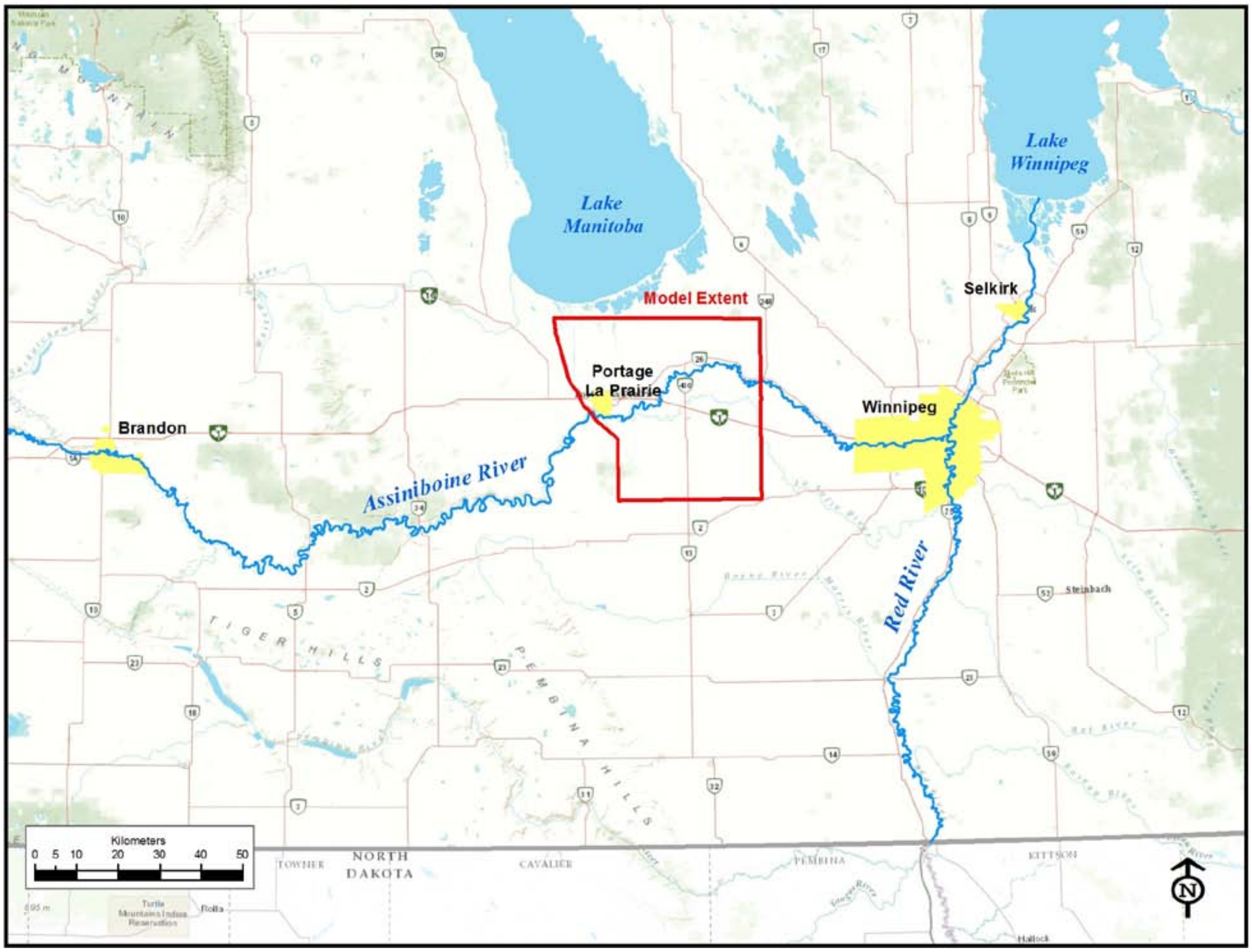

Figure 59: Map showing the extent of the hydrodynamic model study area.

The topographic information used in the model was, for the most part, the elevation and surface elevation data captured by LiDAR, except for some modifications to replicate unregulated pre-development conditions. These modifications approximate the landscape and topographic conditions in the study area, as they would have been prior to the development of water control infrastructure, as well as roads, railways and drains. The changes to the LiDAR topography were as follows:

- removal of the Portage Diversion, the Assiniboine River dikes and the dikes erected to block off overflows from the Assiniboine River to paleochannels
- removal of roads, railways and drains. Other human-made structures, such as dikes built across paleochannels, were also removed
- realignment of the Assiniboine River to its original configuration (the original channel in a relatively short reach just downstream of the current Assiniboine River control structure was shifted when the Portage Diversion was constructed)
- adding two coulees to the landscape that historically existed adjacent to the Assiniboine River downstream of the Portage Reservoir. The historical topographic information was obtained from published reports (see Figure 61)
- raising the bed of the Assiniboine River downstream of the current Assiniboine River control structure to pre-diversion levels (recent bathymetric measurements on the river channel

indicated that there had been significant erosion of the channel immediately below the Portage Diversion) – using cross sections of the river collected in 1921, the pre-development river channel was reconstructed by raising the bottom of the channel back to the elevation that was surveyed in 1921

The pre-development topography used in the hydrodynamic model is one specific scenario amongst many that could be argued to represent the unregulated condition. There are two factors that complicate the definition of unregulated conditions on Lake Manitoba. First, there are a large number of water control structures that affect Lake Manitoba water levels. Second, these structures were built at different times over the past century. Thus, when removing a structure from the landscape to represent unregulated conditions, it raises the question about what topography is appropriate to use in its place. Generally, the answer is to use the topography that was present before the structure was built. This is usually straightforward when determining unregulated conditions for a single water control structure, as there is a defined geographic scope and a single point in time when the structure was built. Thus, it is easier to determine an unregulated landscape based on the landscape in place before the structure was present. However, when dealing with Lake Manitoba, a wide range of landscape changes were associated with the water control structures, both within the basin at large as well as within the model study area. In determining the topography for the hydrodynamic model there is a wide range of options, including the topography from 1965 before the Portage Diversion was built, or the topography from 1912 before the first government–built dikes along the Assiniboine River. The availability of detailed historical topographic data was a limitation. The oldest detailed topographic information available for the study area is the Manitoba Drainage Commission's maps and cross-sections from 1921. A pre-development topography scenario was selected for the hydrodynamic model because it provides a single point of reference, which removes the effect of all man-made alterations to the landscape. Using any topographic dataset other than a pre-development scenario to represent unregulated conditions would have still had some water control structures present on the landscape. The results from the hydrodynamic modelling of the pre-development scenario was intended to be illustrative of overflows and enable consideration of the modeling of other possible unregulated scenarios, if necessary and warranted. This is discussed further later in this report.

This topographic data was input into the model as a mesh, or a triangular grid, used to represent the surface of the land. The model calculates the direction in which flows will move based on relative elevation of neighbouring grids in the mesh. In general, the grid was made finer and more detailed in lower elevation areas where flows would logically be expected (see Figure 60). Conversely, the grid was made coarser in higher elevation areas where flows were less likely. In other words, the size of the grid does not determine overflows, only the level of detail in how the flows would propagate downstream.

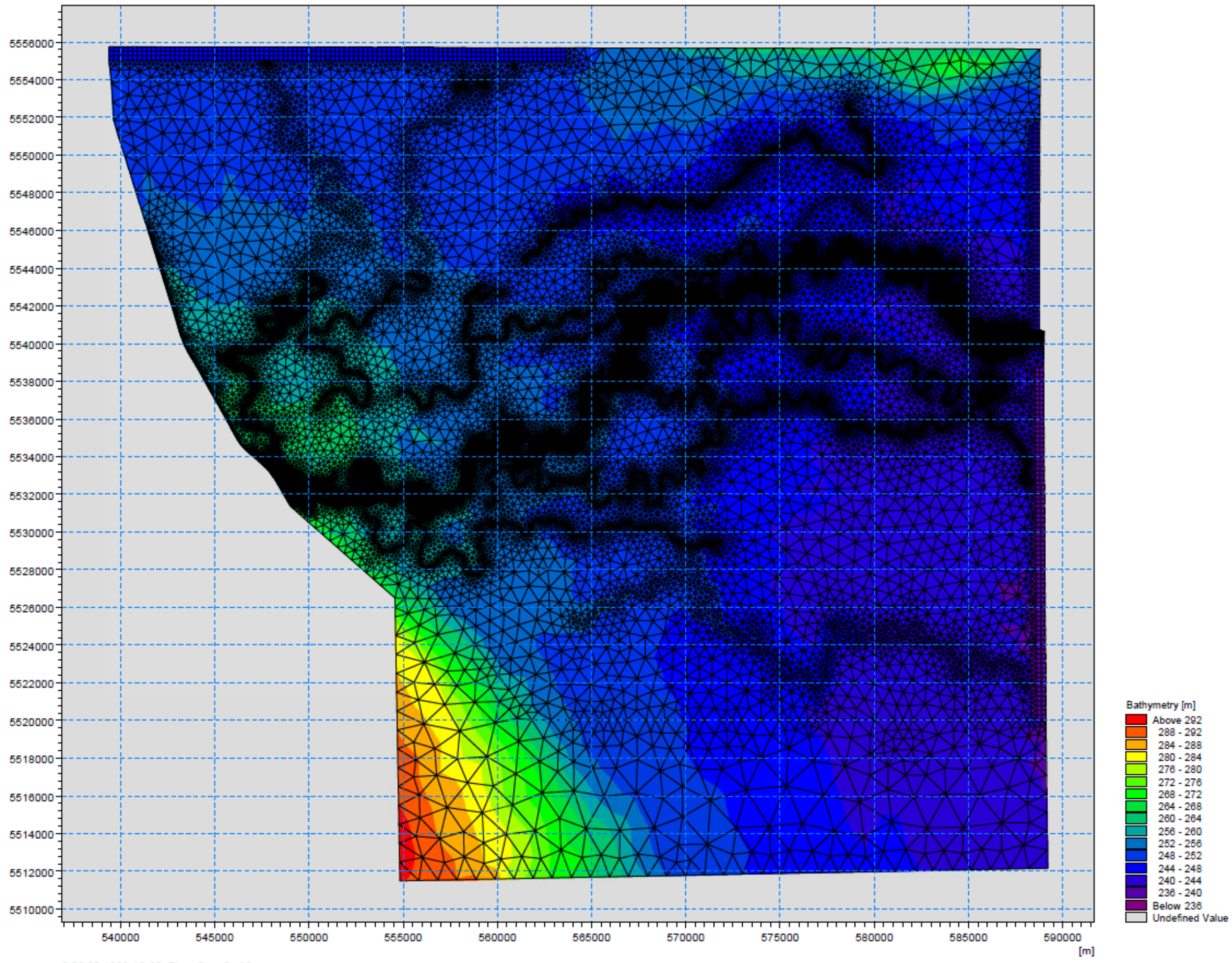

Figure 60: Study area showing the elevation mesh used in the hydrodynamic model. The colours represent the elevation of the ground surface. The larger triangles were placed in areas of higher elevation where flows were not expected, while channels, paleochannels and lower elevation areas have the densest mesh (smallest triangles) since flows were much more likely there.

The hydrodynamic model requires that the water level or flow conditions at the boundary of the study area (the area modelled by the hydrodynamic model) be set; these conditions are called boundary conditions. There are several ways to set the boundary conditions, and different parts of the boundary can be set to have different boundary conditions. It is important that the boundary conditions be set appropriately so that the boundaries do not unrealistically affect the flow patterns and flow volumes in the study area. The western boundary of the model was set as a wall, preventing flows from moving in that direction. However, in portions of the model where flows were expected to continue downstream, past the edge of the boundary, such as the Assiniboine and La Salle Rivers, and the area running down towards Lake Manitoba, the boundary conditions were created so that water did not back up and affect the flows in other parts of the model.

Since the purpose of the model was to provide an estimate of overflows to Lake Manitoba under unregulated conditions, the unregulated flows on the Assiniboine River, described in section 5.1 above, were used as an input to the model. The unregulated flows for the period from April 8 to August 16, 2011 were used as an input into the model. The flows were entered into the model in the upstream end of the Assiniboine River channel at a point just upstream of the present Portage Diversion inlet structure. From this point the model then computed which direction the water flows at regular intervals of time through the entire period of study. In general, the flows in the model follow the Assiniboine River channel downstream until the water levels exceed the capacity of the channel. The model then computed where the overflows would leave the channel and how they would flow across the landscape, by computing movement from cell to cell of the mesh.

The river channel portion of the model was calibrated to ensure that it was an accurate representation of reality. This was done by inputting regulated flows into the upstream portion of the Assiniboine River channel (using the present-day topography) and modifying the Manning's roughness coefficient (the "n" value) so that recorded water levels were replicated by the model. The channel calibration was undertaken for two flow values, 12,000 cfs (340 cms) and 18,000 cfs (510 cms). The overbank flow conditions could not be calibrated because there is no recorded hydrometric data for overflow conditions. Therefore, for the overbank areas in the model, a roughness coefficient typical of grassed overbanks in published technical literature was used.

The hydrodynamic model that was used was large and complex, with 97,000 nodes and 164,000 mesh elements (triangles) covering a model area of over 1,500 km^2 (579 mi^2). Even using a powerful computer, it took approximately two weeks of 24 hours/day computing time to complete a simulation run. Given that the model and the input data had to be developed and refined over time, in order to accurately represent the situation on the ground, creation and development of the model took a significant amount of time.

5.2.2 Overflow Results from Hydrodynamic Model Analysis

The results from the hydrodynamic modelling indicate that under unregulated conditions, assuming pre-development topography, the Assiniboine River would have overflowed its banks just west of Portage la Prairie on April 14 when the flows on the Assiniboine River reached approximately 18,000 cfs (510 cms) (see Figure 62). The overflow to Lake Manitoba would have peaked on May 11 at approximately 5,400 cfs (153 cms). The overflows to Lake Manitoba would have continued over much of the summer, ending on approximately July 17. The total volume added to Lake Manitoba by the overflows from the Assiniboine River would have been approximately 402,000 acre-feet (495,635 dam^3).

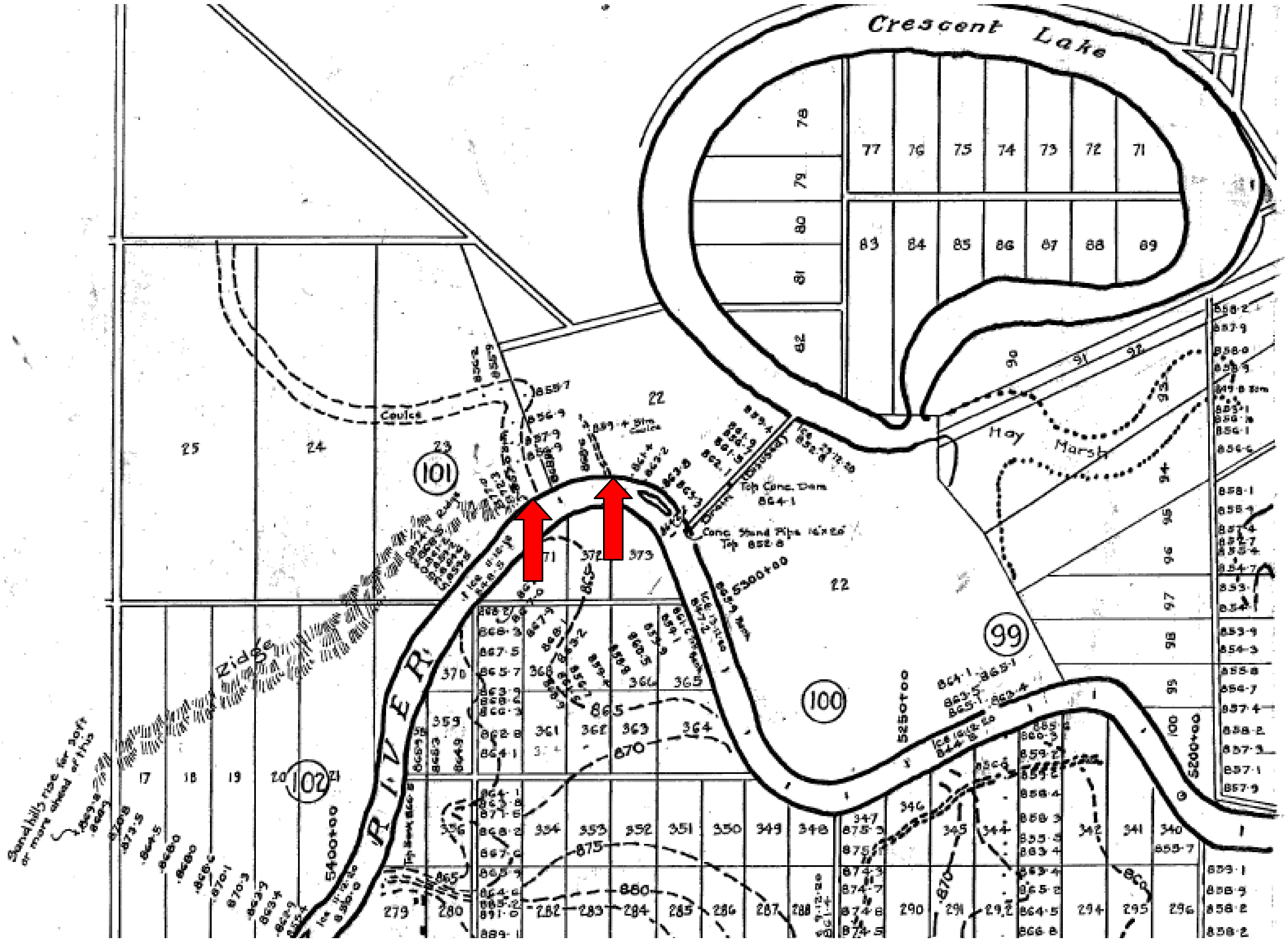

Figure 61: An excerpt from Topographic Map #56 of the 1921 Drainage Commission Report showing the area where overflows to Lake Manitoba would have originated. Note that there are two coulees shown on the map (indicated by arrows). These coulees were the likely points of overflow to Lake Manitoba. Point elevations on the bottom of these channels were used to produce the topography in the hydrodynamic model (Manitoba Drainage Commission, 1921).

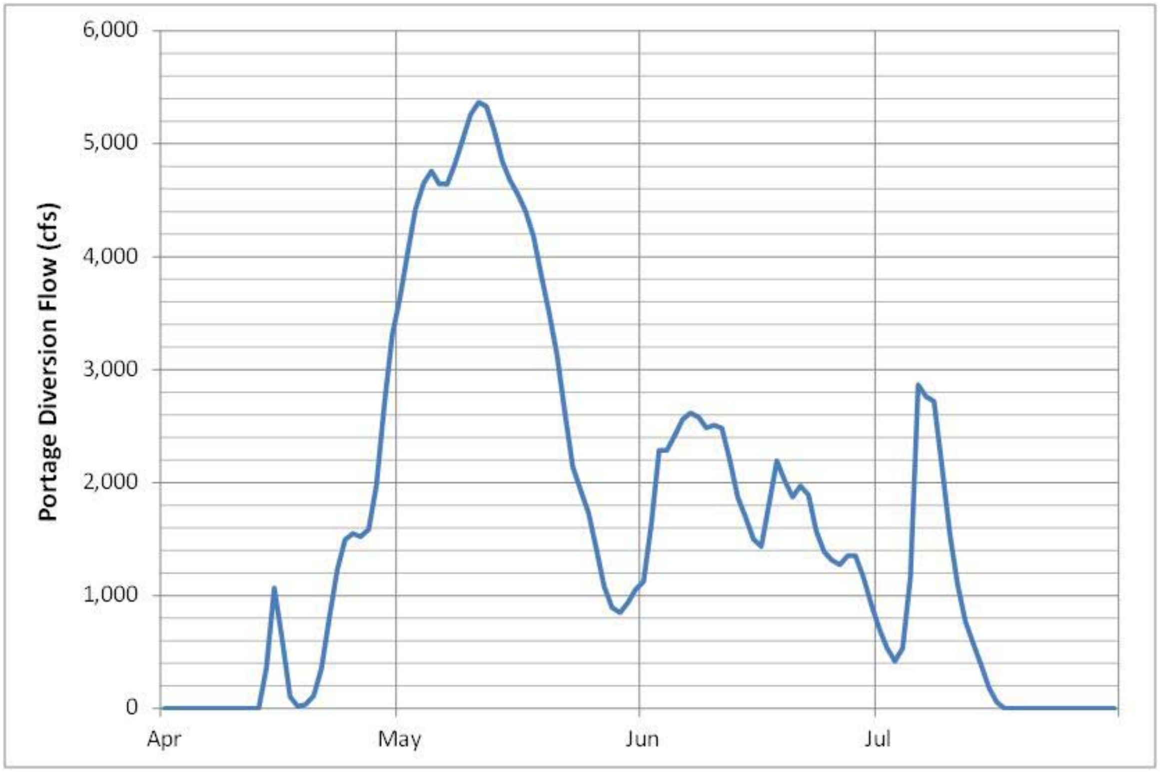

Figure 62: Computed overflow from the Assiniboine River to Lake Manitoba.

Figure 63 below shows the maximum inundated area calculated by the hydrodynamic model within the study area. The model computed a large amount of overflow from the Assiniboine River both to the north and south of the river. The overflows out of the Assiniboine River that reach Lake Manitoba occur to the west of Portage la Prairie; these overflows are visible on the western edge of the map. It can be seen that much larger overflows out of the Assiniboine River occurred downstream of Portage la Prairie. These overflows spread out across the prairie and followed paleochannels downstream or flowed overland. It is worth noting that this model was designed to compute overflows from the Assiniboine River, however, the results on the eastern boundary of the model should not be considered as accurate as those further upstream because the boundary conditions were modified based on the model extent.

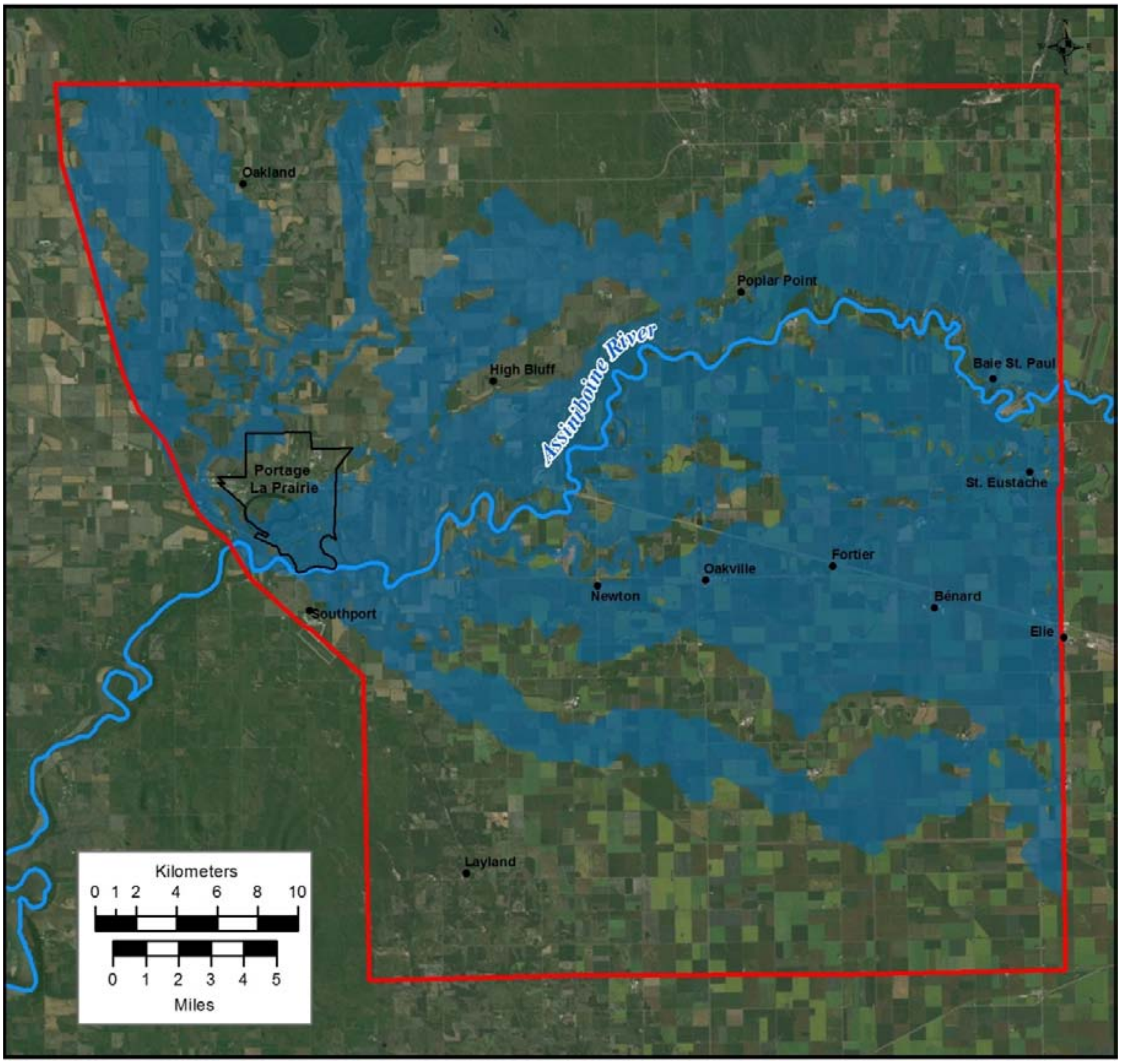

Figure 63: Extent of inundated areas predicted for 2011 under unregulated flows and pre-development topographic conditions. The boundaries of the study area are shown in red.

The overflow from the Assiniboine River to Lake Manitoba took place over two basic routes. First, there was a coulee from the river (clearly shown in Figure 61 above at the left red arrow), which conveyed flow northwestward, where it likely would have joined the Whitemud River and flowed to Lake Manitoba. Unfortunately the model did not extend far enough west to capture the Whitemud River so the water instead travelled northward along the western edge of the model. Second, at higher flows on the Assiniboine River, water overflowed into the Blind (sometimes known as the Fort la Reine) paleochannel (see right red arrow in Figure 61) and followed the meandering course of the channel northward to Lake Manitoba. These findings were compatible with information in the historical record, where some accounts indicated that the overflows reached Lake Manitoba via the Whitemud River (Archives of Manitoba, Sessional Papers, GR 1565, Report to the Minister of Public Works, 1884; Hind, 1860), while other accounts indicated that the overflows travelled via paleochannels directly to Lake Manitoba (Upham, 1890; Prairie Farm Rehabilitation Administration, 1952).

An attempt was also made to estimate the inundated area due to Assiniboine overflows outside of the modelled area, downstream to Winnipeg. Figure 64 below, shows an approximate estimate of the inundated area downstream of the model, based on the modelled results and available topographic information.

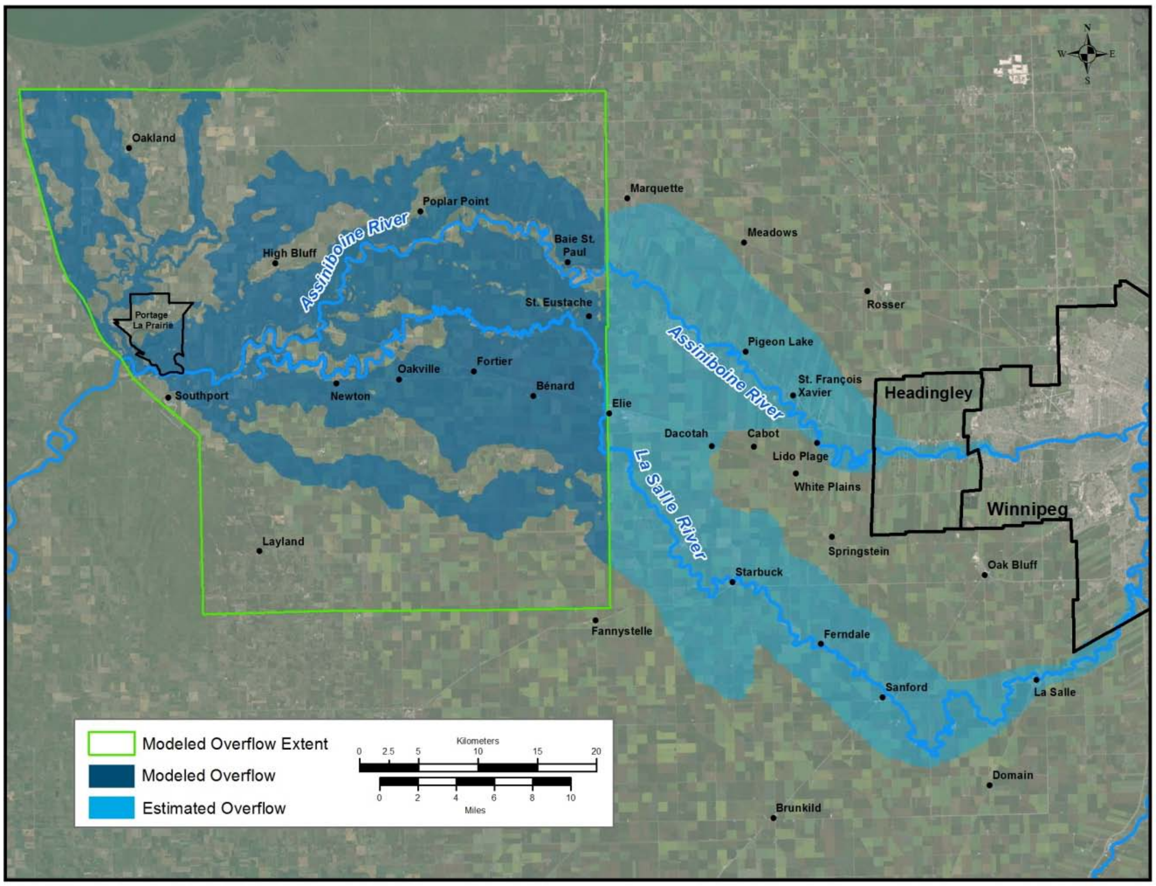

Figure 64: Map showing the modelled overflows within the study area (green box) under unregulated flows and pre-development topographic conditions. The extent of overflows downstream to Winnipeg was estimated based on limited topographic information.

The hydrodynamic model calculated total overflows from the Assiniboine River to Lake Manitoba that were significantly lower than what was expected to have occurred under unregulated conditions. Early estimates based on the historic evidence was that overflows from the Assiniboine River to Lake Manitoba would be as high as 25 per cent of the total unregulated flow on the Assiniboine River above bankfull capacity, estimated to be 10-15,000 cfs (283-425 cms). Instead, the results from the unregulated, pre-development scenario analyzed in the hydrodynamic model show that the peak overflows to Lake Manitoba were only 8.4 per cent of the peak flows on the Assiniboine River and 11 per cent of the peak flow above estimated bankfull capacity.

There are a number of factors that may have resulted in the model underestimating overflows to Lake Manitoba. First, the model did not account for any erosion that would have occurred. In many areas, there were high water velocities associated with the overflows, which would have caused significant erosion. The erosion would have created wider and deeper overflow channels and increased the total overflows. Second, removal of all infrastructure from the landscape in the hydrodynamic model has an indeterminate effect of overflows, and may have actually reduced the volume of overflows to Lake Manitoba. While roads would have initially contained overflows, as Figure 15 and Figure 18 from the 1923 flood and Figure 21 from the 1955 flood illustrate, under flood conditions, roads and embankments can be washed out or overtopped. In some cases, authorities may be forced to breach roads in order to prevent the water from destroying larger sections of road. On the other hand, if the roads and dikes had been left in the model, overflows from the river would have been constrained, in turn raising water levels on the river. The higher water levels would have still resulted in overflows from the Assiniboine River (the river simply would not have had the capacity to convey the extremely high flows) but the location and amounts of overflow would have been different. In other words, different variations of the topography in the model would have produced different overflow results – it is probable that under some topographic conditions the overflow to Lake Manitoba would have been higher than the results that the model calculated with pre-development topography. It is also important to note that, if the Portage Diversion and other water control works had not been present on the landscape, the Assiniboine River would have overflowed its banks during large flood events. Under conditions where the Assiniboine River overflowed its banks more frequently, infrastructure such as roads and railways would have had to have been constructed to accommodate these overflows, meaning that culverts or bridges would have been necessary in some locations to allow overflows to move downstream.

5.3 Unregulated Levels on Lake Manitoba in 2011

The results of the analysis of water levels on Lake Manitoba are displayed in Figure 65 below. Two different unregulated water levels on Lake Manitoba were calculated. The first unregulated level assumes that no overflows from the Assiniboine River occurred. The second unregulated level assumes overflows from the Assiniboine River calculated by the hydrodynamic model based on a landscape that approximates conditions prior to European settlement and alteration of the landscape (pre-development conditions). Figure 65 shows the recorded wind-effect eliminated (WEE) water levels and both computed unregulated levels on Lake Manitoba from 2011to 2012. The figure illustrates that the only time that the recorded WEE water levels were higher than the unregulated water levels was for a short period in the summer of 2011, from June 22 to August 30. Due to the increased outflow capacity of the Fairford River outlet from Lake Manitoba, the recorded WEE water levels dropped below flood stage of 814 feet by February of 2012. In contrast, the unregulated water levels would have peaked only slightly lower during the summer of 2011, but Lake Manitoba would have remained above 815 feet until August of 2012, and above 814 feet well into 2013.

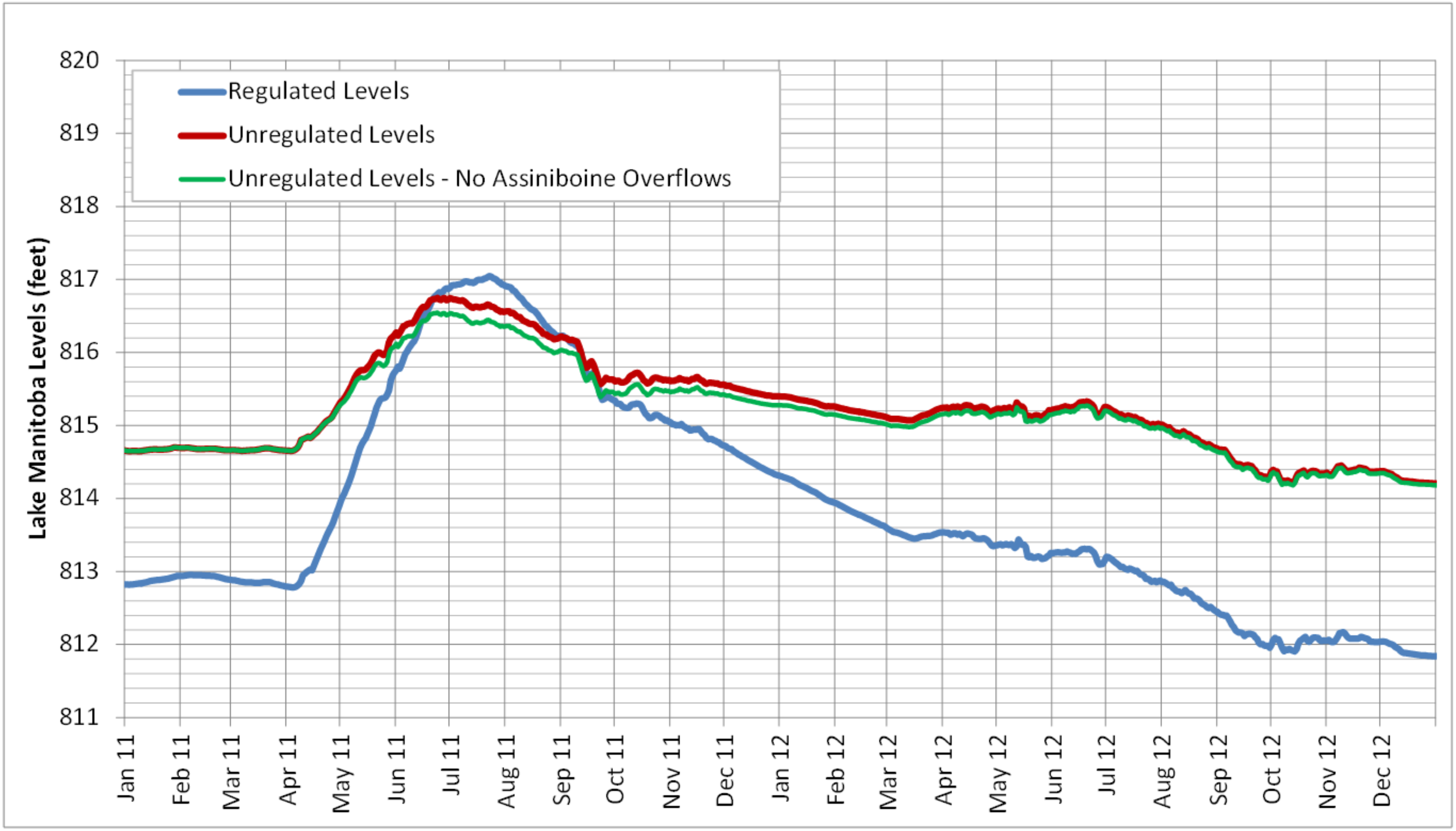

Figure 65: Regulated and unregulated Lake Manitoba water levels in 2011 and 2012, wind-effect eliminated.

Table 6: Summary of Lake Manitoba wind-effect eliminated water levels under different scenarios.

	March 31	May 31	June 31	July 31	August 31	Sept. 31	2011 Peak Level (date)
Regulated	812.80	815.72	816.87	816.93	816.22	815.35	**817.05** (July 23)
Unregulated – no Assiniboine overflows	814.66	816.08	816.52	816.35	816.02	815.46	**816.55** (July 1)
Unregulated – pre-development overflows	814.66	816.24	816.72	816.56	816.21	815.63	**816.75** (July 1)

Note: all lake levels in the table above are reported in feet above sea level.

The January 1, 2011 wind-effect eliminated water level of 812.8 feet (247.741 m) on Lake Manitoba is the highest recorded lake level at the start of the year since the Fairford River water control structure was put into operation. It was more than half a foot higher than the next highest start of year WEE water level. However, Figure 65 shows that under unregulated conditions the water level on January 1, 2011 would have been almost two feet higher at 814.6 feet (248.290 m).

The greatest damage around the south basin of Lake Manitoba was caused by the windstorm on May 31, 2011. Strong winds combined with high lake levels caused major damage to structures and cottages along the lake shore. Figure 66 shows the inflow and outflow volumes and the change in water level from January 1, 2011 to May 31, for both the regulated conditions and the conditions that would have occurred in the absence of the water control works. Even though the total actual inflow over this period was almost 50 per cent greater than unregulated conditions as a result of the inflows from the Portage Diversion, the May 31 WEE level for the lake was still half a foot below the unregulated water level, due to the larger outflow capacity of the Fairford structure and the lower water level before the spring runoff began.

Figure 67 shows the total inflow and outflow volumes and the change in water level from January 1 to the date of peak water levels on Lake Manitoba. For regulated conditions, the inflow and outflow volumes and change in water level are illustrated for the period from January 1 to July 23, the date of the regulated peak water level. For unregulated condition, the inflow and outflow volumes and change in water level are illustrated are for the period from January 1 to July 1, the date of the unregulated peak water level.

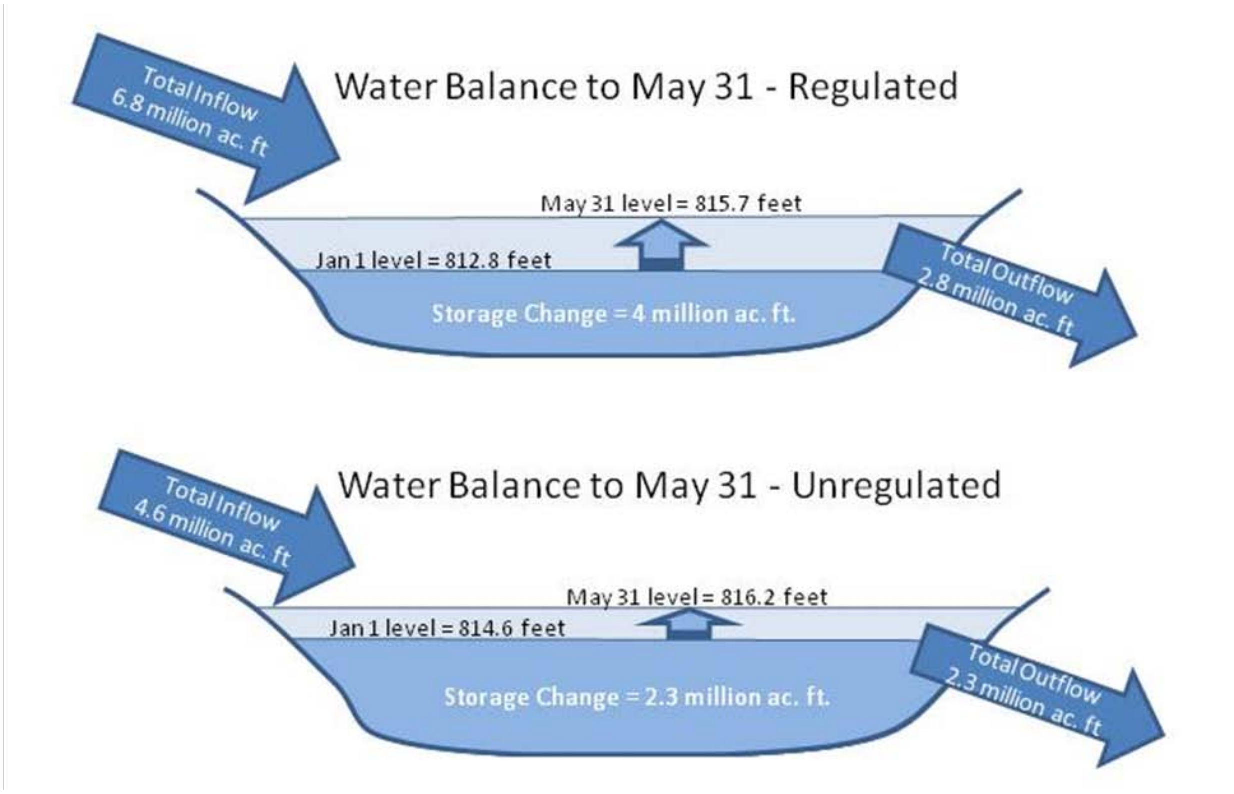

Figure 66: Lake Manitoba inflows and outflows, January 1 to May 31, 2011.

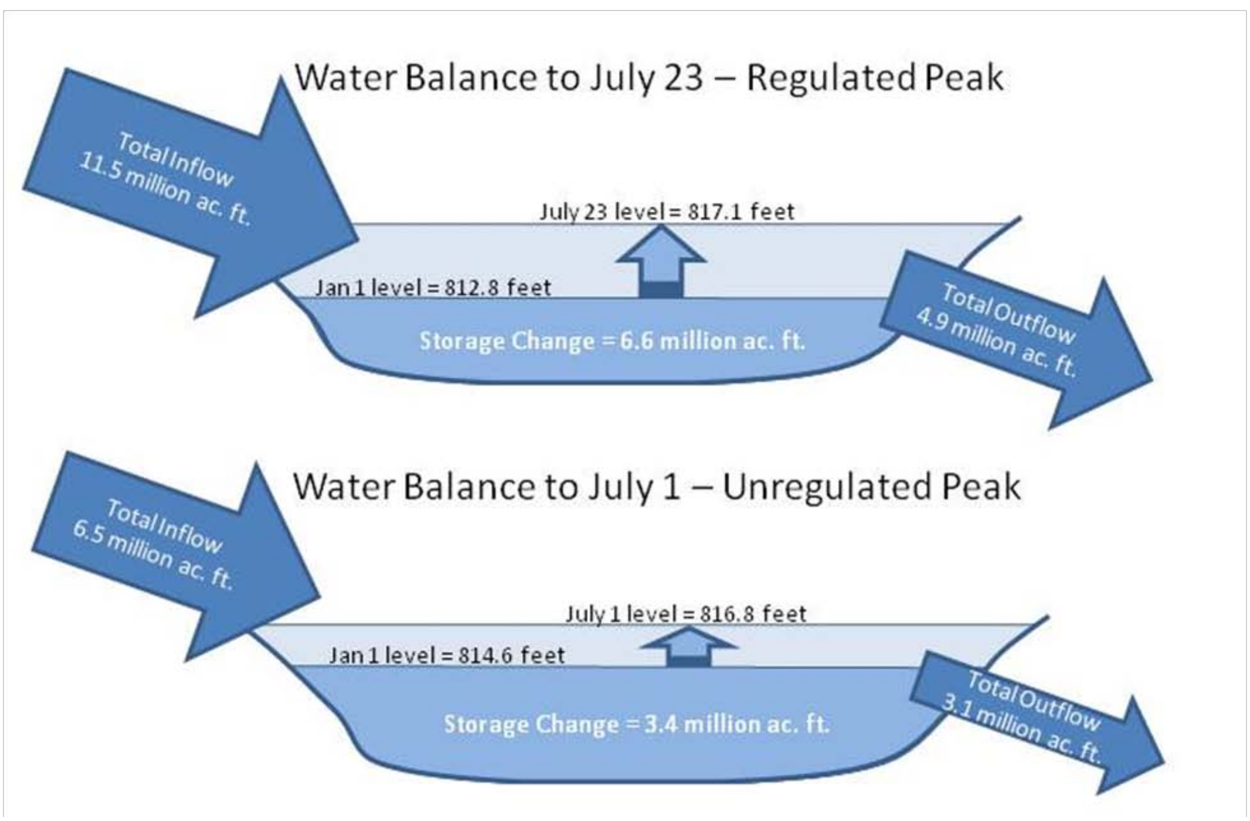

Figure 67: Lake Manitoba inflows and outflows, January 1 to date of peak water levels.

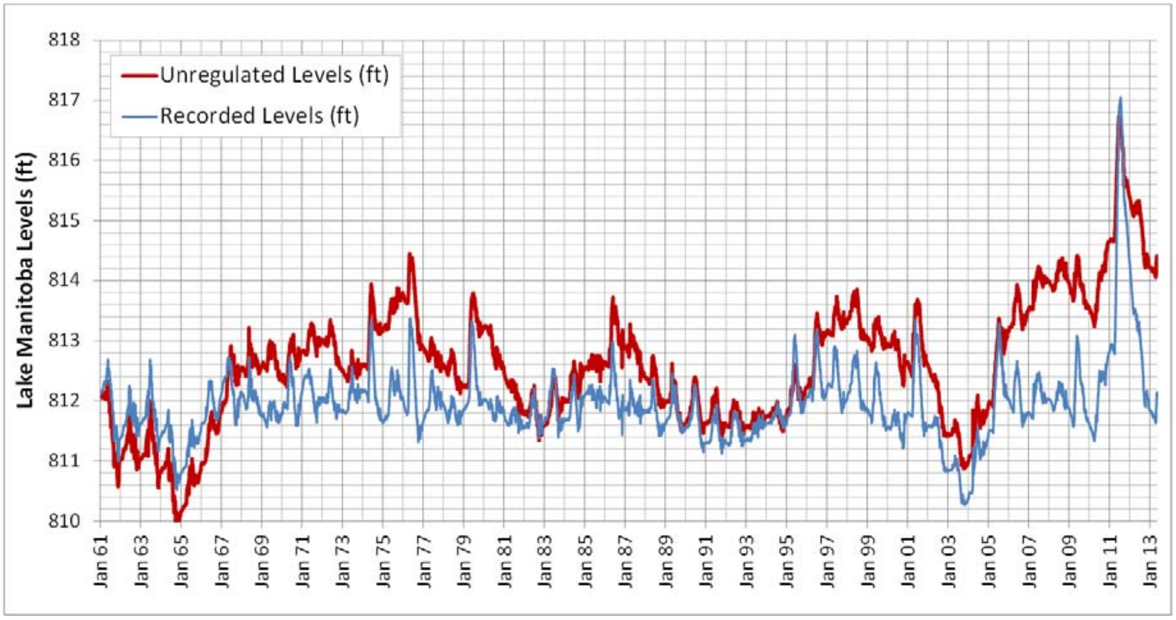

Figure 68: Recorded and unregulated Lake Manitoba water levels since 1961.

Figure 68 shows the recorded daily WEE water levels on Lake Manitoba, as well as the computed unregulated lake levels, from the start of the regulation of Lake Manitoba. The plot shows that regulation has resulted in more stable water levels on Lake Manitoba than would have occurred without operation of the flood control works. Also, the lake levels have generally been lower than the natural levels. This is what would be expected, since the Fairford River water control structure was designed to reduce lake level fluctuations and reduce flooding. The plot also shows that the five-year period leading up to the 2011 flood was unusually wet. The average recorded WEE water level from 2006 to 2010 was 812.1 feet (247.528 m). In the absence of both the Fairford River water control structure and the Portage Diversion the average water level over that same 5-year period would have been 813.8 feet (248.046 m).

5.4 Overflows from Lake Manitoba to the Assiniboine River

As discussed above in section 2.2.1, records from the early nineteenth century indicate that, in 1881 and 1882, Lake Manitoba rose so high that water flowed south from the lake toward the Assiniboine River and eventually rejoined the Assiniboine River downstream of Baie St. Paul (Archives of Manitoba, Sessional Papers, GR 1565, Committee Report of the Manitoba Legislative Assembly, 1884). However, the volume of these overflows was not quantified and preliminary analysis of the potential for such overflows suggests that these flows would only occur at very high Lake levels of at least 817 feet (249.022 m) (Last, 1984).

In 2011, the wind-eliminated level on Lake Manitoba peaked at 817.05 feet (249.037 m) on July 23 and the lake was above 817 feet for 21 days, from July 9 to July 29. No overflows from Lake Manitoba to the Assiniboine River were documented in 2011, although roads may have prevented overflows from occurring. Under unregulated conditions, water levels on the lake would have peaked at less than 817 feet (249.022 m). Therefore, it was assumed in the calculation of unregulated levels that overflows from Lake Manitoba to the Assiniboine River would not have occurred under unregulated conditions.

5.5 Unregulated Levels on Lake St. Martin in 2011

The results of the analysis of water levels on Lake St. Martin are displayed in Figure 69 below. The November 1, 2011 opening date for the Lake St. Martin emergency channel is shown as the vertical orange line. The winter of 2012 was very mild and as a result frazil ice did not develop on the Dauphin River. The warm weather conditions are reflected in the recorded water levels, as well as in the unregulated water levels (purple and green lines). The red line in the hydrograph illustrates the expected lake levels under normal weather conditions when frazil ice would have greatly restricted outflow from the lake.

From January until late February 2011, prior to spring runoff, the recorded Lake St. Martin water level was approximately one foot below the unregulated water level, although this benefit was quickly negated when the flows through Fairford River water control structure were increased. The operation of the Fairford River water control structure, which lowers water levels on Lake Manitoba during high water periods, serves to artificially increase inflows and causes artificially high water levels on Lake St. Martin. The Portage Diversion, by increasing inflows to Lake Manitoba, also artificially adds to the total volume of water that flows through Lake St. Martin. As a result of the operation of these two structures, the water levels on Lake St. Martin were artificially high from early March until early December, 2011. Lake St. Martin reached a maximum water level of 805.50 feet (245.516 m) versus an unregulated peak water level of 803.17 feet (244.806 m), meaning that peak water levels on Lake St. Martin were artificially high by up to 2.4 feet (0.73 m) in this period.

The Lake St. Martin Emergency Channel helped to significantly lower water levels on Lake St. Martin much faster than they would have dropped under unregulated conditions. This is illustrated by the steeper decline in recorded lake levels beginning on November 1, 2011, the date that the emergency channel began operation. If colder temperatures, closer to the seasonal average, had been experienced during the early winter of 2011, unregulated water levels on Lake St. Martin could have peaked at nearly 805.5 feet (245.516 m), approximately the same as the recorded peak water level, due to the effects of frazil ice restricting outflow on the Dauphin River. As a result of operation of the Lake St. Martin Emergency Channel, the recorded water level on Lake St. Martin dropped below the unregulated water level in mid-December 2011 and remained lower than the unregulated level through 2012.

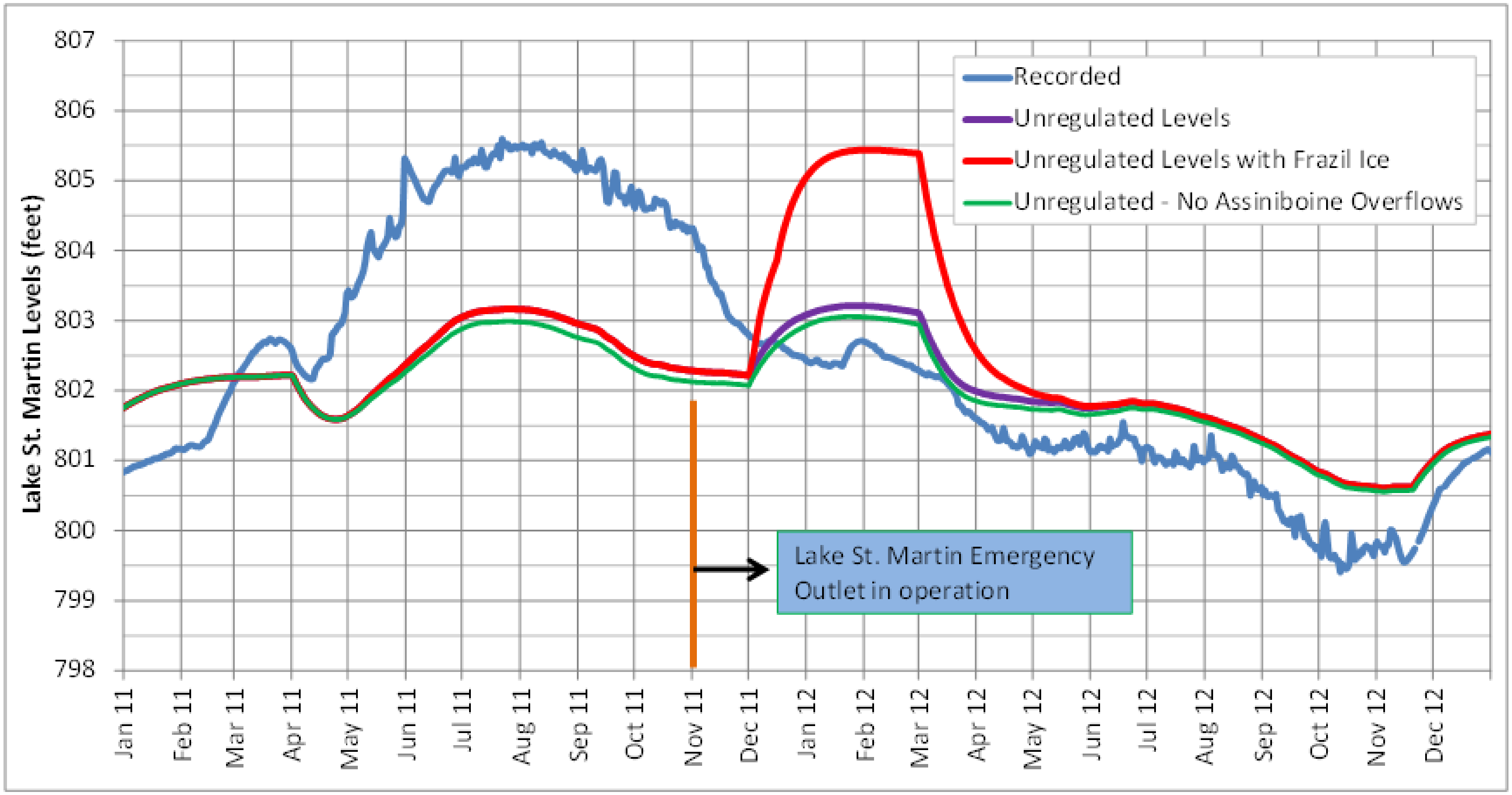

Figure 69: Recorded, and unregulated Lake St. Martin water levels, with and without overflows from the Assiniboine River.

6.0 Conclusions and Next Steps

The purpose of this report was to examine the 2011 flood events on Lake Manitoba and the Assiniboine River and the linkages between these events, and to address the question of whether artificial flooding occurred on Lake Manitoba. This report has reviewed the geographic and historic context of flooding on the Assiniboine River and Lake Manitoba, and presented the results of the analysis of the unregulated conditions in 2011, including modelling overflows from the Assiniboine River based on pre-development conditions. The implications of the results from this analysis are discussed below.

6.1 Artificial Flooding on Lake Manitoba

The computation of the unregulated levels on Lake Manitoba outlined in Section 5.3 indicates that artificial flooding occurred on Lake Manitoba in 2011 for the period from June 22 until August 30, 2011. During that period the regulated water level on Lake Manitoba was higher than it would have been in the absence of water control infrastructure. The incremental artificial flooding peaked in late July, when the regulated water levels were approximately 0.4 feet (12 cm) higher than the unregulated level would have been at the time, but only 0.3 feet (9 cm) above the peak unregulated level.

The actual effect of the artificial flooding, in terms of incremental damages caused in addition to the damages that would have been caused under unregulated conditions, is unclear. In compensation programs for artificial flooding, property damages or economic losses that are incurred at an elevation below the computed unregulated peak water level are deemed to be due to natural causes since, under unregulated conditions, the water level would have reached that level anyway. In other words, flood damages that occur below the unregulated peak water level were not made worse by artificial flooding. The only exception is if the timing of the artificial flooding is different from the recorded peak and is such that the shift in timing causes damages or economic loss. Further, the south basin of Lake Manitoba actually experienced wind affected water levels during the May 31 storm that were higher than the peak regulated water levels. Therefore, any damages in the south basin are attributable to this earlier, natural flood event (see Figure 70).

If there are any incremental effects from this artificial flooding, it would likely be limited to agricultural land around portions of the lake, where 0.3 feet of additional water would have resulted in additional inundated land. However, it is critical to note that the only portion of land for which damages could be considered to have been caused by artificial flooding is that portion of land that is flooded above the unregulated peak water level. At the peak recorded level this would have been land between 816.75 feet (248.945 m) (the computed unregulated peak level) and 817.05 feet (249.037 m) (the recorded peak level). This amounts to a relatively small area of land, as shown in Figure 71 below. It is important to note that for most of the south basin, the recorded peak regulated level would have actually occurred earlier in the year, due to the May 31 wind storm event when regulated levels were lower than unregulated water levels.

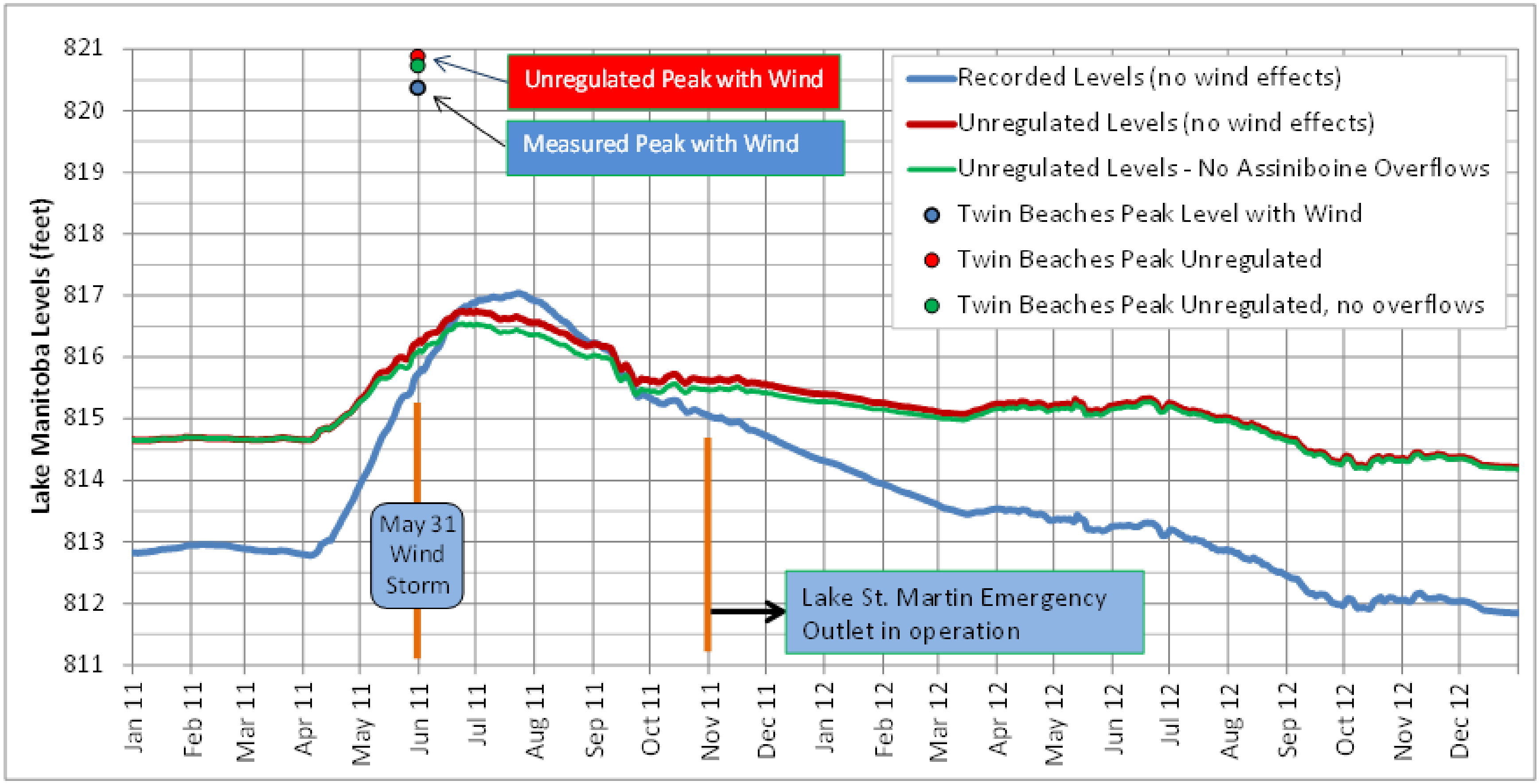

Figure 70: Recorded, and unregulated Lake Manitoba Levels, with and without overflows from the Assiniboine River. The effect of the May 31 wind event on water levels at Twin Beaches, representative of the south basin, is illustrated by the points above the lines of the hydrograph.

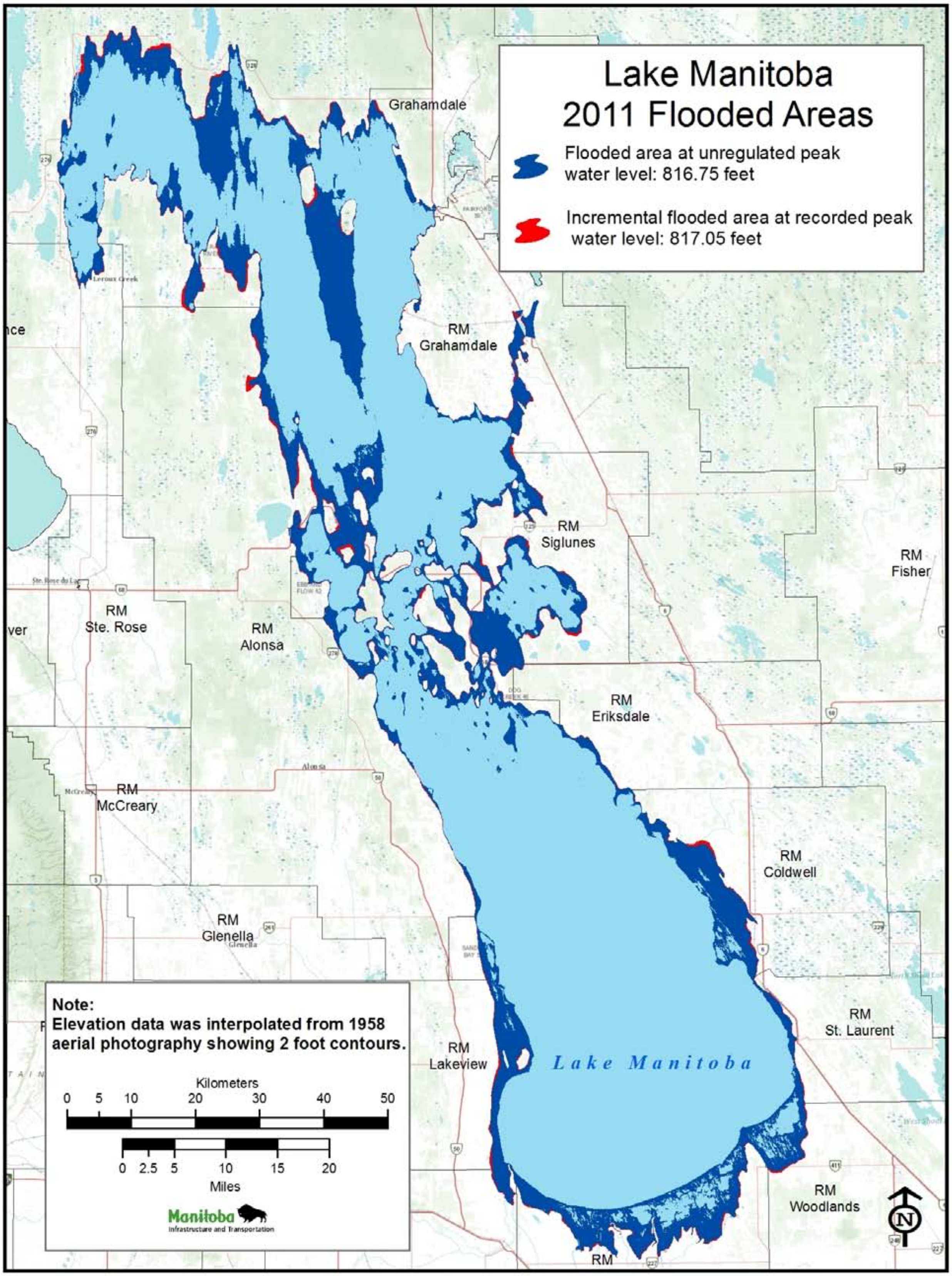

Figure 71: Flooded areas at the computed unregulated peak level and the incremental artificial flooding at the regulated peak level.

6.2 Lake Manitoba Levels on May 31, 2011

The analysis summarized in section 5.3 above shows that on May 31, 2011, the date of the severe windstorm that caused much of the damages to the homes and cottages in the south basin of Lake Manitoba, the recorded levels on Lake Manitoba were well below the unregulated level. In other words, at the time of the May 31 storm event, there was no artificial flooding. In fact, on May 31, Lake Manitoba was approximately 0.5 feet (15 cm) lower than it would have been under unregulated conditions.

Even if the natural overflows from the Assiniboine River are not included in calculation of the unregulated level, the recorded Lake Manitoba level on May 31, 2011 was still 0.4 feet (12 cm) below what the unregulated level would have been. This was due to the significant effect that the enhanced outflow through the Fairford River water control structure had in artificially lowering the lake levels prior to and during the 2011 runoff.

6.3 Assiniboine River Overflows to Lake Manitoba

The hydrodynamic model provided an estimate of the total volume of overflows from the Assiniboine River to Lake Manitoba under unregulated flows and pre-development topographic conditions. The results calculated by the hydrodynamic model showed that, during the extremely high flood conditions on the Assiniboine River in 2011, the total volume of overflows to Lake Manitoba was smaller than expected and relatively insignificant compared to the volumes of other inflows to Lake Manitoba.

It is important to understand that the overflow results from the hydrodynamic model were those that would have occurred under unregulated conditions with a pre-development landscape. In reality, the landscape in 2011 was not pre-development but contained roads, dikes, drains and other man-made changes that would have affected the amount, direction and timing of overflows from the Assiniboine River. As discussed in section 5.2.2 above, it is probable that under unregulated conditions, the overflows to Lake Manitoba in 2011 would have been higher than the results that the model calculated. As such, the hydrodynamic model results calculating overflow to Lake Manitoba should be considered illustrative of the pre-development scenario, and not a definitive determination of the overflows that would have occurred in 2011. Further research and modelling is required to more accurately estimate the overflows that would have occurred in 2011, including the effects of erosion. Until further modelling work is completed, the overflow results presented in this report should be considered a conservative estimate and any conclusions regarding the volume of Assiniboine River overflows should be considered tentative.

Although the total volume of overflow from the Assiniboine River to Lake Manitoba can't be precisely calculated, it is still significant that the overflows under unregulated conditions were verified by the hydrodynamic modelling. Confirmation that overflows from the Assiniboine River to Lake Manitoba would have occurred under unregulated conditions means that, during flood events of a certain magnitude on the Assiniboine River, a percentage of the flows on the Portage Diversion are not artificial.

As discussed in section 6.7 below, it would be valuable to do further modelling work to more firmly establish the relationship between the flows on the Assiniboine River and overflows to Lake Manitoba.

6.4 Artificial Flooding on Lake St. Martin

It is well established that Lake St. Martin is generally negatively affected by the regulation of Lake Manitoba through operation of the Fairford River water control structure, with Lake St. Martin often suffering artificially high or low water levels depending on conditions on Lake Manitoba. As shown in Figure 72, regulated water levels on Lake St. Martin are generally lower than unregulated water levels during dry periods when outflows from Lake Manitoba are reduced. Conversely, regulated water levels on Lake St. Martin are higher than unregulated levels during wet periods when outflows from Lake Manitoba are increased. The net effect of the operation of the Fairford River water control structure is that Lake Manitoba has more stable levels, while Lake St. Martin sees a higher frequency of both high and low levels.

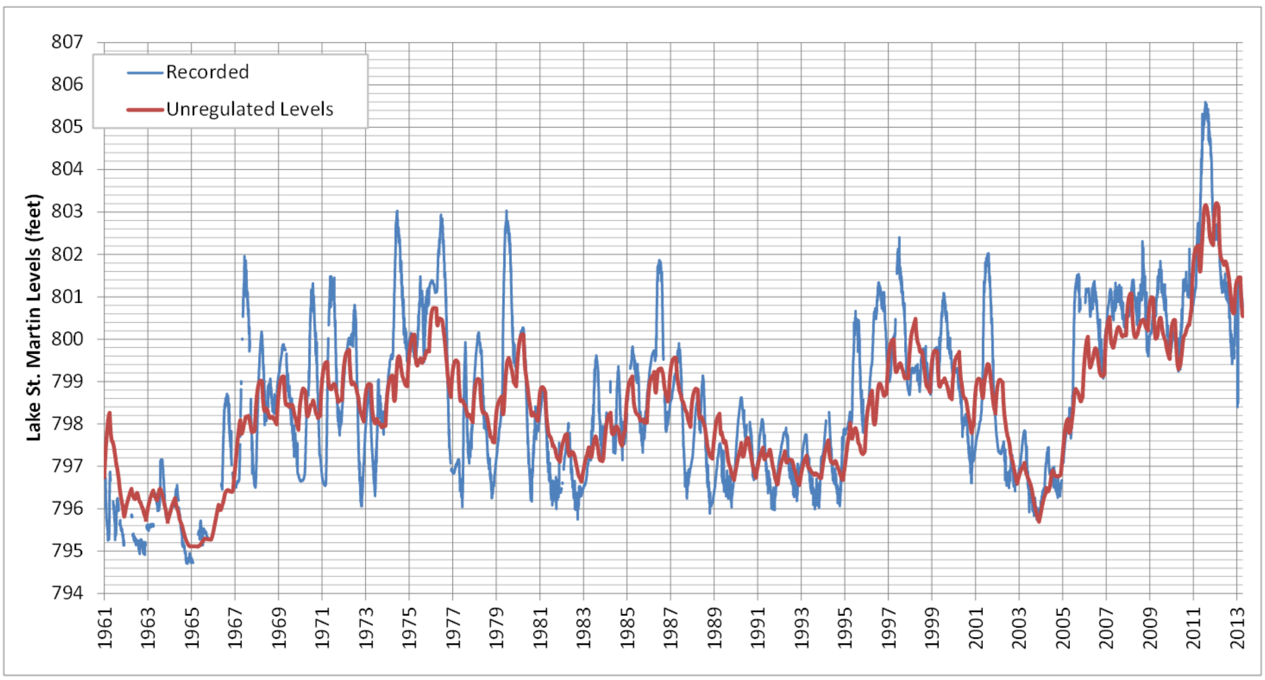

Figure 72: Recorded and unregulated water levels on Lake St. Martin from the start of regulation (1961) to 2013.

As discussed in section 5.5 above, Lake St. Martin did benefit significantly from construction and operation of the Lake St. Martin emergency channel in 2011. The net effect was that the regulated levels on Lake St. Martin dropped below the unregulated levels in December, 2011 and remained below the unregulated levels into 2013. The Lake St. Martin emergency channel has a significant beneficial effect on Lake St. Martin levels, overcoming artificially high inflows from Lake Manitoba and the naturally limited outflow capacity on the Dauphin River. It is because of this significant benefit that both the Lake Manitoba Regulation Review Committee and the 2011 Flood Review Task Force recommended that a permanent outlet channel from Lake St. Martin be constructed.

6.5 Adequacy of Lake Manitoba Regulation

As shown in Figure 68, the Fairford River water control structure has been successful in regulating the levels on Lake Manitoba within the target range in most years since it came into operation, including years in which the Portage Diversion has been used.

As discussed in section 2.3 above, although the Fairford River water control structure was built a decade before the Portage Diversion was completed, the structure was designed to handle the increased volume of water on Lake Manitoba that the Portage Diversion was projected to contribute. The channel improvements and increased outflow of the Fairford River water control structure were never intended to match the capacity of the Portage Diversion at a one-to-one basis. In other words, the Fairford River water control structure was not meant to increase instantaneous outflow by 25,000 cfs (708 cms). Instead, the outflow capacity of the Fairford River was designed to allow Lake Manitoba to be maintained within a target range of 811-813 feet (247.193-247.802 m), based on the total volumes of inflow and outflow expected on the lake (Kuiper, 1958). The projections of inflow volume done at the time the structure was designed were based on recorded inflows and climate (precipitation and evaporation) at that time, and on the projected inflows from the planned Portage Diversion based on the recorded history of flows on the Assiniboine River. Put another way, the FRWCS was never designed to match the capacity of the Portage Diversion at any particular point in time. It was designed to allow Lake Manitoba to be maintained within a desirable range when considering the balance of probable inflows and outflows, including inflows from the planned Portage Diversion. However, since the time that the FRWCS and Portage Diversion were designed, more frequent and higher flows through the Portage Diversion and higher levels on Lake Manitoba have resulted in higher outflows through the FRWCS.

Prior to 2011, the Fairford River water control structure was effective in managing the Lake Manitoba water levels within the desirable range most of the time. The inflows to Lake Manitoba in 2011, both artificial and natural, were exceptionally high and exceeded the design capacity of the water control infrastructure. As a result of the extremely high inflows, Lake Manitoba experienced record high water levels in 2011 and, as discussed in section 6.1, Lake Manitoba did experience artificially high water levels for a period in 2011. Finally, it is also important to note that the greatly increased outlet capacity afforded by the Fairford River water control structure project allows the levels on Lake Manitoba to be brought down quickly after the occurrence of a high lake level event, much more rapidly than would have occurred under unregulated conditions. This can be seen in Figure 70, as the regulated water level dropped lower than the unregulated water level as early as August 2011. The increased outflow capacity meant that, under regulated conditions, Lake Manitoba dropped below flood stage of 814 feet (248.107 m) by February 2012. Under unregulated conditions the lake would have peaked slightly lower, but remained above flood stage much longer, well into 2013.

6.6 Potential Avulsion of the Assiniboine River

As discussed in section 2.1.1, the lower reach of the Assiniboine River has followed a number of different courses in the post-glacial period. The natural process by which the river abandons its channel and follows a new course is called avulsion. The physical characteristics of the channel in the Assiniboine River's lower reaches lend itself to periodic avulsion of the river channel. That is, the river in this stretch creates alluvial ridges, and in some reaches of the stream, the bed of the river is actually above the elevation of the surrounding land, an inherently unstable situation.

There is a history of avulsion on the lower Assiniboine River and many of the paleochannels of the river remain visible in aerial photographs. Under unregulated conditions in 2011, the flows on the Assiniboine River would have been well above bankfull stage and a large proportion of flows would have left the channel and spread out over the landscape. The alluvial ridge that the present-day Assiniboine River has created is potentially unstable during large floods. Were the channel bank to fail or levees/dikes to be breached, there would be the potential for a new avulsion to occur which might cause the river to relocate to a lower but unpredictable position. There was a distinct possibility that in 2011, under unregulated conditions, the huge volume of flows on the Assiniboine River could have caused an avulsion of the channel. This would have resulted in a new course for the Assiniboine River which would have had a damaging affect in the area of the new channel. It was also possible that under unregulated conditions an avulsion could have occurred during a previous large flood such as 1955 or 1976. Therefore, in addition to the flood damage reduction benefit provided by the flood control infrastructure, human management of the river also limits the flows on the river to help keep the river within its bank, thus significantly lowering the chance of an avulsion in which the river changes course.

An avulsion in 2011 could have resulted in the river flowing east by a different route, possibly joining the Red River south of Winnipeg, or potentially even flowing north to Lake Manitoba as it did thousands of years ago. The flood of 2011 was destructive, causing significant damage and hardship. However, if the Assiniboine River had abandoned its present channel and followed a new course, the implications would have been far more significant and even longer lasting. Thus, the water control works not only provide flood protection, they also provide a measure of stability, which helps to maintain the Assiniboine River's present course in a naturally unstable and dynamic reach of the river.

6.7 Next Steps

This report has provided background information and addressed a number of questions relating to the flood of 2011. However, as with most studies and investigations, further work is recommended in a number of areas. The following recommendations build on the findings presented here and will enable stronger conclusions to be drawn from the work.

1. Expand the spatial extent of the hydrodynamic model to include the area upstream where overflows to the Whitemud River occur, and downstream all the way to the Red River at Winnipeg.
    a. Acquire additional LiDAR data upstream and downstream of the present study area to enable further modelling.
2. Conduct additional runs of the hydrodynamic model with roads, dikes and other infrastructure in place. This could be followed by subsequent, iterative model runs that include washouts or

intentional breaches of infrastructure (dikes/roads) in places where the infrastructure is overtopped or breakouts are deemed likely to occur.

3. Conduct a bathymetric survey of the lower Assiniboine River and the inlet channel at the Fairford River water control structure.
4. Obtain additional LiDAR data around Lake Manitoba and Lake St. Martin to accurately delineate the extent of regulated and unregulated flooding.
5. Using the expanded and refined hydrodynamic model, produce overflow results for different flows on the Assiniboine River. Use the overflow results to establish a curve describing the relationship between flows on the Assiniboine River and the overflows to Lake Manitoba.
6. Research to better understand the effect that erosion would have had on the overflows, including the total volume of overflows and the potential for avulsion to occur.

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Appendix A: Operating Guidelines for the Shellmouth Dam

Guidelines for Spring	Guidelines for Summer	Guidelines for Winter
• Outflow below 500 cfs if possible until Assiniboine crest has passed Miniota. • Keep outflows from exceeding 1,600 cfs but not if this raises reservoir above 1,407 feet • Outflows must meet downstream requirements with a minimum of 25 cfs. • If forecast based on observed rain and stream flow indicates reservoir level may rise to 1,406.5 feet, keep outflow below 1,600 cfs. • If forecast based on observed rain and stream flow indicates reservoir level may rise to spillway, set April outflow as high as required to keep level below 1,407 feet. During May or June, if valley crops have been seeded, use peak shaving if necessary to prevent total outflows from exceeding 2,000 cfs.	• Summer target range 1,400-1,404 feet. • Operate to meet downstream needs if possible. Minimum needs are 100 cfs at Brandon and 200 cfs at Headingley. Minimum outflow of 50 cfs and maximum of 1,000 cfs while in summer target range. • If serious summer flood develops, adjust outflows up to 1,600 cfs to prevent spillway overtopping. If spillway is overtopped anyway, use peak shaving to try to maintain 1,600 cfs outflow. • If reservoir level exceeds 1,410.5 feet, increase outflows as required to prevent further rises. • On falling limb after spillway overtopped, operate to maintain 1,200 cfs until reservoir down to 1,406.5 feet. • Operate to prevent decline of more than 0.3 feet per day at bridge downstream of Shellmouth. • When reservoir declines below 1,400 feet, set outflow at minimum of 25 cfs. • During severe drought, meet downstream requirements to a level of 1,390 feet. At lower levels, outflows to be approved at ministerial level following discussions with stakeholders.	• Minimum drawdown level of 1,386 feet. • Target level of 1,404 feet after spring runoff. • Try to avoid large fluctuations in outflow. • Be in a position to get down to 1,386 feet , without exceeding 1,500 cfs outflow, when upper decile forecast indicates a spring level near spillway. • November and December outflows based on lower decile inflow forecast. • January and February outflows based on lower quartile inflow forecast. • March outflow based on upper quartile inflow forecast.

Appendix B: Operating Guidelines for the Portage Diversion

(from the Red River Floodway Program of Operation, Manitoba Natural Resources, 1984)

PORTAGE DIVERSION OPERATION RULES

The Portage Diversion has a capacity of 25,000 cfs (708 m^3/s) at full supply level of 769.0 feet (234.39 m) However, there is a failsafe section which will breach at 15,000 cfs (425 m^3/s).

Operation Objectives

The Portage Diversion will be operated to meet these objectives:

1. To provide maximum benefits to the City of Winnipeg and areas along the Assiniboine River downstream of Portage la Prairie
2. To minimize ice jams forming along the Assiniboine River.
3. Not to increase the water level in Lake Manitoba beyond the maximum regulated level of 812.87 feet (247.76 m), if possible.
4. Prevent overtopping of the failsafe section in the Portage Diversion, if possible.

Emergency Operation

The Assiniboine River dykes between Portage la Prairie and Headingley have a capacity of about 20,000 cfs (566 m^3/s). Therefore, an emergency situation exists when the inflow into the reservoir is 45,000 cfs (1274 m^3/s). When the inflow exceeds 45,000 cfs (1274 m^3/s), it is the policy to maintain 25,000 cfs (708 m^3/s) in the Portage Diversion with the remainder allowed into the Assiniboine River downstream. When the Assiniboine River dykes are overtopped, adjustments must be made to the computed natural flow in Winnipeg. This is discussed under the section Assiniboine River Dykes Overtopped.

Operation Rules

1. Except as provided for under Rule 8, the Portage Diversion shall be utilized to its maximum capability to keep water levels in Winnipeg below 17.0 feet (5.2 m), City Datum.
2. The flow in the Diversion shall not be allowed to exceed 25,000 cfs (708 m^3/s).
3. If flow forecasts indicate that the peak inflow into the reservoir to be 20,000 cfs (566 m^3/s) or more, the Diversion will be put into use as soon as possible to flush out snow blockages and insitu ice.
4. During the period that there is ice on the reservoir, the water level of the reservoir will not be allowed to exceed 865.0 feet (263.65 m) to provide room for releases from breaching of upstream ice jams.
5. The conduits of the Spillway Structure shall be closed while there is water going over the bascule gates.
6. While there is ice on the Assiniboine River downstream of Portage la Prairie it is desirable to limit flows to approximately 5,000 cfs (142 m^3/s) in the River if possible. Flows of this magnitude appear to be optimum flows required to assist in flushing the ice down river without causing major ice jams or flooding to adjacent farm lands through local drainage inlets. This procedure provides additional

capacity, if required, on the River downstream of Portage la Prairie when the second peak arrives. The level of Lake Manitoba should not be taken into account while there is ice on the Assiniboine River, as the period during which there is ice on the River during the spring runoff is only a few days, and diverted flows for this short a period of time have a negligible effect on the level of Lake Manitoba.

7. After the ice has gone from the Assiniboine River downstream of Portage la Prairie, it is desirable to maintain flows less than 10,000 cfs (283 m^3/s) in the River if possible. Flows greater than 10,000 cfs (283 m^3/s) are above the natural bank stage of the River, and backup of local streams which outlet into the Assiniboine may occur at this level. There also may be seepage problems through the dyke, leakage under the dyke through gated culverts and flooding of cultivated land between the dykes.

8. For flows of up to 30,000 cfs (850 m^3/s) under open water conditions, the failsafe section of the west dyke of the Portage Diversion should not be breached if the peak stage in Winnipeg will not exceed 18.0 feet (5.5 m).

Appendix C: Operating Guidelines for the Fairford River water Control Structure

(from: Regulation of Water Levels on Lake Manitoba and along the Fairford River, Pineimuta Lake, Lake St. Martin and Dauphin River and Related Issues, 2003)

The Lake Manitoba Regulation Review Advisory Committee respectfully submits the following recommendations to the Manitoba Minister of Conservation.

1) Lake Manitoba should be managed in a more natural fashion based on the Minimal Log Change Model (Appendix D) developed for the Committee by the Manitoba Water Branch. Utilizing this model, or a refined version, the following operating rules for the Fairford River Water Control Structure (FRWCS) should be applied:

a) Water levels on Lake Manitoba should be permitted to fluctuate between 810.5 and 812.5 feet above sea level (ft asl) over a period of years, insofar as this may be reasonably possible, with the expectation that water levels on the lake may rise to 813.0 ft asl in some years and drop to 810.0 ft asl in others;

b) Any variance in the lake levels outside of the range shall be shared between Lake Manitoba and Lake St. Martin, insofar as this may be reasonably possible;

c) The level of Lake St. Martin should be maintained within a more natural range of 797.0 ft to 800.0 ft asl insofar as this may be reasonably possible, in order to reduce flooding, to provide better access for commercial fishing and recreational interests, to enhance the commercial and sport fisheries, to maintain marshlands in a natural state, to restore the natural aesthetics of the region and to provide for hayland for local ranchers;

d) The minimum flow in the Fairford River should be 800 cubic feet per second (cfs) with a desirable minimum flow of 1,000 cfs insofar as the achievement of both of these flows may be reasonably possible, and

e) An additional water level monitoring station should be installed on Lake St. Martin nearer the existing communities along the north shore.