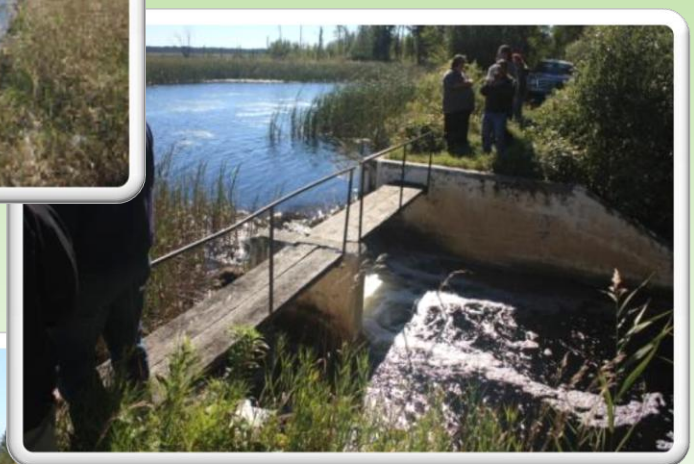
ROSEAU RIVER WATERSHED
DISTRIBUTED RETENTION STUDY



Manitoba
Sustainable Development

Executive Summary

Manitoba Sustainable Development, through its Water Science and Management Branch, is developing water retention plans for watersheds across Manitoba to support integrated watershed management plans. Many individuals and organizations see distributed storage projects as solutions to local watershed management goals including improving water quality and mitigating flooding and drought. When the cumulative impacts of many projects are combined, benefits can occur at the basin scale. This activity supports two initiatives. The first is Manitoba Sustainable Development's Watershed Planning and Programs' integrated watershed management planning process. The second is the larger basin-scale goal of the Red River Basin Commission to reduce flooding on the Red River through distributed storage projects.

This report describes the results of the Branch's first pilot study that investigates the potential of distributed water retention. This study focuses on the Canadian portion of the Roseau River Watershed. The main goal is to identify surface water issues and to provide an engineering analysis to determine a strategic plan to implement water retention in the watershed by:

- Providing general hydrology information of the watershed,
- Summarizing previous reports and plans to identify surface water issues such as water supply, excessive moisture and flooding, and water quality,
- Identifying potential water retention study sites and propose possible projects, and
- Evaluating the potential local and basin scale flow reductions the projects would achieve.

Out of the many potential retention sites assessed, the study found five projects were determined to be high priority:

- Horseshoe Lake
- Sundown Ridge
- Mueller Farm
- Gardenton Floodway-Community Pasture
- Tolstoi

The next step towards implementing any of these retention projects is to select projects for more in-depth assessment and conduct a benefit-cost analysis to determine if the projects are feasible.

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Useful Unit Conversions

1 metre (m) = 3.28 feet (ft)

1 kilometre (km) = 0.62 miles (mi)

1 hectare (ha) = 2.47 acres

1 square kilometre (km^2) = 0.39 square miles (mi^2)

1 cubic dekametre (dam^3) = 0.81 acre-feet

1 cubic metres per second (cms) = 35.31 cubic feet per second (cfs)

1. Introduction

Many individuals and organizations see distributed storage projects as solutions to local watershed management goals, and when combined, the cumulative impacts of many projects can improve water management at the basin scale. The work completed in this report supports two initiatives: the first is Manitoba Sustainable Development's Watershed Planning and Programs' integrated watershed management planning process and the second is the larger basin-scale goal of the Red River Basin Commission to reduce flooding on the Red River through distributed storage projects.

Manitoba Sustainable Development's Watershed Planning and Programs is preparing Integrated Watershed Management Plans for many watersheds across Manitoba. A plan for the Roseau River Watershed is currently being prepared. The information in this report is meant to support the various surface water management goals identified in the planning process. Information from public meetings was instrumental in determining the locations and storage concepts on many of the projects identified in this report. The intent is that the information contained in this report will help the local conservation district, the Seine Rat River Conservation District, make the most out of the limited resources available to construct distributed storage projects.

The Red River Basin Commission set a goal in its Long Term Flood Solutions (RRBC, 2011) report to reduce the 100-year flood event on the Red River by 20 % through distributed storage. The Commission has undertaken studies in the U.S. portion of the Red River to determine the volumes of storage required in Red River tributaries to achieve its main stem goals. Following the RRBC's efforts on reducing peak flows, the Red River Watershed Management Board funded the Roseau River Watershed District to develop a retention strategy in the United States portion of the watershed. Houston Engineering, Inc. and HDR, Inc. completed the Roseau River Watershed Expanded Distributed Detention Strategy (Houston Engineering, Inc. and HDR, Inc., 2013) which identified and evaluated ten proposed locations in the Upper Roseau River Watershed and eleven locations in the Lower Roseau River Watershed. A HEC-HMS model was developed in the American study that was also used in this study to evaluate hydrologic impacts of retention projects. While the ability of the retention projects in this report to reduce Red River flood peaks have not been quantified, this report will start to build an information base in the Canadian portion of the basin that continues the work to reduce flooding along the Red River.

The purpose of this report is to develop a water retention plan for the Roseau River Watershed in Manitoba to contribute to the integrated watershed management planning process by:

- Providing general hydrology information of the watershed,
- Summarizing previous reports and plans to identify surface water issues,
- Identifying and evaluating potential water retention sites, and
- Evaluating the potential local and basin scale flow reductions the projects would achieve.

The Surface Water Management Section was fortunate to have many partners collaborate in providing information and developing the retention plan, including:

- Roseau River IWMP Project Management Team
- Seine-Rat River Conservation District
- Rural Municipalities of Stuartburn, Piney, Emerson-Franklin, and Montcalm
- Red River Basin Commission
- Manitoba Agriculture
- Manitoba Infrastructure
- Various branches and divisions within Manitoba Sustainable Development

2. Roseau River Watershed Background

2.1 Geography

The Roseau River Watershed is located in southeastern Manitoba and northwestern Minnesota (Figure 1). The Roseau River main channel headwaters are in the area east of Lost Lake in Lake of the Woods County, Minnesota and flows in a west to northwest direction towards Roseau, Minnesota. North of Roseau, the river turns in a more westerly direction and continues to where it crosses the international border at Caribou, Minnesota and continues its northwesterly direction through Gardenton, Manitoba. Just before reaching Dominion City, Manitoba the river turns and starts flowing in a southwesterly direction. At Dominion City the river turns back in a northwesterly direction, takes a turn to the south and enters the Red River just east of Letellier, Manitoba.

The upper tributary/headwater component of the Roseau River drainage area can be described as fan-shaped, while the remaining drainage area following the course of the river is generally long and narrow in shape. The watershed is approximately 177 km long. The natural course of the Roseau River follows a meandering path in a principally northwestern direction over an approximate distance of 340 km from source to mouth. The Roseau River crosses the Canada-U.S. border at roughly the midpoint of its course and terminates at the Red River approximately 15 km north of the International Border. There have been a number of man-made changes that have altered the natural course of the Roseau River (i.e. diversions, channelization, blockages, etc.) on both sides of the International Border.

During the Roseau River's course from its headwaters to the Red River, four main tributaries join at various points in Minnesota; South Fork Roseau River, Hay Creek, Sprague Creek, and Pine Creek. Sprague Creek and Pine Creek originate on the Canadian side of the watershed. Table 1 gives the approximate lengths of the Roseau River and its tributaries.

Table 1: Stream lengths of main watercourses in Roseau River Watershed

	Approximately Length (km)
Roseau River	343.7
South Fork Roseau River	79.4
Sprague Creek	59.9
Pine Creek	42.2
Hay Creek	27.4

The Canadian portion of the watershed is bounded on the north by the Rat River and Whitemouth River Watersheds, on the east by the Bird River/Whiteshell River watershed, on the west by the Red River and on the south by the International Border. The watershed encompasses a drainage area of approximately 5,820 km^2. The drainage area for the Canadian portion of the watershed is approximately 2,580 km^2 (44 % of the total watershed).

The Canadian portion of the Roseau River Watershed has sixteen waterways that are designated as provincial waterways. A waterway is designated as provincial if it is an artificial or man-made waterway and is a 3rd order drain or higher. Waterways are designated as provincial by an Order-In-Council.

Within this portion of the watershed, there are also two provincial dams – Arbakka Dam and Dominion City Dam.

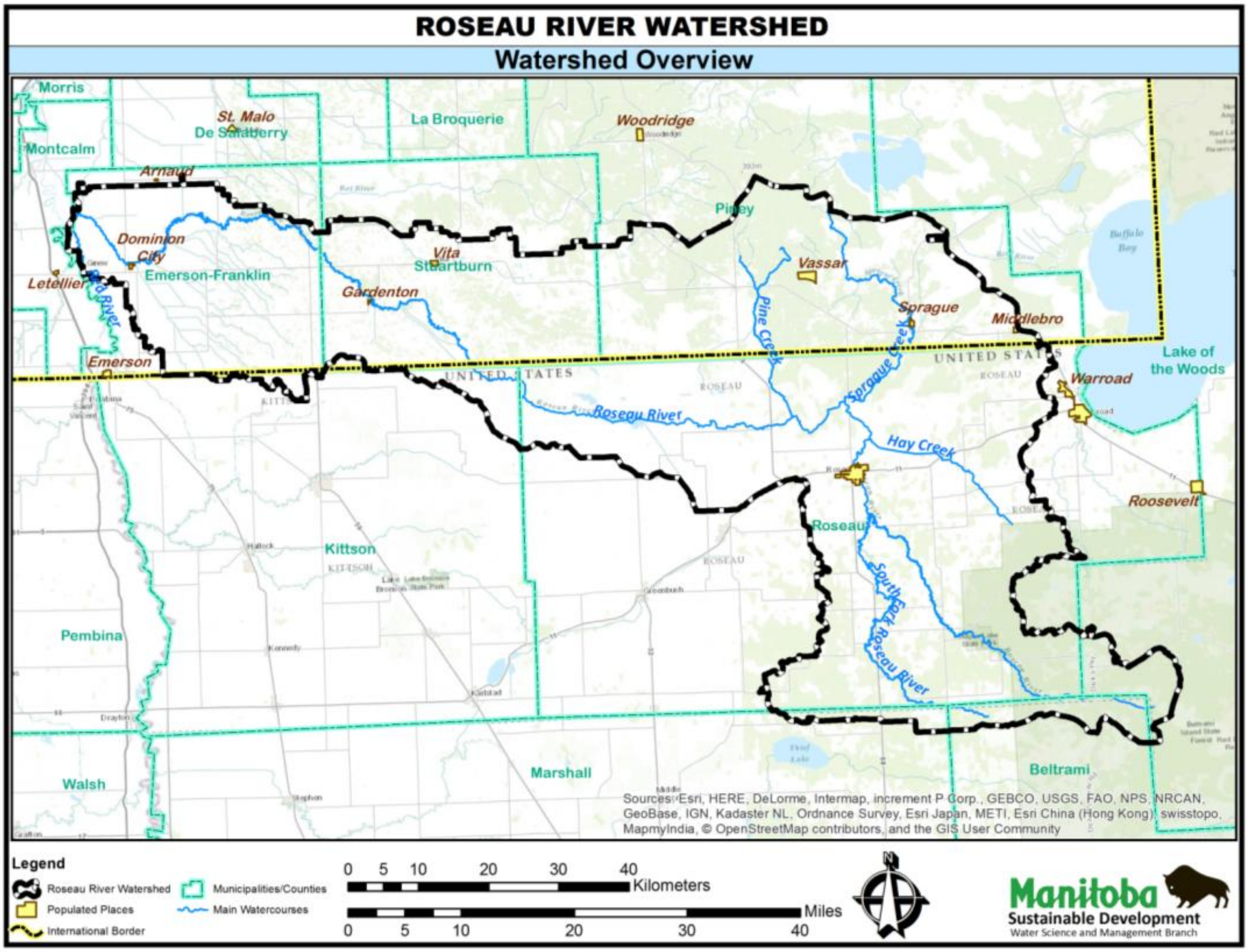


Figure 1: Roseau River Watershed

2.2 Climate

The climate in the Roseau River Watershed is characterized by variability and extremes in temperature and precipitation. The watershed experiences extremes on a monthly, seasonal and yearly basis – short, warm summers and long, cold winters.

Three stations were used to compare temperature and precipitation variability:

- Emerson, Manitoba (Climate ID: 5020881) – Latitude 49.00 N, Longitude 97.24 W, Elevation 242 m. (Temperature and Precipitation data from 1894 to present)
- Sprague, Manitoba (Climate ID: 5022760) – Latitude 49.02 N, Longitude 95.6 W, Elevation 329.2 m. (Temperature and Precipitation data from 1916 to present)

- Roseau, Minnesota (Climate ID: GHCND: USC00217087) – Latitude 48.85N, Longitude 95.77W, Elevation 319.1 m. (Temperature and Precipitation from 1909 to present)

Precipitation

In general, about one-fifth of the total annual precipitation is in the form of snowfall. Approximately 90 % of the snowfall occurs during the November to March period. The other 10 % generally occurs in either April or October.

The period of 1944 to 2014 was analyzed for average precipitation variability for all three stations and the results are shown in Table 2.

Table 2: Precipitation comparisons for Emerson, Sprague and Roseau (values in mm)

	Average Yearly Total Precipitation	Wettest Year	Driest Year	Wettest Month on average	Driest Month on Average
Emerson	514.2	1991 – 851.0	1961 – 226.0	July – 83.9	February – 16.8
Sprague	581.0	1991 – 883.3	1994 – 112.0	June – 98.1	February – 19.1
Roseau	489.6	1968 – 761.5	2006 – 276.9	June – 94.0	February – 10.3

Figure 2 provides a comparison of the average monthly total precipitation recorded at Emerson, Sprague and Roseau for the period 1944-2014.

Temperature

The continental climate that governs the Roseau River Watershed shows its influence in the large temperature extremes that occur on a monthly, seasonal and yearly basis.

Figure 3 provides a comparison of the average monthly temperature recorded at Emerson, Sprague and Roseau for the period 1944-2014.

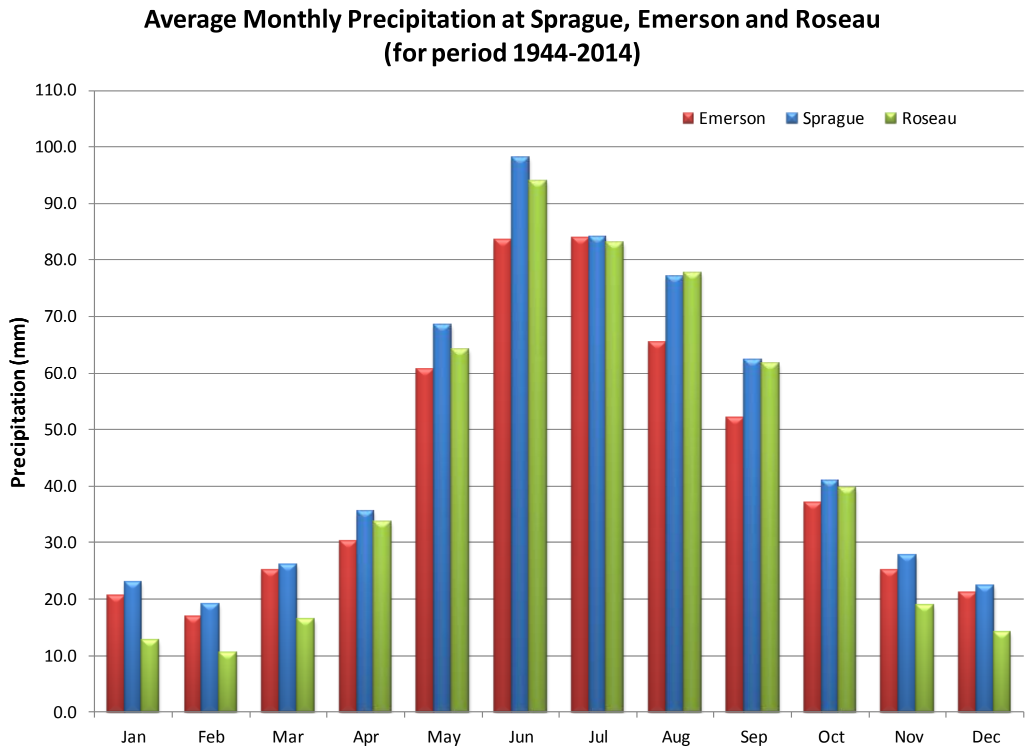


Figure 2: Comparison of Average Monthly Precipitation at Emerson, Sprague and Roseau (1944-2014)

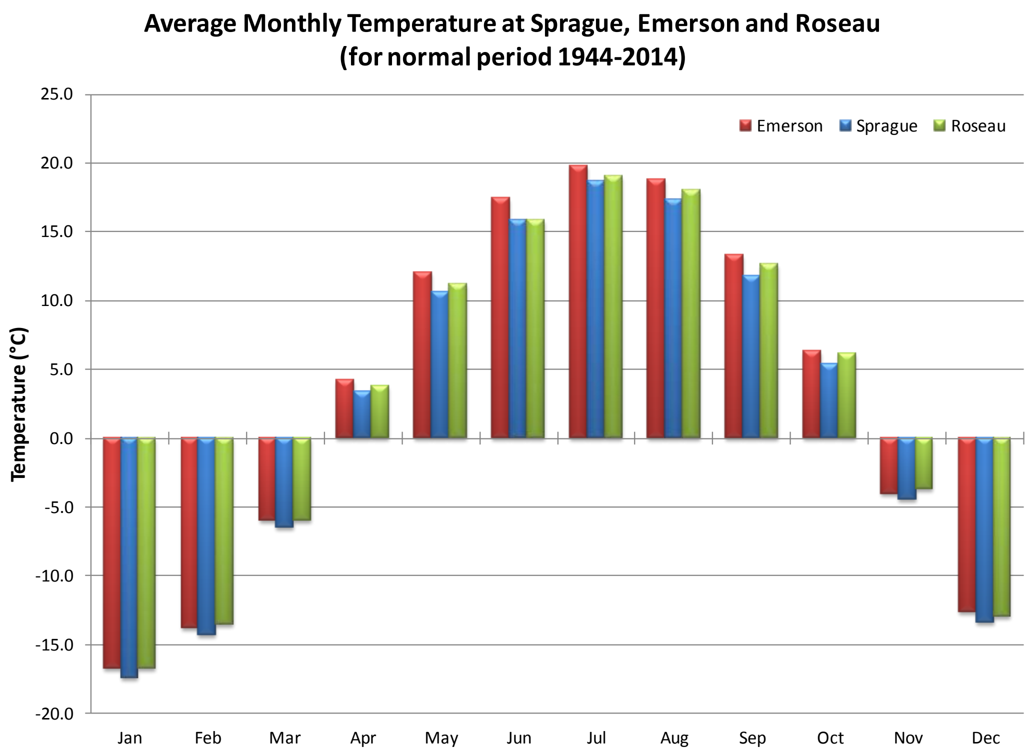


Figure 3: Comparison of Average Monthly Temperature at Emerson, Sprague and Roseau (1944-2014)

2.3 Hydrology

Hydrometric Data

The collection of streamflow and water level data is critical to the understanding of the availability, variability and distribution of water resources and provides the basis for responsible decision making on the management of this resource. Water level and stream flow data supports activities such as policy development, operation of water control works, flow forecasting, water rights licensing, drought and preparedness assessments, water management investigations, hydrologic studies, water quality modelling, ecosystem protection and scientific studies.

Stream flow and level data have been recorded at seventeen locations within the Roseau River Watershed for varying time periods since the 1910s. The list of these seventeen hydrometric stations is provided in Table 3 and the locations are shown in Figure 4.

Hydrometric data is available from the following sources:

- Archived Canadian data - http://wateroffice.ec.gc.ca/search/search_e.html?sType=h2oArc
- Realtime Canadian data - http://wateroffice.ec.gc.ca/index_e.html
- United States data - http://water.usgs.gov/data/

Table 3: Operation period for hydrometric stations in the Roseau River Watershed

Agency	Station Number	Station Name	Years of Operation	Type of Data	Gross Drainage Area km^2
USGS	05103000	Roseau River near Malung, MN	1939-1946	Flow	652.7
USGS	05104000	South Fork Roseau River near Malung, MN	1911-1946	Flow	808.1
USGS	05104500	Roseau River below South Fork near Malung, MN	1946-2015	Flow	1,113.7
WSC	05OD031	Sprague Creek near Sprague Creek	1928-1981	Flow	
USGS	05106000	Sprague Creek near Sprague Creek, MB	1928-2015	Flow	455.8
WSC	05OD027	Pine Creek Diversion near Piney, MB	1953-1996	Flow	156.0
WSC	05OD032	Pine Creek near Pine Creek, MN	1928-1953	Flow	
USGS	05107000	Pine Creek near Pine Creek, MN	1928-1953	Flow	193.2
USGS	05107500	Roseau River at Ross, MN	2007-2015	Flow	2,823.1
USGS	05112000	Roseau River below State Ditch 51 near Caribou, MN	1917-2015	Flow	3,677.8
WSC	05OD030	Roseau River near Caribou, MN	1917-1997	Flow	
WSC	05OD004	Roseau River at Gardenton, MB	1915-2015	Flow & Level	4,440.0
WSC	05OD014	Roseau River at Stuartburn, MB	1924-1969	Flow	4,510.0
WSC	05OD001	Roseau River near Dominion City, MB	1913-2015	Flow & Level	5,020.0
WSC	05OD033	Main Drain near Ridgeville, MB	1983-1987	Flow	50.8
WSC	05OD029	Main Drain near Fredensthal, MB	1960-1982	Flow	29.4
WSC	05OD028	Main Drain near Dominion City, MB	1960-2015	Flow & Level	225.0

Note: USGS – Unites States Geological Survey
WSC – Water Survey of Canada

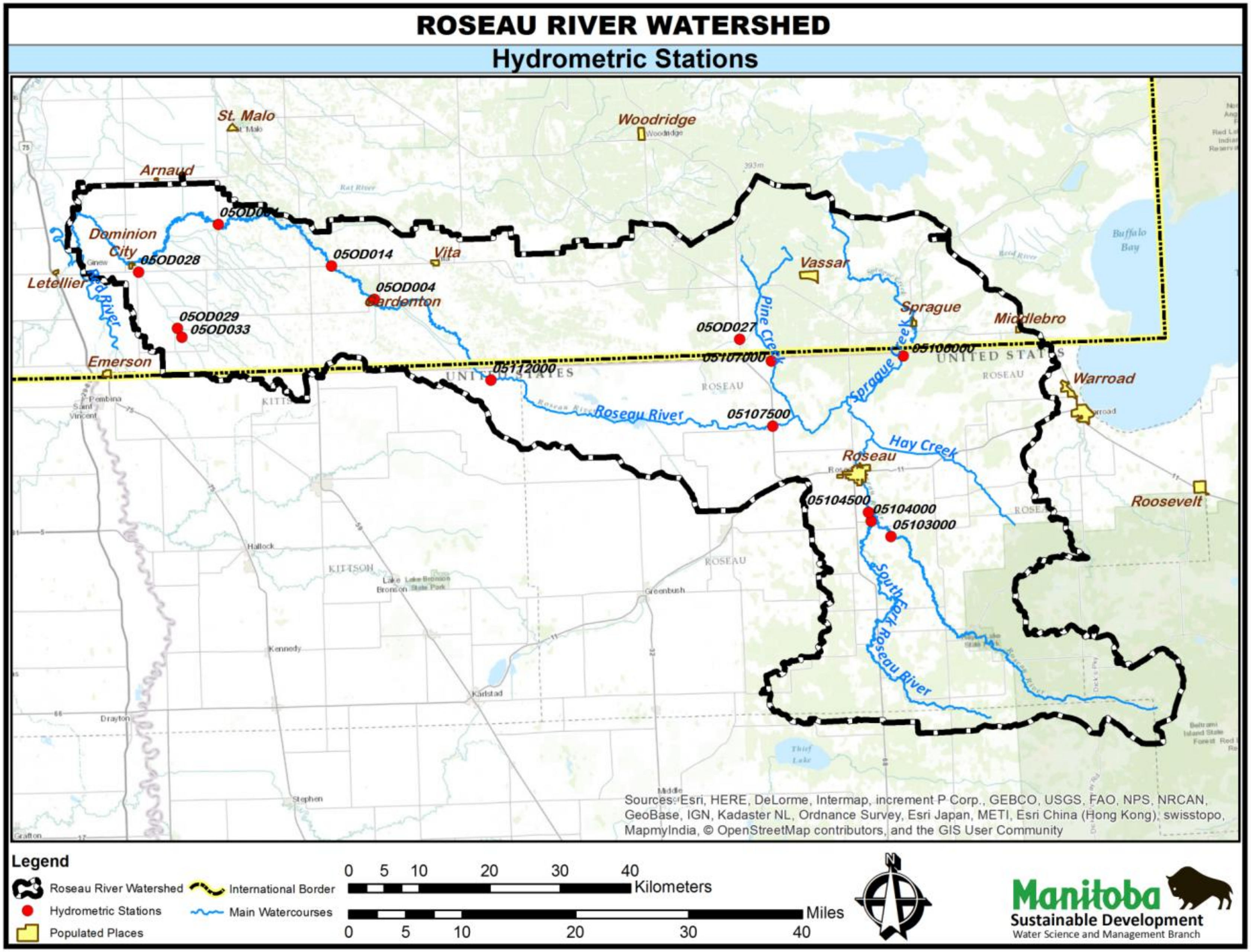


Figure 4: Roseau River Watershed – Hydrometric Stations

Annual and Mean Monthly Discharge

The annual flow on the Roseau River has a large amount in variation from year to year as conditions can range from severe drought to severe flooding. This is typical of prairie watersheds. The annual flow at the station near Dominion City is shown on Figure 5. To extend the annual record to 1913, data missing for winter months in some years were estimated by a correlation relationship with the Red River at Emerson gauge. The highest annual volume of approximately 1,000,000 dam^3 in 2004 is nearly 25 times more than the lowest recorded volume of 40,400 dam^3 in 1988. The median flow at the station near Dominion City is approximately 340,000 dam^3, however the annual flow can easily be either half or double this value. This variation in flow conditions contributes to many water management challenges.

The average annual volume of water contributed by the Roseau River to the Red River is 416,000 dam^3 (Roseau River International Watershed, 2007). This contribution from the Roseau River represents 8.6 % of the total average volume of flow for the Red River measured at Ste. Agathe (4,817,000 dam^3) and 6.1 % of the total average volume of flow for the Red River measured at Lockport (6,774,000 dam^3). The percent contribution of the Roseau River decreases at Lockport due to the addition of flow from the Assiniboine River within the City of Winnipeg.

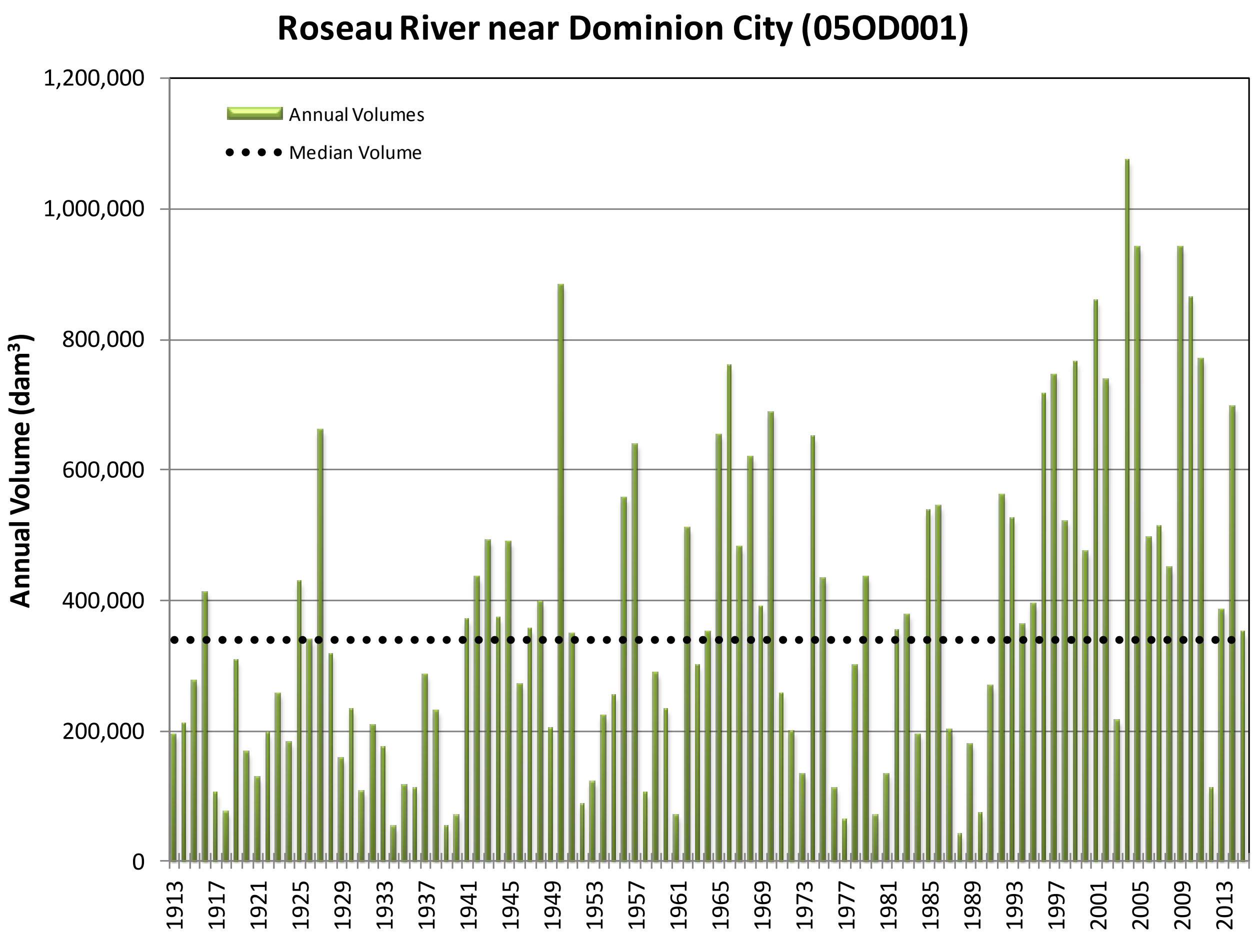


Figure 5: Annual Flow Volumes for Roseau River near Dominion City

The tributaries which contribute flow to the Roseau River within Canada can also display a wide ranch of conditions geographically and over time. As noted in the Roseau River Watershed's

Inventory Report (Roseau River International Watershed, 2007), a difference should be noted in the discharge data for the three tributaries; Sprague Creek, Pine Creek Diversion and Main Drain. The Main Drain has zero discharge during many months, while the other two tributaries generally have some flow. This distinction is a result of the organic wetlands in the eastern portion of the watershed around the Pine Creek Diversion and Sprague Creek which store water throughout the year and provide groundwater recharge and stream base flow even during dry seasons. The clay soils around the Main Drain do not store moisture, but rather facilitate immediate runoff of precipitation, and thus there are months when discharge drops to zero in the Main Drain.

Average monthly flows for six stations, three on the Roseau River and three on tributaries, were calculated and are represented in Figure 6 and Figure 7. Monthly discharge data for stations on the Roseau River and its tributaries is included in Appendix A, Tables A1 through A8.

On the Roseau River main stem, the greatest average flow occurs during the month of May, ranging from 35 cms at Caribou to 41 cms at Dominion City. For the main three Roseau River tributaries in Canada, the greatest average flow occurs during the month of April, ranging from 2 cms at Piney to 6 cms at Sprague Creek. It should be noted that Sprague Creek's gross drainage area is roughly twice the size of the other two tributaries, accounting for the large difference in their respective flow values.

Typically the majority of flow is generated from snow melt and spring rains. Roughly 65 % of the flow in the Roseau River occurs from April to June. In general the percentage of flow drops in July through September, increases slightly in October, and then drops again over the winter months. For the Roseau River tributaries, the greatest percentage of flow occurs during the month of April. One difference between the tributaries is that the Main Drain has roughly 60 % of its flow occurring in April, where the other two tributaries have the same percentages occurring over three months – April, May and June.

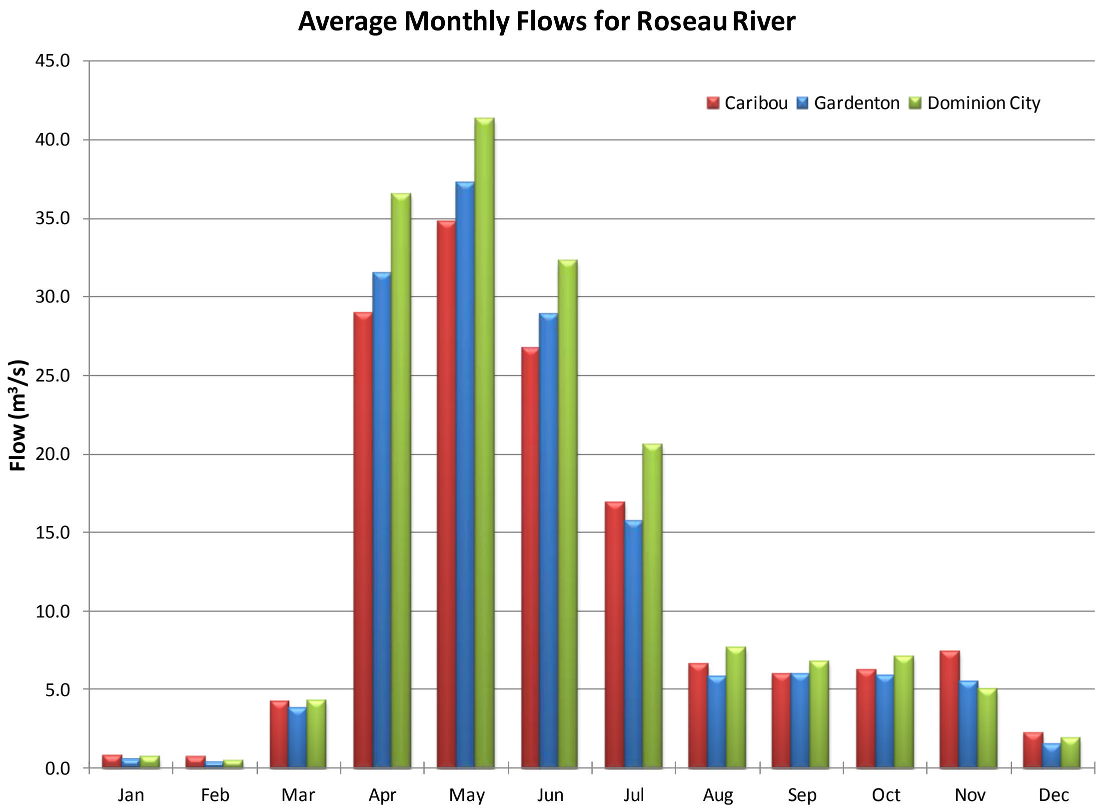


Figure 6: Average Monthly Flows for Roseau River (1961-2014)

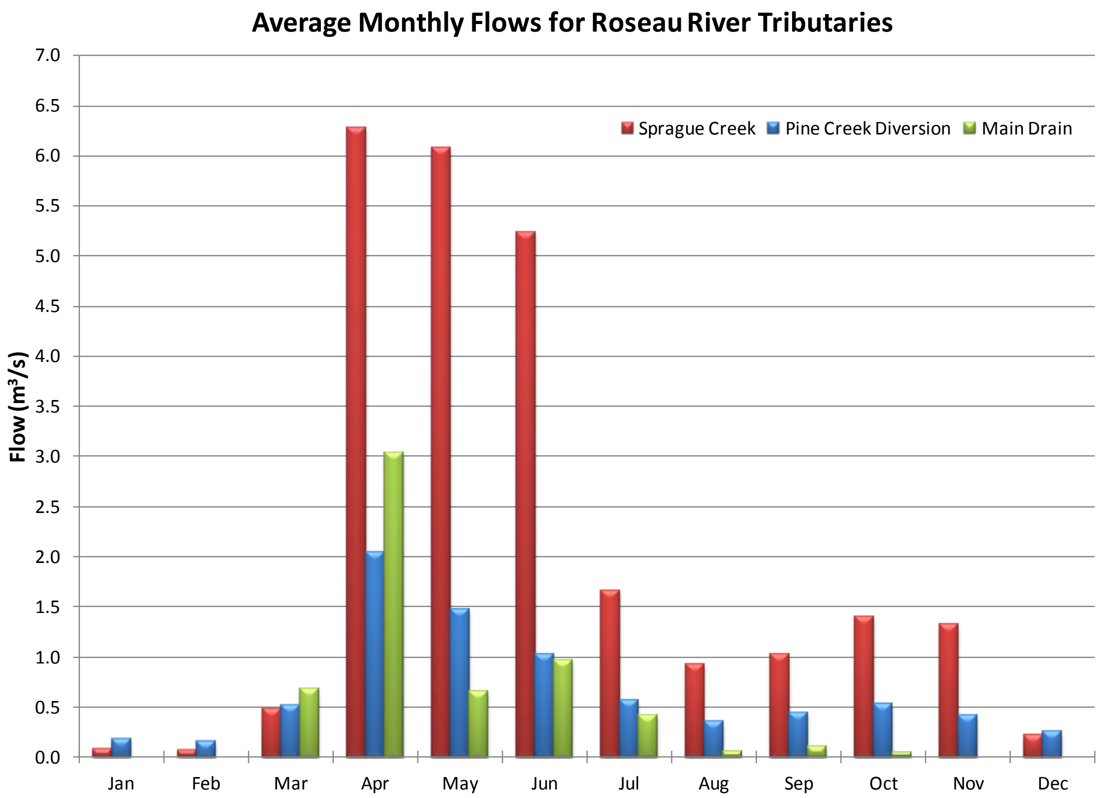


Figure 7: Average Monthly Flows for Roseau River Tributaries (1961-2014)

Peak Flows

Frequency analysis determines how often a certain peak flow is expected to occur in a given period. The frequency analyses for six stations within the Roseau River Watershed are included in Table 4.

The top five flood events and their respective return periods for the Roseau River and its tributaries are shown in Table 5 and Table 6.

Table 4: Peak flows for various return periods

	Return Period						Years of Data
	1% (1:100) cms	2% (1:50) cms	5% (1:20) cms	10% (1:10) cms	20% (1:5) cms	50% (1:2) cms	
Roseau River near Caribou (05112000)	114	106	94	84	71	48	96
Roseau River at Gardenton (05OD004)	144	130	110	94	77	51	102
Roseau River near Dominion City (05OD001)	213	183	146	119	93	58	102
Sprague Creek near Sprague Creek (05106000)	95	83	65	51	36	16	71
Pine Creek Diversion near Piney (05OD027)	20	18	15	13	11	7	38
Main Drain near Dominion City (05OD028)	57	49	39	31	24	13	43

Table 5: Top Five Flood Events for the Roseau River

	Water Year	Peak Flow (cms)	Return Period
Roseau River near Caribou (05112000)	2002	122	1:200
	1950	114	1:100
	2004	98	1:25
	1996	94	1:20
	1997	93	1:20
Roseau River at Gardenton (05OD004)	1950	153	1:160
	2002	123	1:30
	1997	115	1:25
	1927	114	1:25
	2004	111	1:20
Roseau River near Dominion City (05OD001)	1950	230	1:140
	2002	170	1:35
	1997	152	1:22
	1974	145	1:20
	1927	142	1:16

Table 6: Top Five Flood Events for the Roseau River tributaries

	Water Year	Peak Flow (cms)	Return Period
Sprague Creek near Sprague Creek (05106000)	2002	229	>1:500
	1974	70	1:20
	2004	56	1:12
	1942	55	1:12
	1941	52	1:10
Pine Creek Diversion near Piney (05OD027)	1967	17.8	1:60
	1979	14.3	1:15
	1996	13.6	1:12
	1960	13.3	1:12
	1993	11.9	1:8
Main Drain near Dominion City (05OD028)	1979	45.6	1:35
	2002	42.5	1:25
	2006	37.0	1:16
	1964	35.4	1:14
	2010	34.1	1:13

The Roseau River Watershed's Resource Inventory (Roseau River International Watershed, 2007) examined some of the conditions producing some of the most recent events along with the estimated frequency of occurrence as follows:

Spring 1966 – 8 % frequency occurrence near Dominion City. The 1966 spring flood resulted from high autumn soil moisture and a very heavy winter snow cover. A major blizzard in early March greatly increased the snowpack and created a high flood potential. While spring flooding did occur, it could have been much worse but for a very gradual melt and very little spring rain.

Spring 1996 – 6 % frequency occurrence near Dominion City. In 1995, soil moisture was above average going into the winter and cumulative snowfall was approximately 140 % above normal during the winter of 1995/96. A 100 mm rainstorm in the U.S. portion of the watershed in May 1996 was a prime reason for the spring flooding that occurred later that month.

Autumn 2000 – 43 % frequency occurrence near Dominion City. Twice the normal October rainfall in the U.S. portion of the Roseau River Watershed was followed by a record 75 mm rainfall over the Manitoba portion of the watershed during the first week of November 2000. Flooding occurred during November due to the resultant record high flows and from backwater flows that were a result of both stationary and frazil ice.

Summer 2002 – 3 % frequency occurrence near Dominion City. A record rainstorm of 200-300 mm on June 8-9, 2002 produced the highest flows on record at the U. S. boundary near Caribou, MN. The Gardenton Floodway sustained a record high flow and needed to be reinforced by emergency diking to prevent serious outbreaks and flooding. Serious flooding did occur in areas downstream of Gardenton, much of it on tributaries and in the form of overland flow. Record flooding also occurred in the Manitoba headwater areas on Sprague Creek and Pine Creek. The peak flow on Sprague Creek was 3 times as great as the previously highest flood since 1928. The village of Sprague was seriously flooded on June 10th and 11th, 2002.

Summer 2005 – 7 % frequency occurrence near Dominion City. The spring runoff was somewhat above average but did not produce flooding. A series of rainstorms during late June and early July raised the Roseau River at Dominion City to the second highest summer flow on record, second only to that of 2002. The summer peak at Gardenton was the 5th highest on record. Minor flooding occurred along the Roseau River from Gardenton to the Red River. High Red River levels created record high summer levels in the portion downstream of Dominion City in early July (i.e. Lake Roseau). A 100-125 mm downpour near the U.S. boundary south of Dominion City on July 2 caused extensive flash flooding in the R.M. of Franklin.

2.4 Existing Infrastructure

Drain Network

The Roseau River watershed planning area is divided into two sub-watersheds (WS) and their designated numbers are 2 and 87. The upper area (WS 87) includes the drainage area for Pine Creek and Sprague Creek and the lower area (WS 2) includes the drainage area for the Roseau River after it enters Canada at Caribou, Minnesota. The entire watershed area including the waterways is shown in Figure 8. The notable waterways and infrastructure in these two sub-watersheds are listed in Table 7.

Table 7: Waterways and infrastructure in the Roseau River Watershed

Sub-watershed (WS)	Municipalities/RMs	Waterways (Maximum order)	Infrastructure
WS 2 (Lower watershed)	Municipality of Emerson-Franklin, R.M. of Montcalm, R.M. of Stuartburn, R.M. of Piney	River: Roseau (5th order), Jordan (3rd order), North Branch Jordan (2nd order) Creek: Conroy (3rd order) Drain: Kyle (2nd order), Harlow (3rd order), Main (3rd order), Fredensthal (3rd order), Ridgeville (3rd order), Stewart (3rd order), Casson (2nd order), Langside (3rd order), Vita (3rd order), Vita South (3rd order), Gardenton (3rd order), Arbakka (3rd order)	Dominion City Dam and Reservoir, Arbakka Dam, Gardenton Floodway, Horseshoe Lake Dam
WS 87 (Upper watershed)	R.M. of Piney	River: Roseau (5th order) Creek: Pine (East/West) (5th order), Sprague (3rd order), Mud (2nd order) Drain: Sprague (3rd order)	Pine Creek Diversion

(Source: Designation of Drain Maps)

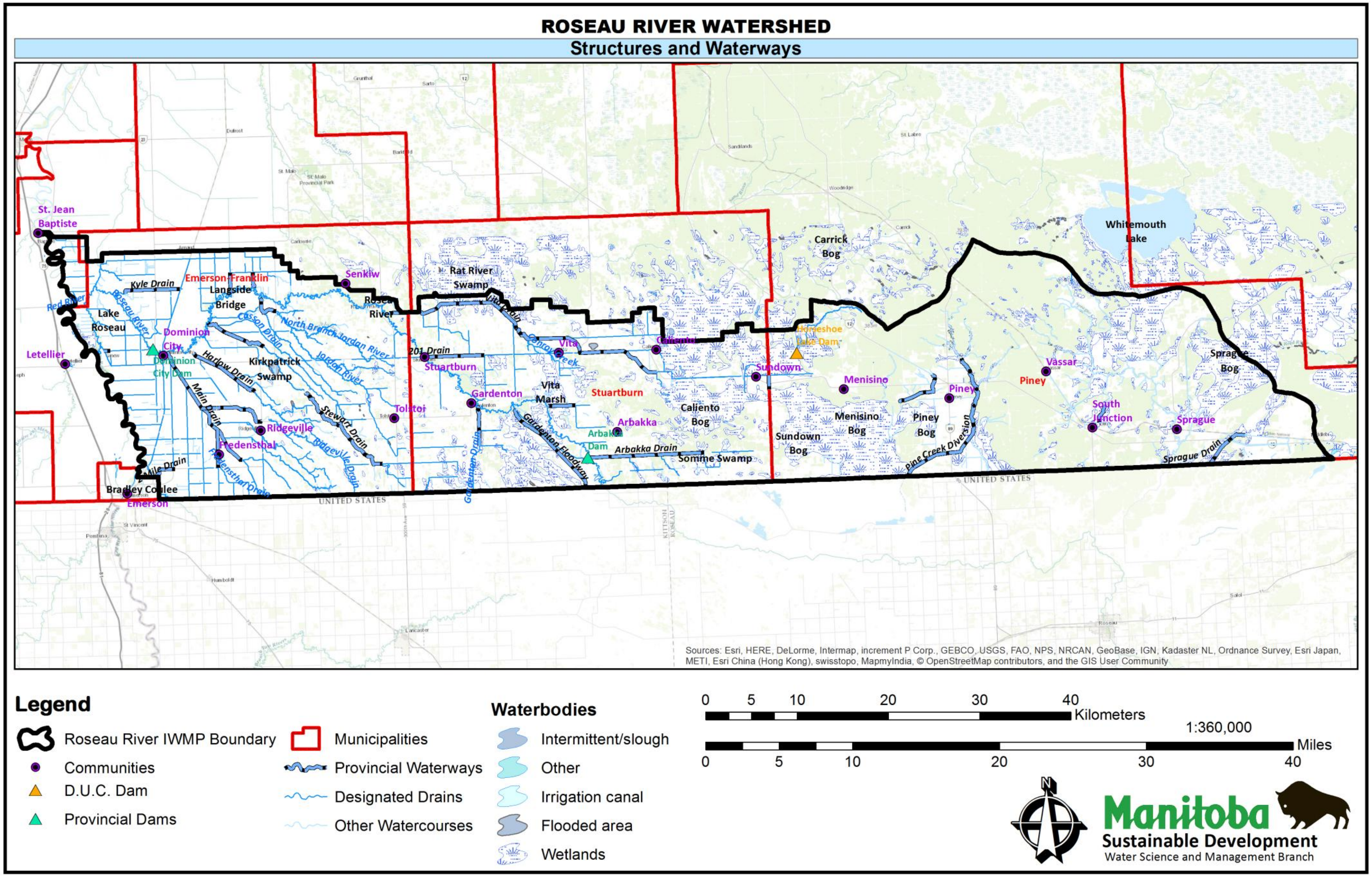


Figure 8: Watershed infrastructure map

The waterways in Manitoba are classified on a scale from 1^{st} order to 7^{th} order, with the 1^{st} order being the smallest and the 7^{th} order being the largest. The majority of drains in the Roseau River Watershed are classified as first order (i.e. a drain having a tributary drainage area of one square mile or less), second order (i.e. a drain having a tributary drainage area of more than one square mile), or third order (i.e. a drain below the confluence of two second order drains) (MNRE, 1983). The municipalities, towns and villages typically maintain all 1^{st}, 2^{nd}, and some 3^{rd} order artificial drains, whereas the Province of Manitoba typically manages and maintains most of the 3^{rd} and higher order artificial drains. Within the Canadian portion of the Roseau River Watershed there are approximately 187 km of provincial waterways and approximately 764 km of municipal drains.

Major drains in the western part of the watershed include the Main Drain, Harlow Drain, Stewart Drain, Casson Drain, Jordan River, and the recently constructed Inter-municipal Drain. Major drains in the central part of the watershed include the Vita Drain and Arbakka Drain. Major drains in the eastern part of the watershed include the Pine Creek Diversion and Sprague Drain.

Diversions and Water Management Structures

There are four noteworthy man-made blockages or diversions in the Canadian portion of the Roseau River and its tributaries that have altered or impeded the natural flow. Modifications include: the Pine Creek Diversion in the eastern part of the watershed within the RM of Piney; the Gardenton Floodway in the central part of the watershed within the RM of Stuartburn; and the Dominion City Dam in the western part of the watershed within the RM of Franklin; and the Horseshoe Lake impoundment in the central part of the watershed within the RM of Piney.

Pine Creek Diversion

The Pine Creek Diversion was constructed in 1952 and put into operation in 1953 to provide a constant water supply to the wildlife impoundments that were constructed for the Roseau River Wildlife Management Area (RRWMA) in Minnesota along the Canada-U.S. border. The Master Plan for the RRWMA states that while the diversion project was requested and financed by the State of Minnesota, the actual construction work carried out in Canada was completed by the Province of Manitoba (MNDNR, 1980). The overall plan for the Roseau River Watershed District notes that the diversion was constructed in accordance with a written agreement between the Province of Manitoba and the State of Minnesota dated February 18, 1952 (RRWD, 2004).

The Pine Creek Diversion starts roughly 4.0 km northeast of Piney Customs and runs for approximately 11 km in Canada and the U.S. The diversion follows a southwesterly path in Canada for approximately 7 km before turning south at the Canada-U.S. border and dispersing into Pool #1 of the RRWMA. The diversion is a passive system in which there is no dam structure at the inlet and no structure or definitive endpoint at its terminus in the RRWMA. The portion of the Pine Creek Diversion within Canada is classified as a Provincial Waterway. Flow diverted through the Pine Creek Diversion eventually makes its way into the Roseau River channel in Minnesota after passing through the RRWMA pools and associated ditch systems. While flow from the original Pine Creek channel was significantly diverted, provisions were made to allow for a limited flow to continue moving south into the U.S. where the original Pine Creek channel meets the Roseau River channel.

Gardenton Floodway/Arbakka Dam

The Gardenton Floodway was constructed in the late 1920s due to inadequate capacity in a stretch of the Roseau River channel just south of Vita for conveying high spring flows. The floodway was designed to contain increased flood flows in Canada that were caused by the construction of channel improvement works and drainage networks along the Roseau River in Minnesota between 1904 and 1918 (IRREB, 1975). At the time, agricultural land and a number of homesteads in the low lying area adjacent to the Roseau River channel, as well as the nearby community of Vita, were put at risk during the spring runoff period. By diverting the high spring flows through the floodway, area homes and the community of Vita were protected from floodwaters that would have otherwise inundated the area.

The entrance to the Gardenton Floodway is located roughly 3.2 km northwest of where the Roseau River crosses the International Border and follows a northwesterly direction for approximately 9.7 km until it empties back into the Roseau River channel just upstream from the community of Gardenton. The floodway consists of north and south dikes constructed with local materials to contain flows. The Roseau River follows a defined channel through the floodway along the inside edge of the east dike. In order to divert the flow from the Roseau River, a wooden control dam was constructed in the natural river channel in 1930. The original dam burned down and a new concrete structure – referred to as the Arbakka Dam – with a stop-log system was built in 1965 just to the east of the original dam location. The Gardenton Floodway is considered a Provincial Waterway.

The International Roseau River Engineering Board (IRREB, 1975) noted that original conveyance capacity of the floodway in 1930 was 150 cms, but due to the deterioration of the dikes by 1975, the capacity had been reduced to 113 cms. Given that another 30 years has passed with further deterioration and settlement of the dikes as well as vegetation growth within the floodway channel, the current channel conveyance is unknown but likely less than the 113 cms noted in 1975 (UMA, 2002). Due to the absence of a regular flow in the original Roseau River channel from the Arbakka Dam to just before Gardenton, the channel has become overgrown with vegetation. The IRREB (1975) noted that the original, albeit limited, flow of this stretch of the Roseau River prior to 1930 was 19.8 cms and UMA (2002) estimated that with the vegetative overgrowth the channel capacity in this stretch is now likely somewhere on the order of 3 to 6 cms.

Dominion City Dam

The Dominion City Dam was constructed in 1957 by the Prairie Farm Rehabilitation Administration immediately downstream of Dominion City to establish a water supply reservoir for the community. The dam had been requested by the RM of Franklin council in a resolution dated July 14, 1953. After the community was connected to a water supply pipeline from Letellier in 1988, the dam was retained for irrigation, stock-watering, and recreation purposes (Gaboury et al., 1995). Dam construction involved a concrete slab and buttress-type weir directly in the natural river channel with a stop log system in place to allow for manipulation of the upstream reservoir levels. The dam is 1.2 m high and has a storage volume of 148 dam^3 at a summer target level of 213.9 m (Gaboury et al., 1995). The original storage capacity at full supply level was 419 dam^3. The IRREB (1975) noted that during spring flood periods, the dam becomes submerged but has minimal backwater effect and little effect on the flow regime of the Roseau River.

Due to the negative effect of the dam on fisheries resources in the Roseau River in 1992 the Province of Manitoba, with the support of the South East Border Wildlife Association, carried out the Roseau River Fisheries Enhancement Project. This project involved the addition of riprap on the downstream side of the dam to create a series of rapids (pool and riffle system) that allow for fish passage up and over the dam. Prior to the construction of this pool and riffle based system, fish passage to the Roseau River upstream of the Dominion City Dam was limited to times when there was high flow and the height of the dam was exceeded.

Horseshoe Lake

The Horseshoe Lake impoundment is a Ducks Unlimited project located on Sections 16 and 21, Township 2, Range 10E, in the RM of Piney, 6.5 km east of Sundown, just across the Stuartburn-Piney municipal boundary, and can be accessed via a trail that runs approximately 3.2 km north off Provincial Road #201. It is a flooded fen developed on peat and is habitat for waterfowl. Ducks Unlimited Canada (DUC) originally developed Horseshoe Lake as an impoundment project and is currently responsible for maintaining and operating the lake. The project construction was completed in 1956.

Horseshoe Lake was created via the construction of an earth fill dam across the outlet at section 17-2-10E. The earth fill dam was constructed to 240 m in length with a maximum fill of 4 m and was originally constructed with a 3 m top, 3:1 rip-rapped front slope, and 2:1 back slopes. In the middle of the dam, a 3.5 m high reinforced concrete structure was built with an overflow width of 6 m to pass surplus waters and to control the water level on the lake. The last 0.3 m of the structure is controlled by a stop-log system. By the time construction of the dam was completed in 1956, the reservoir had filled to the level where it was overflowing through the structure. The approximate flooded area at a full supply level of 30 m covers 3.5 km^2 and has a total shoreline length of 17 km.

3. Surface Water Issues and Opportunities

3.1 Information gathering

Watershed Tour

On August 25th, 2015, members of the Surface Water Management Section participated in a watershed tour with local representatives from the Roseau River IWMP project management team. The purpose of the tour was to provide the project team with a firsthand experience of the watershed and perspective from landowners with local knowledge of the water issues and to identify and evaluate potential water retention sites.

The tour started in Vita with a meeting of tour participants to discuss the purpose of the tour and background information on the sites to be visited. Sites visited on the tour included:

- Horseshoe Lake (also known as Sundown Lake)
- Drain out of Horseshoe Lake crossing old P.R. 201
- Sundown Bog
- Caliento Bog
- Arbakka Dam/Gardenton Floodway
- Community Pasture/Gardenton Floodway

Participants in the tour included:

- Jodi Goertzen – District Manager of the Seine-Rat River Conservation District (SRRCD)
- Cornie Goertzen – Chair of SRRCD; IWMP Project management Team member
- Jim Swidersky – Vice-Chair of SRRCD; Reeve of RM of Stuartburn; IWMP Project management Team Chair
- Ed Penner – Chair of Roseau River Sub-district (SRRCD board member); Councillor for RM of Stuartburn; IWMP Project management Team member
- Ken Prociw – Roseau River sub-district member; Councillor for RM of Piney; IWMP Project management Team member
- Orest Kuryk– Roseau River sub-district member; Councillor for the RM of Emerson-Franklin
- Mark Lee – Manager of Surface Management Section; Manitoba Sustainable Development
- Sung Joon Kim – Hydrologic Application and Research Engineer; Surface Management Section, Manitoba Sustainable Development
- Ken Rakhra – CD Support Engineer; Surface Management Section, Manitoba Sustainable Development
- Tara Wiess – Hydrologic Technologist; Surface Management Section, Manitoba Sustainable Development

Past Reports

Many studies have been completed on the Roseau River under various topics. Many of these reports contain useful information that is still relevant to current watershed management activities. A search was completed and many reports related to the Roseau River Watershed issues are listed chronologically below. The past studies were reviewed for any past retention project ideas that may still be relevant. A summary of reports is included in Table 8.

Table 8: Past reports on the Roseau River Watershed

Year	Title	Authors
1960	Proposed Roseau River Dam & Reservoir East of Dominion City	Water Resources Branch, J. H. Dicks
1960	Roseau River Flood Control Investigation	Water Control and Conservation Branch, Planning Division
1966	Investigation of the Effect of Proposed Flood Control Works in United States on the Roseau River in Canada	Canada Department of Agriculture
1971	Flood Control Roseau River, Minnesota General Design Memorandum	Department of the Army U.S. Army Corps of Engineers
1972	Plan of Study, Coordinated Water Use and Control, Roseau River Basin Manitoba, Minnesota	International Roseau River Engineering board
1973	Cost of Mitigating Works in Canada - Interim Report to The International Joint Commission by the International Roseau River Engineering Board	Joint Studies for Coordinated Water Use and Control Roseau River Basin
1973	Report On Senkiw Dam Roseau River Project	P.J. Rivard, N.L. Iversion
1974	Report on Flood Control through the Canadian Section of the Roseau River (Hydrology Sector Component - International Roseau River Study)	PFRA
1975	Effect of Proposed Increased Peak Flows on the Morphology of the Roseau River in Canada	Water Resources Branch, Planning Division
1975	Joint Studies for Co-ordinated Water Use and Control in the Roseau River Basin Appendix A - Historical Documents and References Appendix B - Water Resources Appendix C - Related Resources Appendix D - Socio-Economic Characteristics Appendix F - Coordinated Plan Formulation Appendix E - Project Investigations	International Roseau River Engineering Board
1981	Final Supplement: Environmental Impact Statement, Flood Control, Roseau River, Roseau and Kittson Counties, Minnesota	U.S. Army Corps of Engineers
1983	Water Resources Branch Provincial Procedure Directive on Designations of Drains.	Manitoba Department of Mines, Natural Resources and Environment (MNRE)
1995	Pool and Riffle Fishways for Small Dams.	Manitoba Natural Resources Fisheries Branch
2003	Development and Application of a Calibrated Flood Routing Model for the Canadian Portion of the Roseau River Watershed	UMA Engineering Ltd.
2004	Overall Plan for the Roseau River Watershed District.	Roseau River Watershed District (RRWD)
2007	Roseau River Watershed Plan	Roseau River International Watershed
2007	Roseau River Watershed Resource Inventory: Background document for the Roseau River Watershed Plan	Roseau River International Watershed
2013	Roseau River Watershed District Roseau River Wildlife Management Area Pool 2 and Pool 3 Outlet (Preliminary Engineer's Report)	HDR Engineering Inc
2013	Roseau River Watershed District Expanded Detention Strategy	Houston Engineering Inc./ HDR Engineering Inc.

Roseau River IWMP Project Management Team Public Surveys

The Roseau River IWMP project management team conducted public meetings and an on-line survey. Public meetings were held at Vassar, Dominion City and Vita in January and February, 2016. During the public meetings a survey and group activity were conducted for collecting information on water management issues and suggestions of potential storage retention sites.

In total, 111 surveys were submitted and the results were summarized in “What We Heard: Public Engagement Meetings for the Roseau River Integrated Watershed Management Plan”. The top water management issues from the surveys can be condensed down to:

1. Surface water management issues including peak flows on the Roseau River, water flow restrictions or lack of, flooding and inundation, land drainage, water retention and jurisdictional water management issues between Canada and the United States of America.
2. Surface water quality for domestic use, wildlife, aquatic life and recreation
3. Ground water quality for domestic use
4. Ecosystem health and natural areas included functioning and healthy riparian areas and buffer zones for additional water quality benefits beyond just for domestic use, preserving plant and animal biodiversity in the watershed, and many elements of recreation such as development, access, use and enjoyment as it relates to the Roseau River.

3.2 Summary of Issues and Opportunities

The above sources of information were used to understand current and past surface water management issues in the Roseau River Watershed. Major issues identified in the information gathering exercises related to water management in the Roseau River Watershed were generally related to excessive moisture and flooding, wildlife and recreation development opportunities, reliable water supplies, drainage, and water quality.

When identifying potential retention projects, the capability for the projects to help address these issues was considered.

Excessive Moisture and Flooding

Over the past two decades, many Manitoba rivers have experienced an increased frequency of flooding. In such a wet period, it is common for flooding issues to be prominent. Individual retention projects may not have a significant impact on peak flows on the main stem of the Roseau River. However, they will have local benefits and their cumulative impact help reduce peak flows on the main stem. Small retention projects will also be overwhelmed by large flood events (100-year events) but may be effective in controlling moderate floods (10-year events).

The majority of water moves through the watershed during the spring freshet. Flooding is most common during years with high antecedent soil moisture, heavy snow pack, and rapid melt. Spring rains can quickly exacerbate spring flooding. The watershed has also experienced rainfall induced summer flooding. In fact, the 2002 summer flood is the flood of record for parts of the watershed. While spring flooding often has minimal impact on agriculture if water recedes to allow land to dry prior to seeding, summer floods can be devastating as crops are quickly damaged if inundated for more than a few days.

As stated in the introduction, the primary focus of the retention study will be to find projects that can reduce peak flows. This will address local watershed management goals and also complement efforts in other parts of the Red River Basin to reduce peak flows on the Red River.

Floods generally occur when the channel capacity is exceeded. However, flooding is also common in the lower reach of the Roseau River from backwater from the Red River. This area is commonly called “Lake Roseau” during flood events. Flooding issues were also mentioned with regards to the large wetland complexes (for example, Sundown Bog) rising during wet periods and impacting agricultural activity such as pasture and hay land.

Erosion in the Roseau River rapids area has been a significant problem over the past 30 years and can negatively impact water quality. The Roseau River Rapids extends for several kilometres below the Village of Roseau River. Pine Creek Diversion and Vita Drain have also been reported to have erosion issues.

Recreation Opportunities

Many stakeholders mentioned taking advantage of opportunities to expand wildlife and recreation throughout the watershed. The natural beauty and opportunities for fishing, tubing, and canoeing were frequently mentioned as an underdeveloped tourism resource for the communities. While recommending recreation opportunities, such as riverside picnic areas and better access to the main stem of the Roseau River, is not within the scope of this retention study, some of the retention areas identified could also provide recreational opportunities.

Wildlife Enhancement

Enhancing wildlife by increasing aquatic habitat through retention projects was mentioned in the public meetings as well as during watershed tours. Creating or enhancing wildlife habitat would offset prior habitat loss from land put into agricultural production. Projects that have potential to enhance wildlife will be identified.

Water Supply

Drought and water supply concerns were discussed at the public meetings. Participants were asked to provide input into the impacts of drought, vulnerability to it, their ability to respond to the impacts of drought and to identify actions to reduce the severity or impacts of drought. For surface water, the quality of water supply seems to be more of a concern than quantity. Most water for human uses is supplied from groundwater sources. Groundwater is generally more reliable than surface water. However, many of the domestic water wells are shallow and could be susceptible to supply issues during droughts. The Surface Water Management Section of Sustainable Development is currently assessing drought preparedness in more detail and the results will be provided in a separate report.

Even without human use as a surface water supply concern, retention projects can be valuable to augment flow during dry periods to mitigate drought impacts to aquatic habitats. Small retention projects will generally not have multi-year storage and will only provide relief during short term droughts.

Drainage

Similar to many prairie watersheds, the natural stream network has been augmented by a large artificial drainage network. Drainage is often a contentious issue at the local and watershed scale.

While providing many benefits to water management and agriculture production, excessive drainage contributes to many other watershed and ecosystem issues. There is a concern that increased drainage of marginal farmland and wetlands in the last number of decades has contributed to flooding.

In some areas of the watershed, improved drainage would improve agricultural production and solve local flooding issues. On the other hand, increased drainage may increase flooding and erosion in other areas of the watershed, negatively impact water quality, reduce water availability for wildlife, and reduce the resiliency of the watershed to drought. As a result of the negative effects of artificial drainage, many stakeholders are interested in reducing drainage for the benefit of water management at the watershed scale. Better management of drainage was frequently cited at the public meetings and on-line survey as a watershed issue.

Water retention projects may help drainage issues in a few ways. One, they may reduce the need for drainage if upstream flows are reduced. Secondly, retention can offset some of the negative effects of past drainage or future drainage. The Province of Manitoba is looking to have a no-net-loss of water retention capacity in watersheds moving forward. Retention projects can contribute to a sustainable drainage plan within a watershed.

Water Quality

The Roseau River generally has good water quality most of the time. However, many respondents to the public survey had water quality as an important issue to include in watershed management planning. Water quality was identified with respect to domestic use, wildlife, aquatic life and recreation.

In addition to local water quality concerns, the contribution of the Roseau River to the Red River and Lake Winnipeg’s water quality is also important to consider. The Province of Manitoba and many stakeholder organizations are taking action to reduce nutrient loading to Lake Winnipeg. Any reduction in nutrient loading in the Roseau River will add to the collective action of all Lake Winnipeg Basin residents.

Many people are interested in developing water retention to remove nutrients from water. This occurs by uptake of nutrients by aquatic plants and through settling. Retention sites that may have potential to remove nutrients will be flagged when sites are assessed.

4. Watershed Modelling Approach

U.S. Army Corps of Engineers Saint Paul District conducted a study, the “Red River of the North Hydrologic Modeling”, in two phases to develop consistent hydrologic models for various Red River tributary watersheds that contribute to the Red River up to the United States/ Canada border. The USACE Hydrologic Engineering Centre (HEC) HEC-HMS model was selected as the preferred method because a uniform set of tributary hydrologic models is needed to look at the hydrology of the basin as a whole and also the existing models applied for various tributary watersheds in the basin have some uniformity with HEC-HMS. The HEC-HMS models were developed as a planning tool for users to evaluate existing and proposed water management. As a part of the project, HDR Engineering, Inc. developed the HEC-HMS model for the Roseau River Watershed as a whole including the Canadian portion.

To ensure consistent assessment results between Canada and the U.S., the hydrological model HEC-HMS, and related GIS data sets prepared by HDR Inc., are used for this study.

4.1 GIS Modelling Methodology

GIS analysis was a large part of the hydrologic modelling and the project evaluations. The GIS analysis required to undertake the hydrologic modelling was completed by studies undertaken in the U.S. portion of the Roseau River Watershed. The Red River of the North Hydrologic Modeling – Phase 2 report produced by the U.S. Army Corps of Engineers Saint Paul District (USACE, 2013) details how various base data including the elevation models and Soil Conservation Service (SCS) curve numbers used in this study were produced. A short summary of the methodology is included below.

Elevation Models

The elevation model used for this distributed retention study was developed by HDR Engineering, Inc. (U.S. Army Corps of Engineers, 2013). Elevation in the form of digital elevation models was obtained from several sources and compiled into a single study-area wide dataset. A single elevation dataset was created from LiDAR, non-LiDAR and transitioning elevation datasets. Vertical elevation datums were adjusted for a consistent NAVD88 datum standard across the entire watershed. The final five-metre resolution elevation dataset was applied in the hydrologic conditioning process.

A LiDAR digital elevation model (DEM) does not include subsurface culverts that move water across roadways, railways and other blockages. Some modifications on the LiDAR DEM are required to generate flow paths close to observation for a model. The International Water Institute (IWI) and HDR Engineering, Inc. created a hydrologically conditioned elevation model by removing and/or altering these blockage portions in the LiDAR DEM. Due to a lack of local information in the Canadian portion of the watershed, some portions were not completely conditioned. Where necessary, these portions were hydro-conditioned in more detail.

SCS Curve Numbers

IWI and HDR Engineering, Inc. developed initial SCS curve numbers from land use and Hydrologic Soil Group (HSG) classification based on the Natural Resources Conservation Service (NRCS) curve number assignment approach from the National Engineering Handbook. HDR Engineering, Inc. used land use types as a determinant in assigning curve numbers to the dual HSG codes (A/D, B/D, and C/D). The curve numbers were then converted from a 24 hour curve number to a 10-day equivalent.

For the U.S. portion of the study, the National Land Cover Database (NLCD) provided remotely-sensed land use data representing 2001 conditions. Manitoba Land Initiative (MLI) provided a similar dataset for the Manitoba portion of the study area.

In the U.S., soils data were obtained from the NRCS detailed soil survey, the Soil Survey Geographic database (SSURGO). Soils information in Manitoba was obtained from detailed soil surveys, the Agricultural Interpretations Database (SoilAID), from Agriculture Canada. The SoilAID data did not directly include HSG classifications. HSG classifications were estimated using two parameters: 1) the depth to a water impermeable layer and 2) the most restrictive saturated hydraulic conductivity within the first 40 inches of the soil column.

Retention Site Evaluation

The storage capacity at each potential retention site was evaluated using GIS. A possible maximum retention water level for a potential retention site was estimated by evaluating surrounding elevations and residential and private properties using the LiDAR DEM and satellite images. A stage-storage curve is the most critical information to evaluate retention capacity of a potential site. Stage-storage curves were created for each potential site using detailed elevation information derived from the LiDAR DEM.

4.2 HEC-HMS Approach

HEC-HMS Model

The HEC-HMS model used in this study was built off of an existing model developed by HDR Engineeing and made publicly available though the International Water Institute's Red River Basin Decision Information Network website (http://www.rrbdin.org/resources/hydrologymodels/ phase-2-northern-basin). HDR Engineering performed a terrain analysis on LiDAR data - generalized a 5 m X 5 m Digital Elevation Model (DEM) - to determine HEC-HMS modeling parameters, calibration, and synthetic model development. The models are parameterized for rainfall runoff modeling and not snowmelt modeling. The hydrologic routing was based on roughly cut cross section data and coarsely constructed HEC-RAS models and simplifying assumptions were used to model major hydraulic structures.

Recently, the USACE Hydrologic Engineering Centre (HEC) released a new version of the HEC-HMS model (version 4.0) which added water quality assessment capability. HDR Engineering Inc. used the previous version (version 3.5) of HEC-HMS for the Roseau River model development. To see the potential of water quality assessment with the model, the model was converted to the new 4.0 version for this study. The differences between two models are very minimal but some parameters and data formats needed to be adjusted to convert the model from version 3.5 to version 4.0.

Design Storms

As the HEC-HMS models are more easily parameterized for rainfall runoff modeling, the Red River Basin Commission developed a "Red River Basin Standardized Melt Progression Event Analysis"

(Houston Engineering, Inc. and HDR, Inc. 2013) to improve spring snow melt events simulation. The analysis used temperature data at observation locations throughout the Red River Basin to estimate general snowmelt conditions during a typical spring. The temperature analysis was applied to a 10-day runoff scenario depth to develop equivalent rainfall depths for the 10-day runoff using the composite 24-hour NRCS curve number for the portion of the Red River Basin. The developed equivalent rainfall depth was then applied using the Minnesota Principal Spillway Temporal Rainfall Distribution. The resultant Red River Basin Standardized Melt Progression Event (Houston Engineering, Inc. and HDR, Inc. 2013) was used to determine volume and peak flow reduction criteria based on the Long Term Flood Solutions recommendations.

The storm events used in the U.S. retention study were developed over the entire basin and a storm event was assumed to occur simultaneously over the entire basin. Additionally, aerial reduction factors were not applied to adjust for point rainfall and a safety factor was added following NRCS small dam design standard. As a result, the model simulation overestimated the 100-year peak flow based on observed hydrometric statistics. For this study, the snowmelt runoff scenario was adjusted to generate simulated 10-year and 100-year events close to historical flood frequency statistics for both peak flow and volume at the Roseau River at Dominion City station.

Water Quality Modelling

There is a strong desire to investigate the influence water retention projects can have on water quality, particularly the removal of nutrients. To test the additional water quality assessment capability in the new 4.0 version of HEC-HMS, the version 3.5 Roseau River model was converted to the newer version. The water quality parameters were entered into the model for individual sub-watersheds. However, a number of technical issues with the water quality and sediment transportation functionalities were found when the Roseau River model was run. The HEC-MHS software has a number of river routing options. The water quality and sediment transportation functionalities only work with specific routing methods. Running the water quality simulations for the entire watershed would require a significant modification of the model, mostly due to these limitations on the available routing methods for performing water quality simulations. Therefore, at this time it was decided not to invest the large amount of time required to make the model modifications to be able to simulate changes in water quality.

5. Potential Water Retention Projects

5.1 Project Assessment Overview

The following provides details of the numerous retention projects investigated. The projects were selected based on information from the IWMP public meetings, past studies and reports, field tours, and desktop analysis of LiDAR data. The purpose or benefit each project could achieve is based on public input and engineering judgment. In many cases, a project and its operation should focus on a primary purpose. For example, it is difficult to have a project provide both flood protection as well as water supply benefits.

All project details are based on a cursory assessment only. More detailed engineering would be required to determine if a project is feasible. This would include information gathering such as surveys and geotechnical investigations leading to refinement of the project design, cost, storage capacitates, land acquisition requirements, operation procedures, etc. All projects would still need to obtain regulatory approvals required by *The Environment Act, The Water Rights Act*, and if affecting a Provincial Waterway, *The Water Resources Administration Act.*.

The proposed storage capacity for each site is not necessarily an optimized design but rather a possible maximum capacity at a potential site for project planning purposes. The calculations were based on LiDAR data. The Roseau River Watershed Expanded Distributed Detention Strategy (Houston Engineering, Inc. and HDR, Inc., 2013) focused on locations being able to detain three to four inches of runoff from a minimum of 52 km^2. To not exclude any potential sites in the Canadian portions of the watershed, this threshold was not applied. The drainage area contributing to each project location and the depth of runoff were calculated and are provided in Table 9. The depth of runoff retained is a simple calculation of the storage capacity divided by the gross contributing drainage area and is a good indication of the project's flood reduction potential.

The cost estimates for the projects are very coarse. It is difficult to estimate a cost without more detailed investigation. However, the potential cost is an important planning component and, although rudimentary, valuable to include at this point. The cost estimates were based primarily on projects of similar scope that the Surface Water Management Section has designed for conservation districts. The cost estimate of a project could vary significantly from the estimates provided after more detailed investigation. For example, a geotechnical investigation may reveal good material nearby, or poor material that requires suitable clay material to be hauled to the site. Land acquisition cost is not included in this study

A project priority was assigned to each project. High priority projects were judged the most likely to be feasible for the conservation district to pursue in the short term. Low priority projects were judged to be the least feasible at this time. The priority was based on a qualitative assessment which considered construction cost, land ownership, potential benefit, and public interest. The conservation district manager and watershed planner provided input to the assessment.

5.2 Potential Projects

In total, ten potential storage retention sites were selected for a preliminary assessment including a conceptual design, storage capacity, potential benefits, and cost. HEC-HMS model was set up for each retention site to simulate 10-year and 100-year flood events. A summary of the project details is provided in Table 9. A map of project locations is provided as Figure 9. The project locations are represented as red circles, with the size of the circle representing the maximum potential storage capacity at the site.

Table 9: Retention project summary

Map ID	Project name	Purpose[1]						Max Storage Capacity (dam^3)	Drainage Area (km^2)	Depth of Runoff Retained (mm)	Cost ($)	Priority
		Flood Control	Water Supply	Wildlife	Recreation	Water quality	Other					
1	Horseshoe Lake	Y	P	Y	Y	P		10,200	66.1	154	350K-500K	High
2	Sundown Ridge	Y		Y		P		6,000	90.98	66	500K-750K (West) 1.1M-1.65M (South)	High
3	Mueller Farm	P	P	P	Y	P		200	29.3	6.8	180K-270K	High
4	Kirkpatrick Swamp	Y	Y	P		P		5,000	47.8	105	800K-1.2M	Medium
5	Gardenton Floodway-Community Pasture	Y		P		P		55,000	66.3	758	6.5M-10M	High
6	Old Roseau River	P		P	Y	P		200	4160	0.04	700K-1.05M	Medium
7	Tolstoi	Y	Y					4,600	29.0	159	300K-450K	High
8	Senkiw Dam	P	P		Y			7,100	4650	1.5	Not assessed	Low
9	Sprague	Y	P	P				45,000	139	324	1.8M-2.7M	Low
10	Somme Swamp	Y		P		P		26,000	167.6	6.1	3.6M-5.4M	Low

Note 1.: Y – Yes; P – Possible

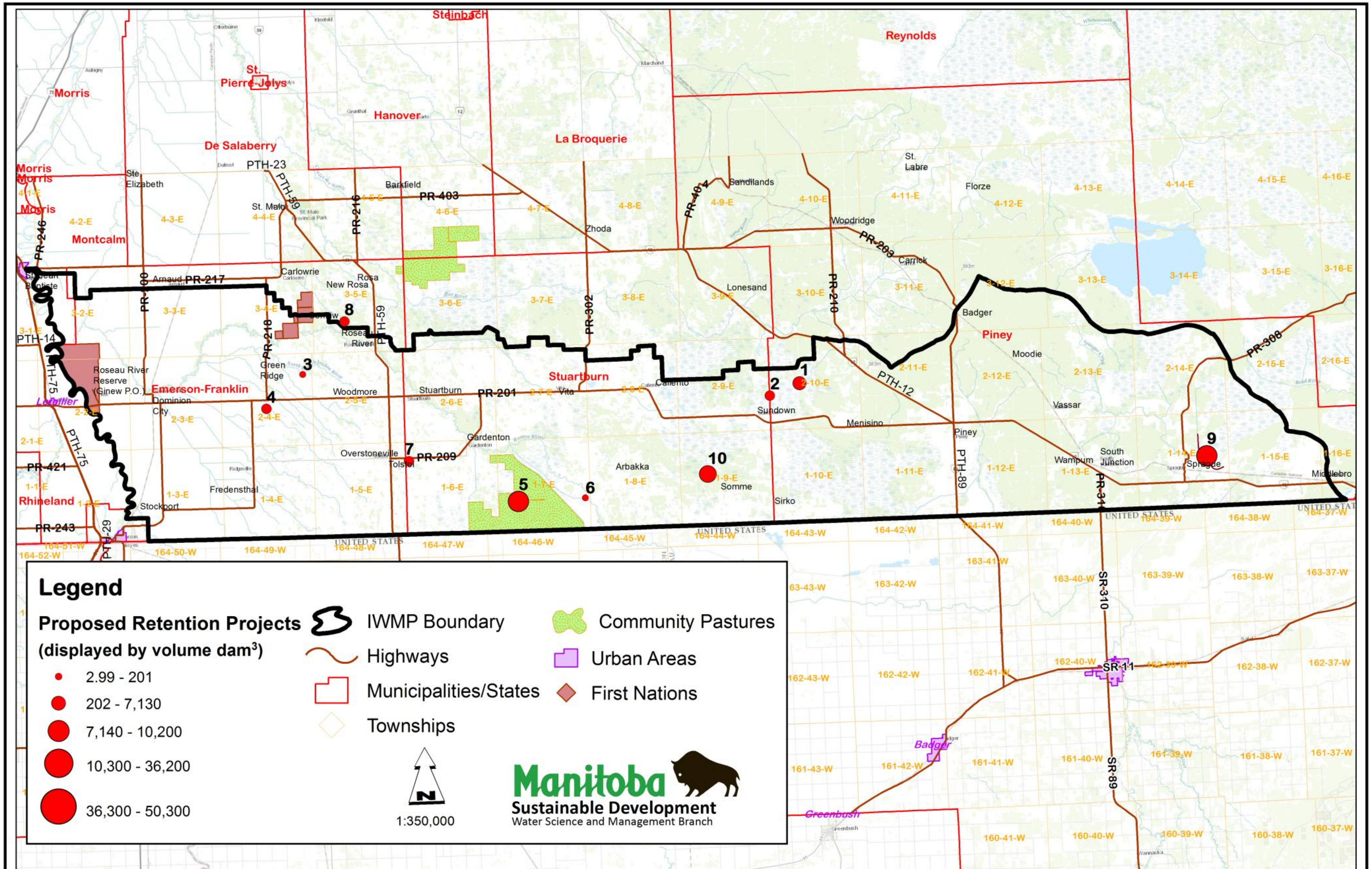


Figure 9: Map of potential retention projects

Horseshoe Lake Project

Horseshoe Lake is located on N1-2-10-E 6 and S21-2-10-E, in the RM of Piney. The lake is approximately 6.5 km east of Sundown, just across the Stuartburn-Piney municipal boundary, and can be accessed via a trail that runs approximately 3.2 km north off Provincial Road 201. Approximately 85 % of the proposed storage area is Crown land.

Ducks Unlimited Canada (DUC) developed Horseshoe Lake as an impoundment project in 1956 and is currently responsible for maintaining and operating the lake. It is noted that some issues related to ownership and authority for the current structure and the use of lake are still to be resolved among Provincial Government, DUC, and local governments. This is currently a complicating factor in the project moving forward.

Figure 10: Existing Horseshoe Lake control structure

The current structure would be replaced with a new spillway structure and a drawdown chamber. Dikes on either side of the new spillway structure would be raised to a level of 336 m for approximately half a kilometre. The current dike elevation is approximately 334.5 m. Raising the dike elevation to 336 m would create a flooded area of approximately 8.2 km^2 with an expanded storage capacity up to 10,100 dam^3. To ensure that the dike and structure do not wash out during major floods that exceed the design capacity of the structure, an emergency spillway would need to be incorporated into the dike to divert excess water around the control structure. The estimated cost for this potential retention project is between $350,000 and $500,000.

During spring snowmelt period, inflows to the reservoir would be retained until the peak flow passes then the drawdown chamber would be operated with consideration to downstream conditions. When the downstream conditions become normal or below normal, the outlets would be operated to lower the lake level to near the current level.

The site could also have benefits for wildlife in the area but an operation plan would need to be coordinated with wildlife experts to ensure operation for flood control is compatible with wetland habitat. The storage volume could possibly be used for agricultural needs or irrigation downstream if demand exists and delivery is compatible with the flood control operation.

Elevation-volume-area curves are provided on Figure 11, and a site layout is provided on Figure 12.

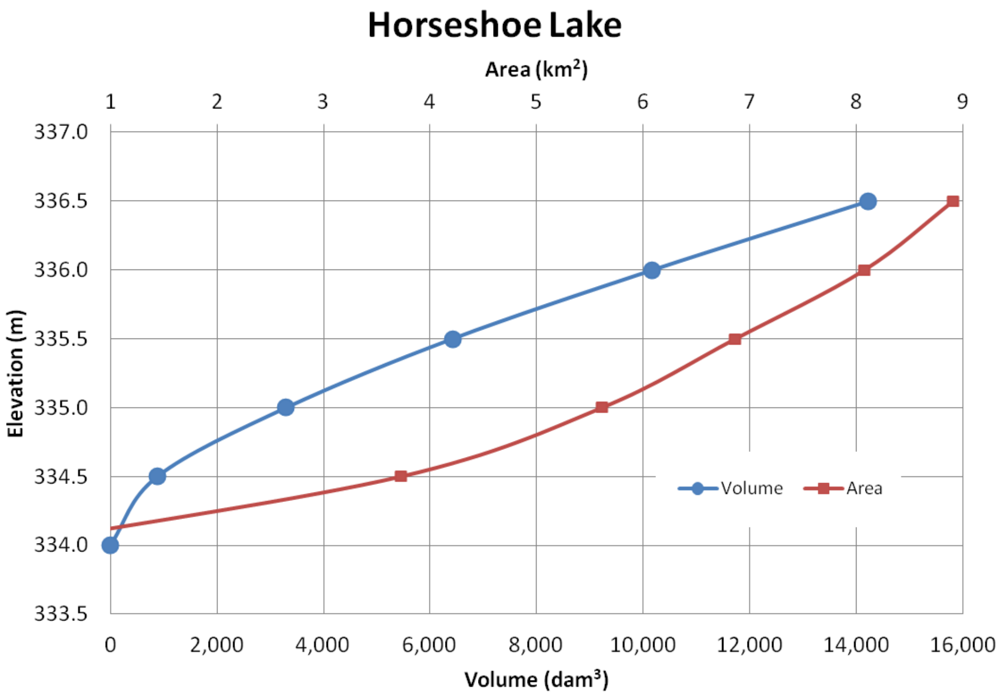


Figure 11: Horseshoe Lake Retention Elevation-Volume-Area curves

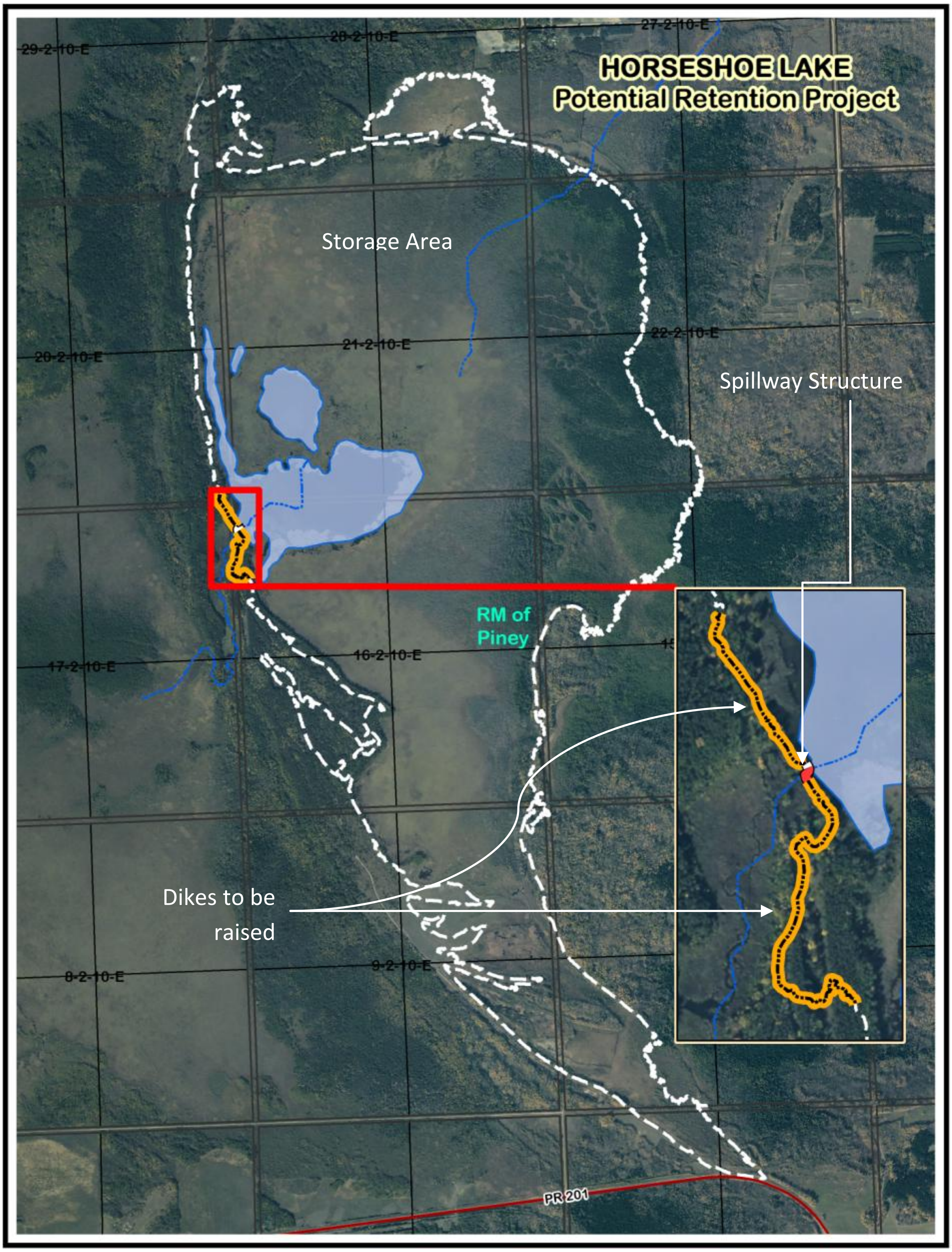


Figure 12: Horseshoe Lake Project Site Plan

As shown on Figure 13, the retention effect for a 10-year flood event with the potential retention shows that the retention site could hold most of the inflow and reduce the outflow peak to less than 10 % of the inflow peak. It appears that the retention site could even manage the 100-year flood events well, which would help reduce high water levels in downstream areas such as the Sundown Bog and Caliento Bog. This simulation used a spillway elevation of 335.3 m and did not include operation of a drawdown chamber.

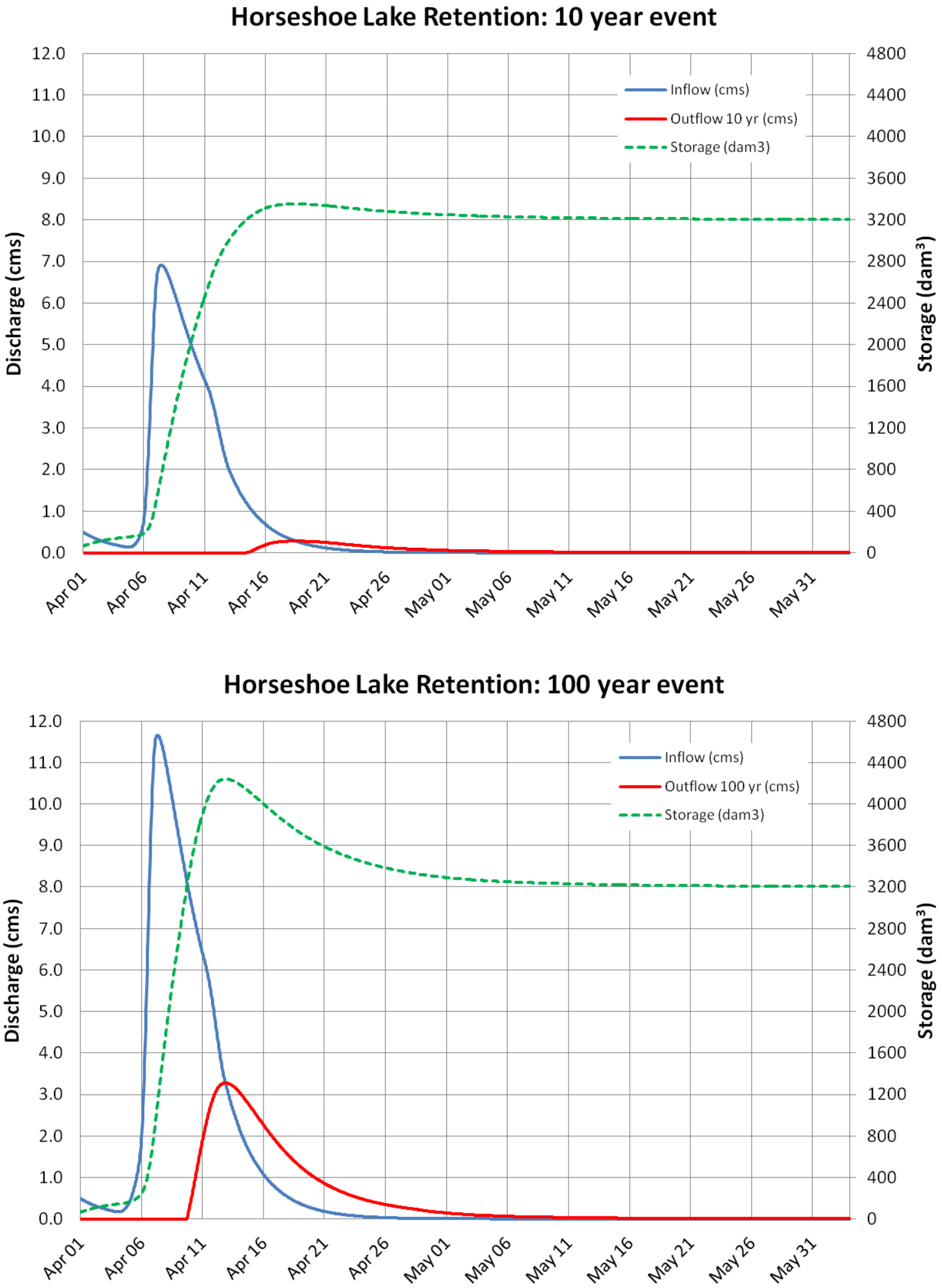


Figure 13: Horseshoe Lake retention effects

Sundown Ridge Project

The proposed retention area of interest is located on the north side of the old Provincial Road 201 in sections 12 and 13-2-9E, northeast of the Sundown community and directly downstream of Horseshoe Lake. Currently, water drains toward Sundown Bog through the three existing culverts at the old PR 201 (Figure 14). The contribution from this outlet to Sundown Bog was noted by locals to be contributing to the recent high water levels in the bog.

In this study, the project site is named "Sundown Ridge" retention site as it uses the ridge along the Sundown community to prevent water from moving westward uncontrolled. Two control outlets at the west and south ends of the retention site are proposed to better manage the contribution to downstream areas such as the Sundown Bog and the Caliento Bog. The concept is that by using two control structures, some water can be diverted west while some continues south to Sundown Bog. The Sundown Ridge project would create a storage area of 6.0 km^2 with a storage capacity up to 6,000 dam^3. About 41 % of the potential retention area is Crown land. Elevation-volume-area curves are provided on Figure 15, and a site plan is provided on Figure 17.

South End Control Structure (drain outlet at old PR #201 crossing)

At the south end project site, three existing culverts would be replaced with new three 1200 mm drop inlet culverts in the old PR 201 crossing and two 600 mm gated culverts would be added for draw down purposes. The municipal road would be raised approximately 2.0 m to an elevation of 327 m from the ridge eastward for approximately 3.5 km. Raising the road adds a substantial cost to the project. The total estimated cost for this portion of the project is $1.1 million to $1.65 million.

Figure 14: Existing culverts at the old PR 201 crossing

West End Control Structure

The west side project site is located in W 12-2-9E in the Stuartburn municipality, approximately one kilometre north of the Sundown community.

This portion of the project includes raising the ridge approximately 2.0 m to 327 m for about one kilometre by building a dike and installing a control structure. The control structure would include three 1200 mm drop inlet culverts where the creek crosses with two additional 600 mm gated culverts for draw down. The total estimated cost of this portion of the project is between $500,000 and $750,000, with half of the cost for dike construction.

During spring snowmelt period, the inflow to the reservoir would be retained until the peak flow passes then the gated culverts would be operated to draw down the water level with consideration of downstream conditions. When the downstream water level condition is close to or below normal, the operation would commence, releasing stored water and drawing down the reservoir.

Although not investigated in this project, a reduced cost option could be to not increase the storage volume, but construct control structures in the area to be able to divert some water to the west and control the flow south into Sundown Bog. The merit of this option was not evaluated in depth.

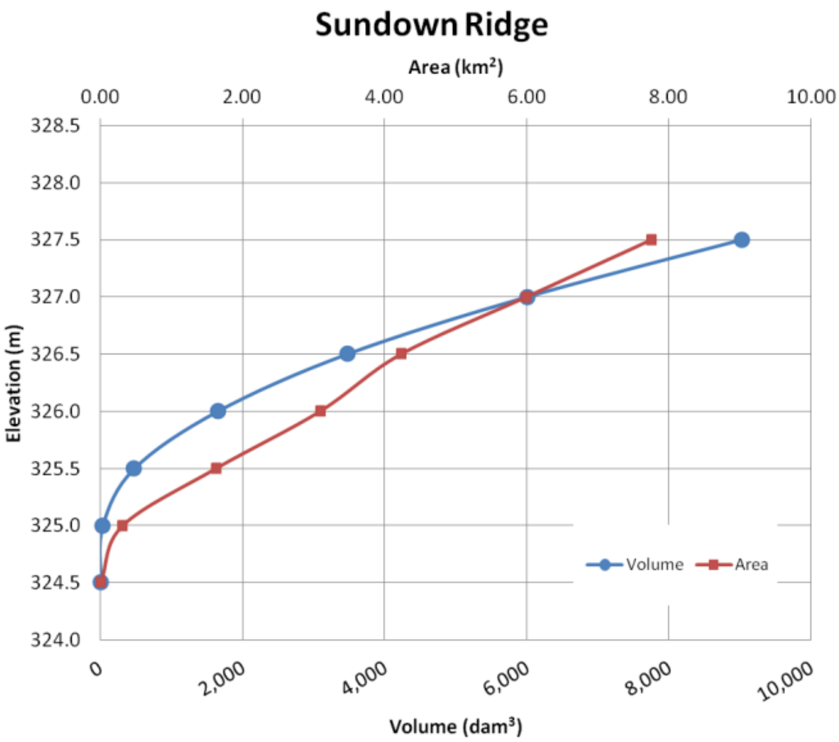


Figure 15: Sundown Ridge Retention Elevation-Volume-Area curves

Figure 16: Sundown Ridge, location of west control structure

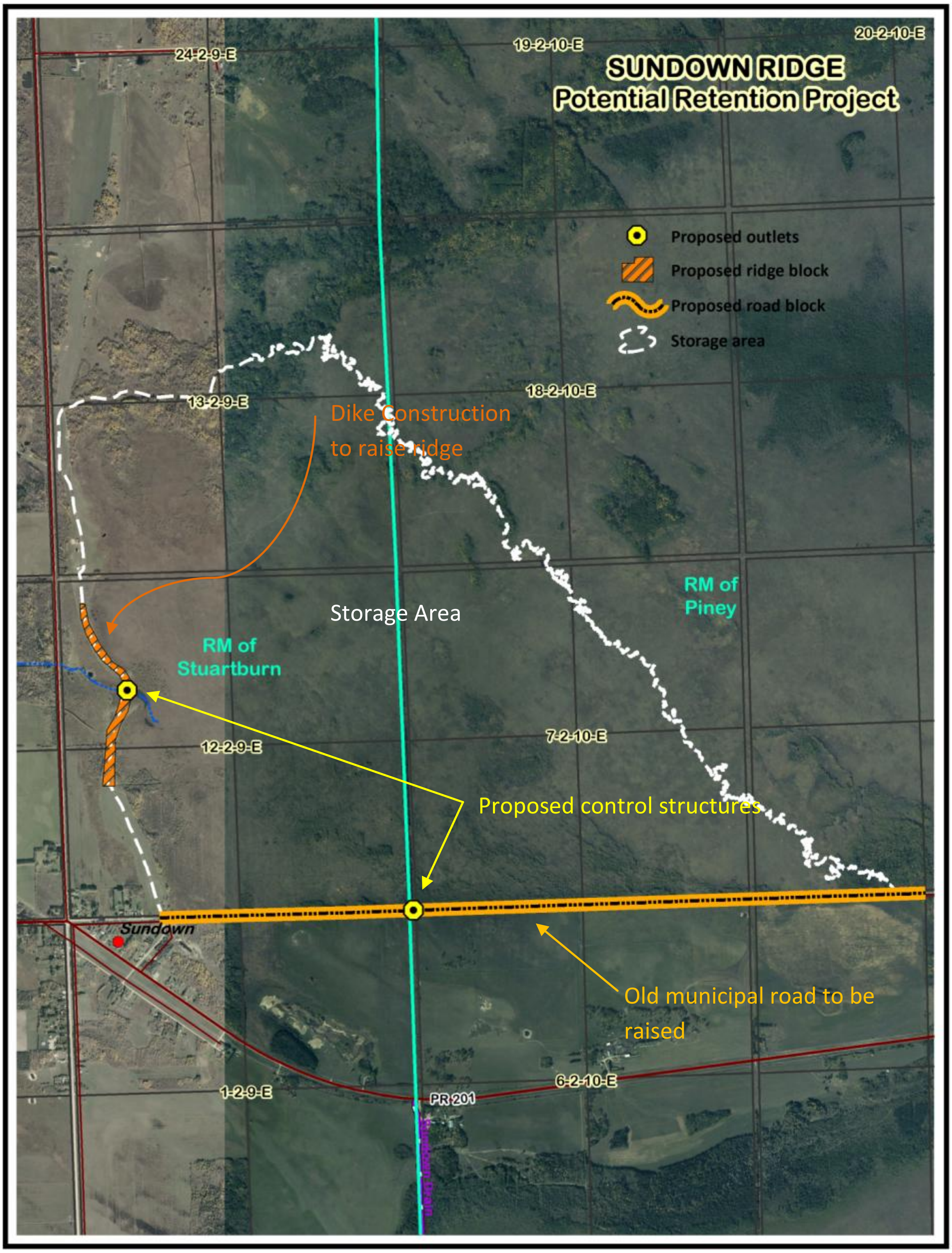
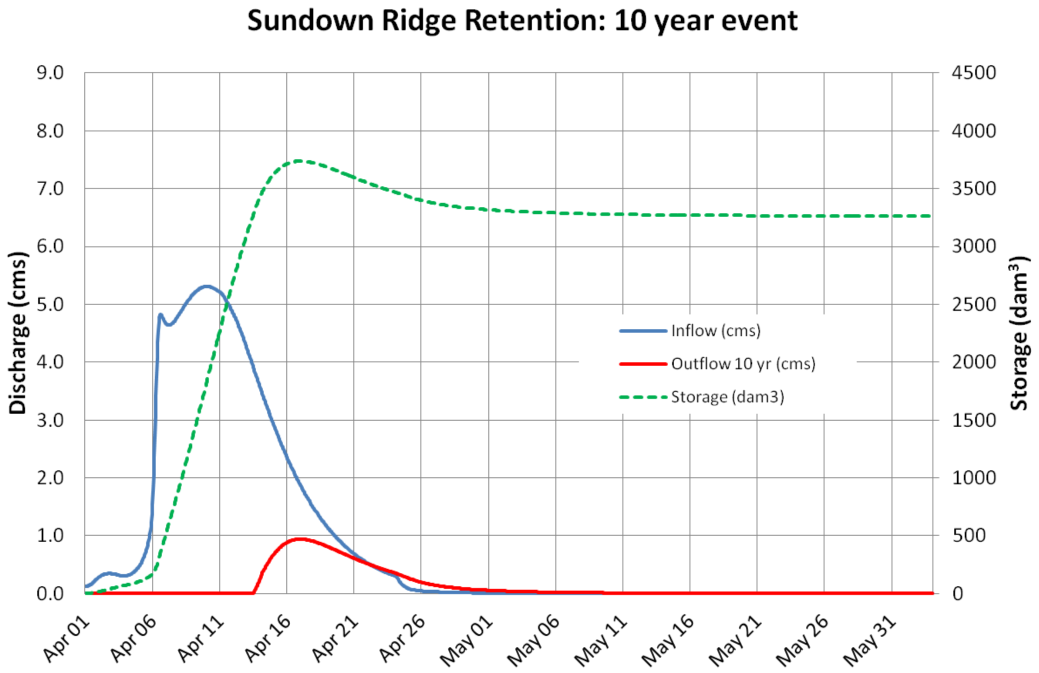


Figure 17: Sundown Ridge Project Site Plan

Benefits and potential impacts

The retention project could reduce the peak flows by 83 % and 67 % for 10-year and 100-year flood events, respectively, which would significantly reduce downstream flood impacts. Furthermore, the combined storage of the Horseshoe Lake and Sundown Ridge projects could retain all inflows for a 100-year event (Figure 18). Having retention control on both Horseshoe Lake and Sundown Ridge would provide significant benefits for better management of extreme flood events in Sundown Bog and Caliento Bog.



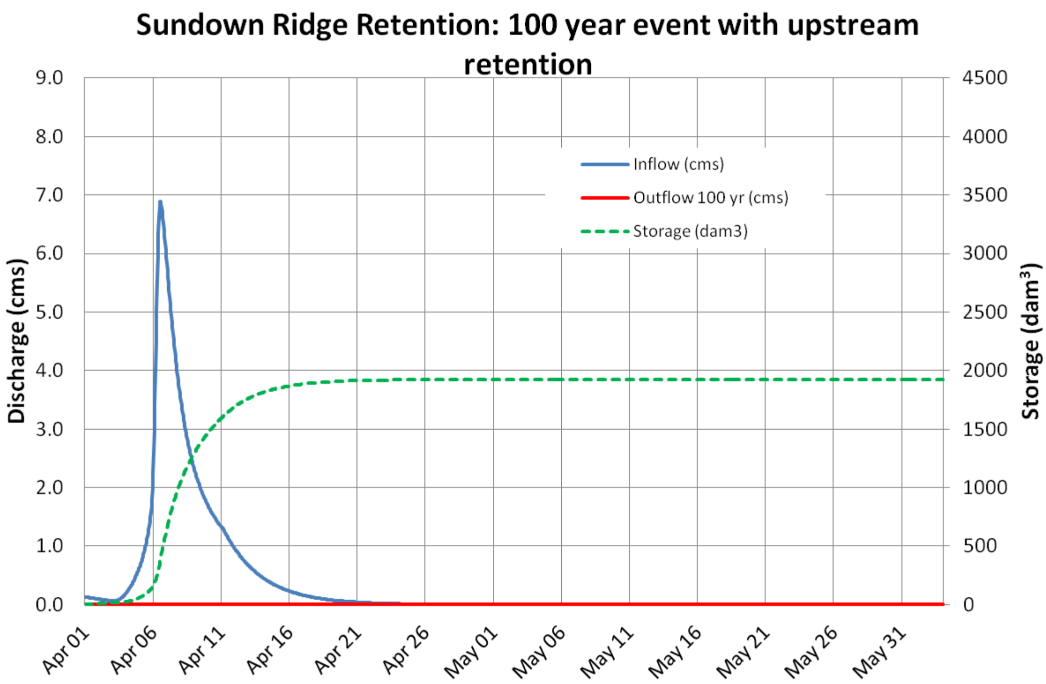


Figure 18: Sundown Ridge retention effects

Mueller Farm Project

Mueller Farm is located on the north branch of the Jordan River in NE 25-2-1E, in the Emerson-Franklin municipality, approximately 6 km from the Green Ridge community. The land owner has pursued constructing this project for a couple of years and has already begun construction of a portion of a dam. The owner also obtained a drainage license for this project to allow a maximum level of 262.5 m. It is recommended to reconstruct the existing dam to include a sheet pile rock spillway, a gated culvert for draw down, and an earthen emergency spillway. The retention project would create a storage area of approximately 0.12 km^2 with a storage capacity up to 310 dam^3. The total estimated cost of the project is between $180,000 and $270,000.

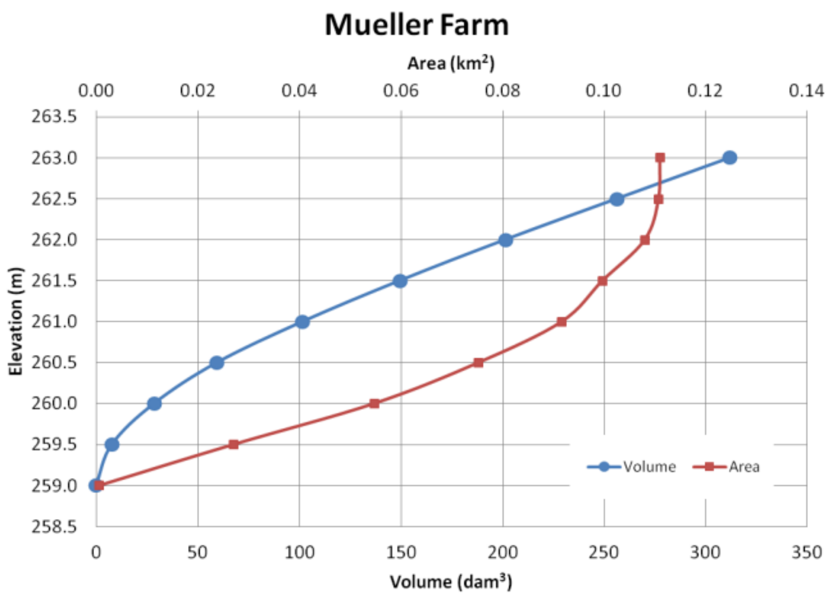


Figure 19: Mueller Farm Retention Elevation-Volume-Area curves

Figure 20: Mueller Farm Project site

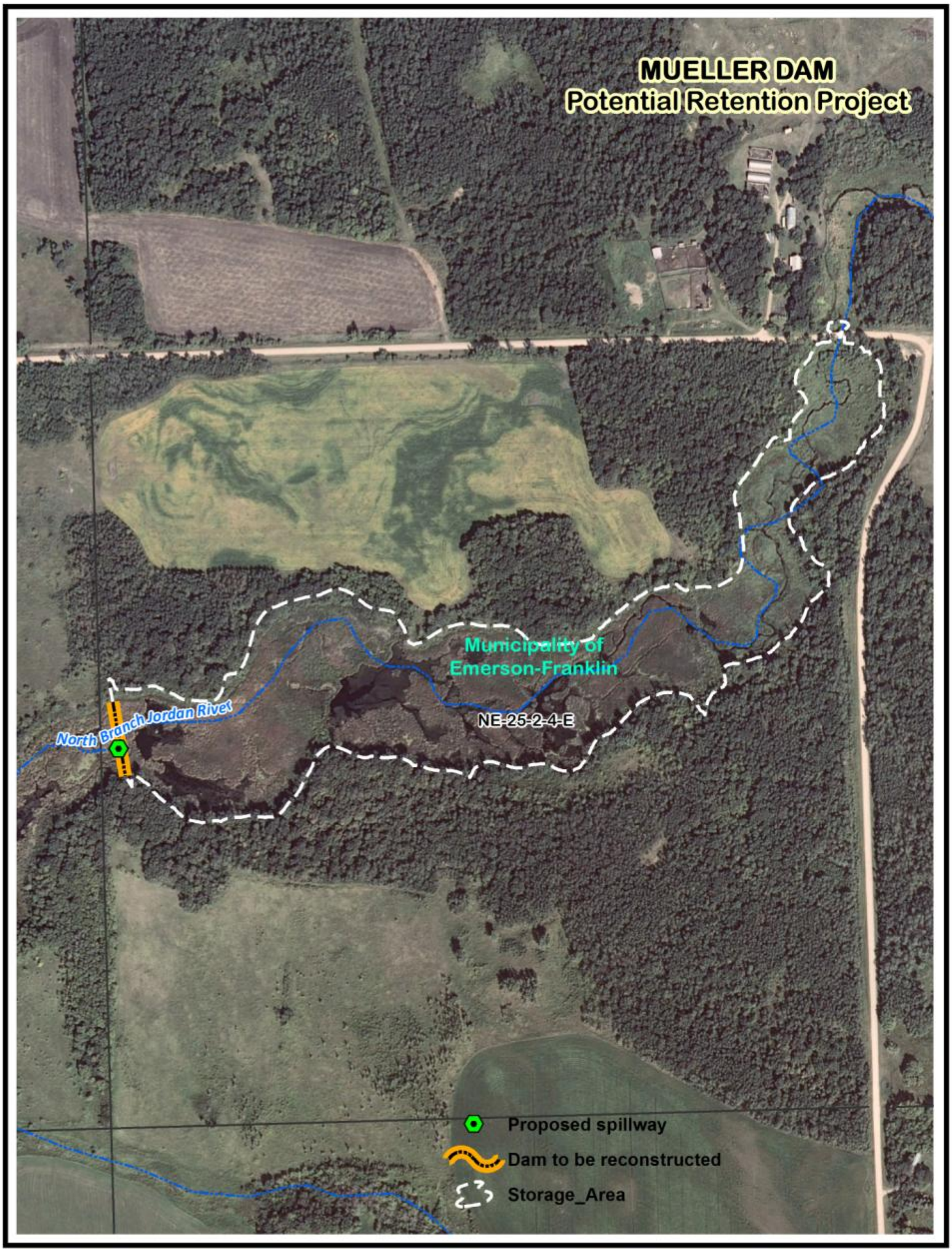


Figure 21: Mueller Farm Site Plan

Benefits and potential impacts

The primary purpose of the dam is recreational. It could also provide a water supply for watering livestock. The retention project does not have a large storage volume and does not provide any significant or peak reduction for the 10-year or higher flood event. The project may provide some peak reduction benefit during small flow events.

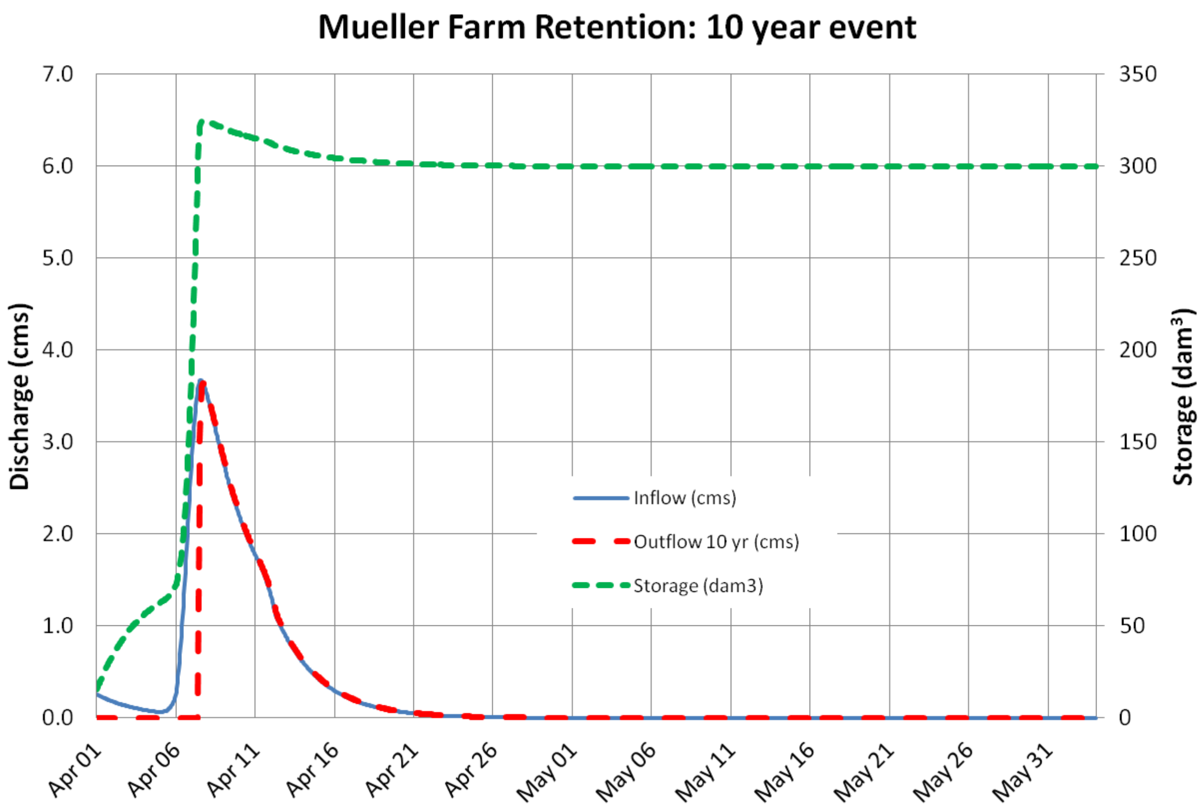


Figure 22: Mueller Farm Retention Effects

Kirkpatrick Swamp Project

Kirkpatrick Swamp is located in the Emerson-Franklin municipality in sections 16 and W 15-2-1E. The site is situated southeast of the intersection of Provincial Roads 218 and 201, approximately 3 km south of the Green Ridge community. The area of interest was proposed as a potential retention site for flood protection, water supply, and wildlife habitat purposes by some local residents during an IWMP public meeting. Some neighboring land owners expressed concerns over this potential retention project. The retention area is comprised entirely of private property. If the project is investigated in more depth in the future, reconfiguring the diking and storage area will likely be necessary based on the preference of the private land owners. The configuration presented below is a maximum storage volume scenario.

The project concept is to build dikes on the western portion of the retention area and raise the southern municipal road between section 16-2-4E and section 9-2-4E to a level of 260 m. A sheet pile weir and a gated culvert is recommended to be installed at the drain outlet for draw down. This project would create a storage area of approximately 2.8 km^2 with a storage volume of approximately 5,000 dam^3. The estimated cost of this project is between $800,000 and $1,200,000.

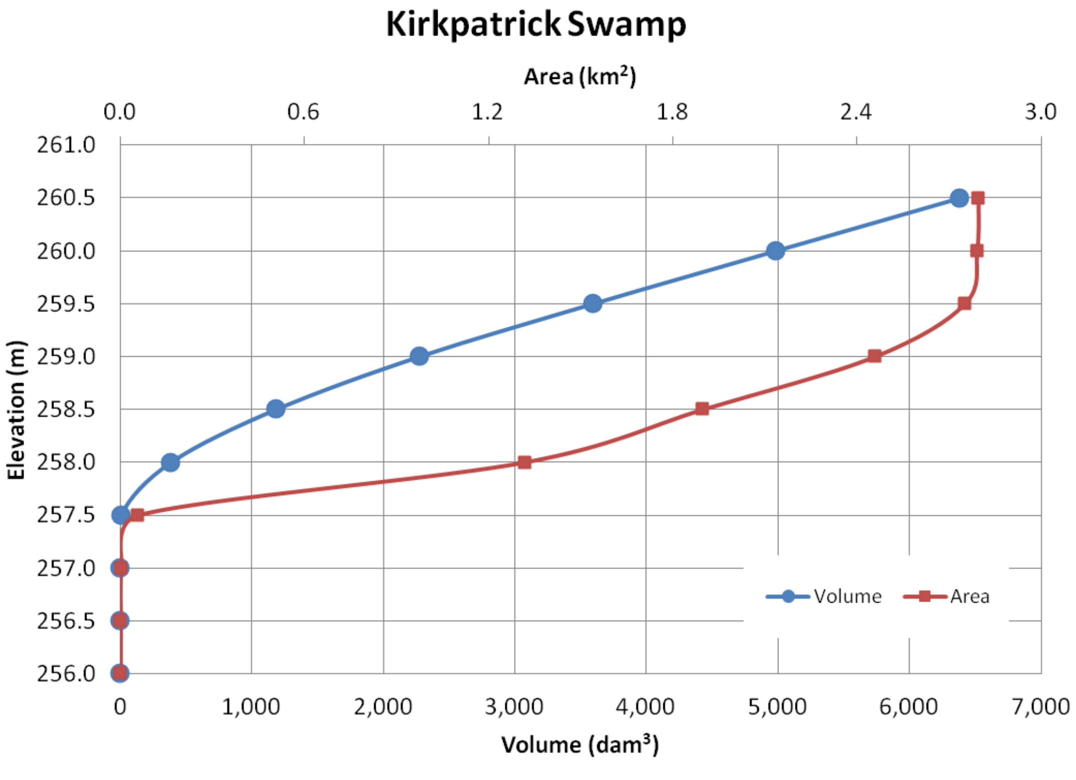


Figure 23: Kirkpatrick Swamp Elevation-Volume-Area curves

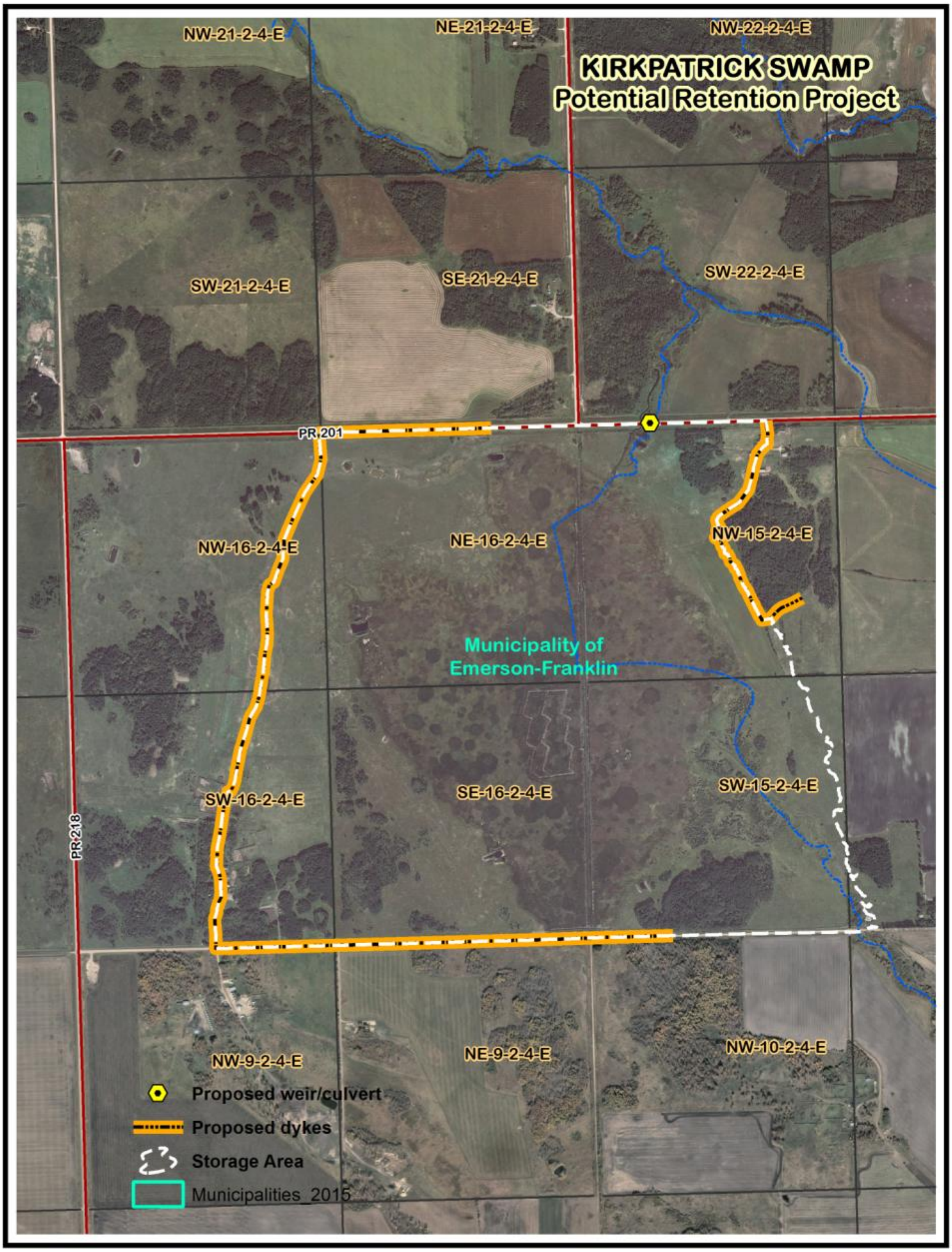
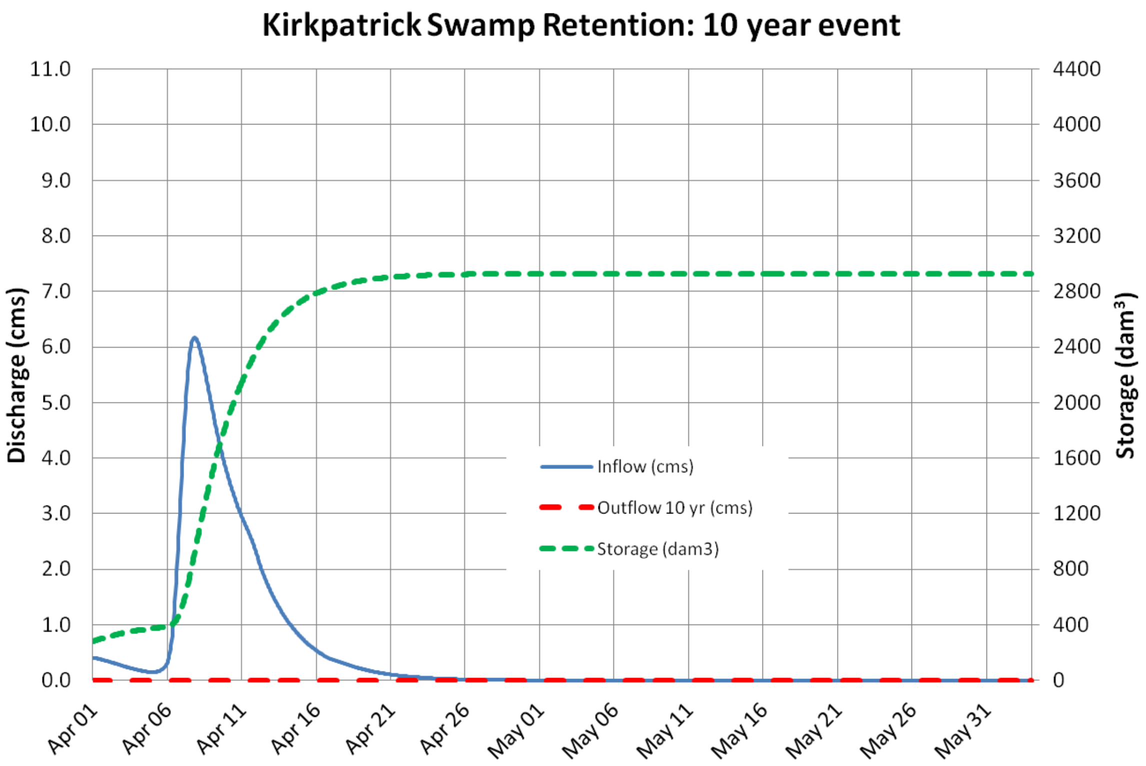


Figure 24: Kirkpatrick Swamp Project Site Plan

Benefits and potential impacts

The Kirkpatrick retention has good potential for peak flow reduction. The storage volume could fully control the 10-year flood event and could significantly reduce the 100-year flood event peak flow (Figure 25).



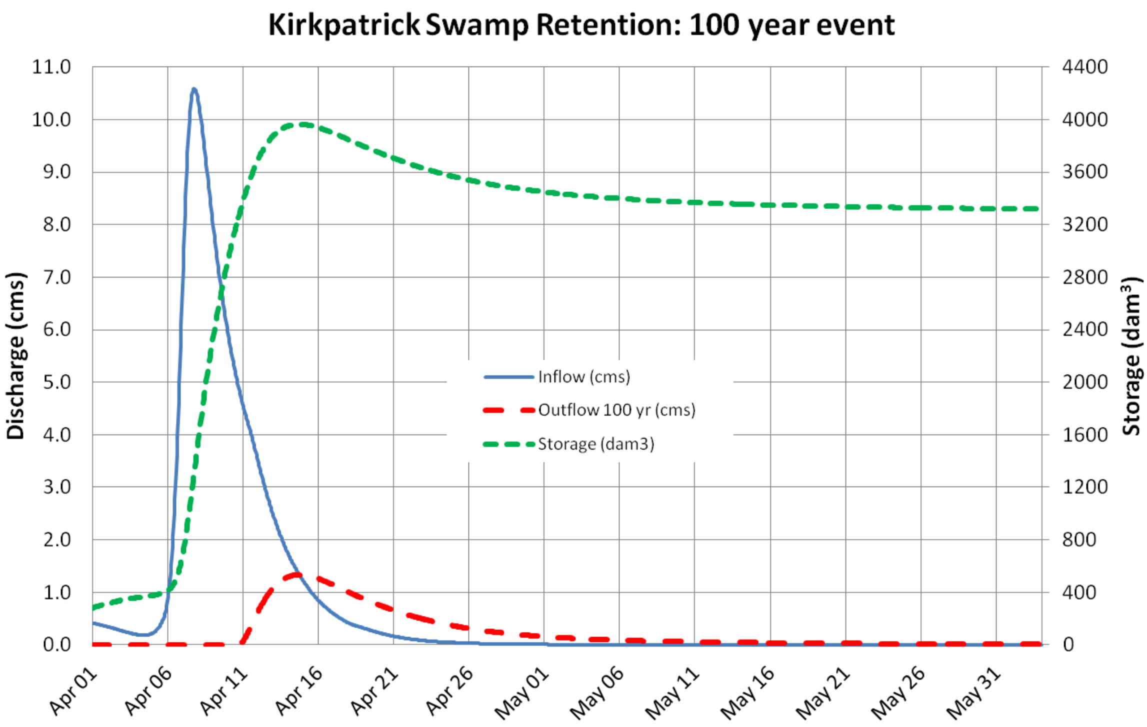


Figure 25: Kirkpatrick Swamp Retention Effects

Gardenton Community Pasture and Floodway Project

The proposed project site is located on the west side of the Gardenton Floodway approximately 6 km southwest of the town of Gardenton and encompasses a portion of the Gardenton Community Pasture. The Roseau River International Watershed Board report (UMA Engineering Ltd., 2003) also proposed a number of flood mitigation options in the area and the proposed project in this study is similar to the small reservoir option in the report which is less expensive than other options. The proposed retention area is all on Crown land.

The project concept is to build a 12 km long dike to create an off channel storage reservoir in the community pasture on the west side of the Gardenton Floodway and to divert flows from the Gardenton Floodway into the reservoir area. The south dike of the Gardenton Floodway may need to be reinforced or reconstructed. At the outlet, a control structure, rock weir spillway and an emergency spillway would be constructed. A structure to control flow into the retention area from the Gardenton Floodway would be required. This project would create a storage area of approximately 19.0 km^2 with a maximum storage volume of approximately 55,000 dam^3. The estimated cost of the project is between \$6.5 million and \$10 million.

Operation of the control structures would determine when the project would divert water from the Gardenton Floodway. When the pasture is in use for grazing in the summer months, the project may not be available for flood storage. The project may only be available for use during spring snow melt events. Operation needs to accommodate the priorities of Agriculture and Agri-Food Canada‘s Community Pastures Program.

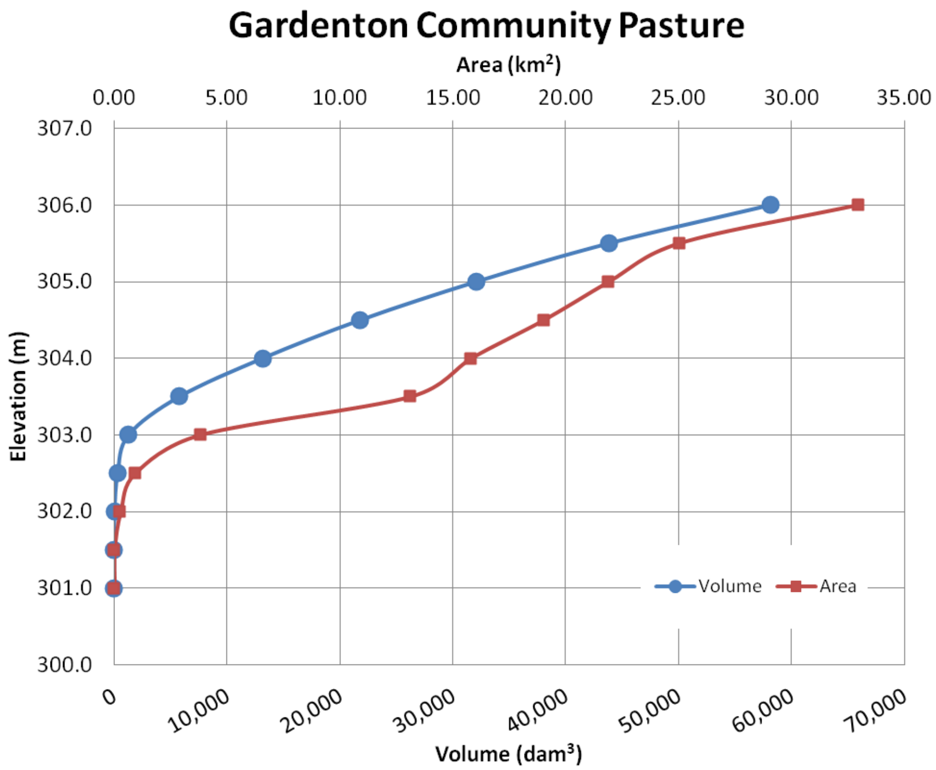


Figure 26: Gardenton Community Pasture Retention Elevation-Volume-Area curves

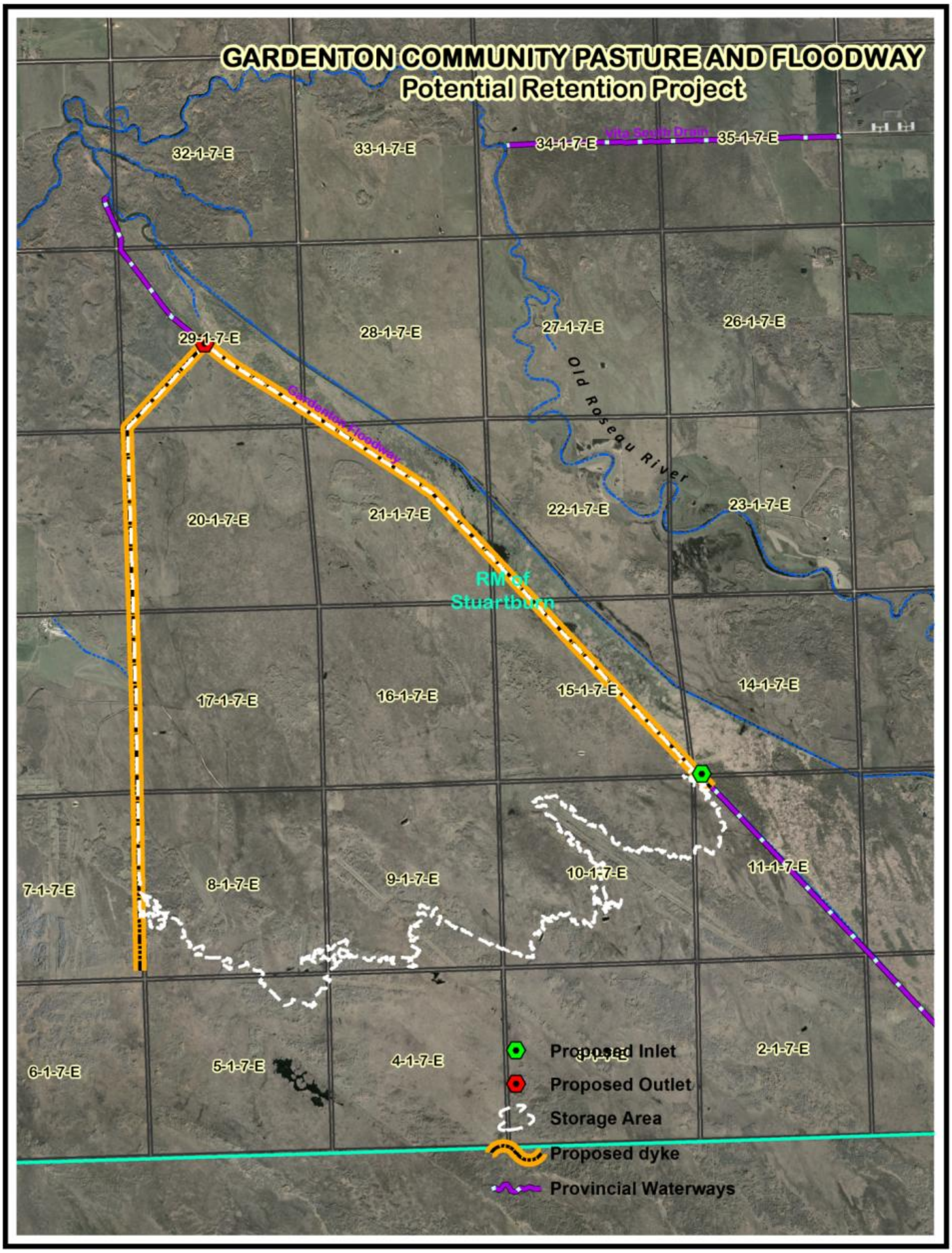


Figure 27: Gardenton Community Pasture and Floodway Site Plan

Benefits and potential impacts

HEC-HMS model was simulated for a scenario that half of the main stem flow was diverted into the retention site and let the rest of the flow to the Gardenton Floodway. The main stem of the Roseau River typically shows two peaks during spring snowmelt period. The first is generated by local runoff and the later peak is from the main stem peak flow from south of the border. To evaluate the peak reduction effects of the retention site on the main stem, the flow at the downstream convergence of three outflows from Gardenton Floodway, the old Roseau River and the retention site were compared with the total inflow at the diversion (Figure 28). The large storage volume of this project could fully retain the peak flow from local contributions and reduce the mainstem peak flow more than 5 % for the 10-year flood event and 8 % for the 100-year event (Figure 28).

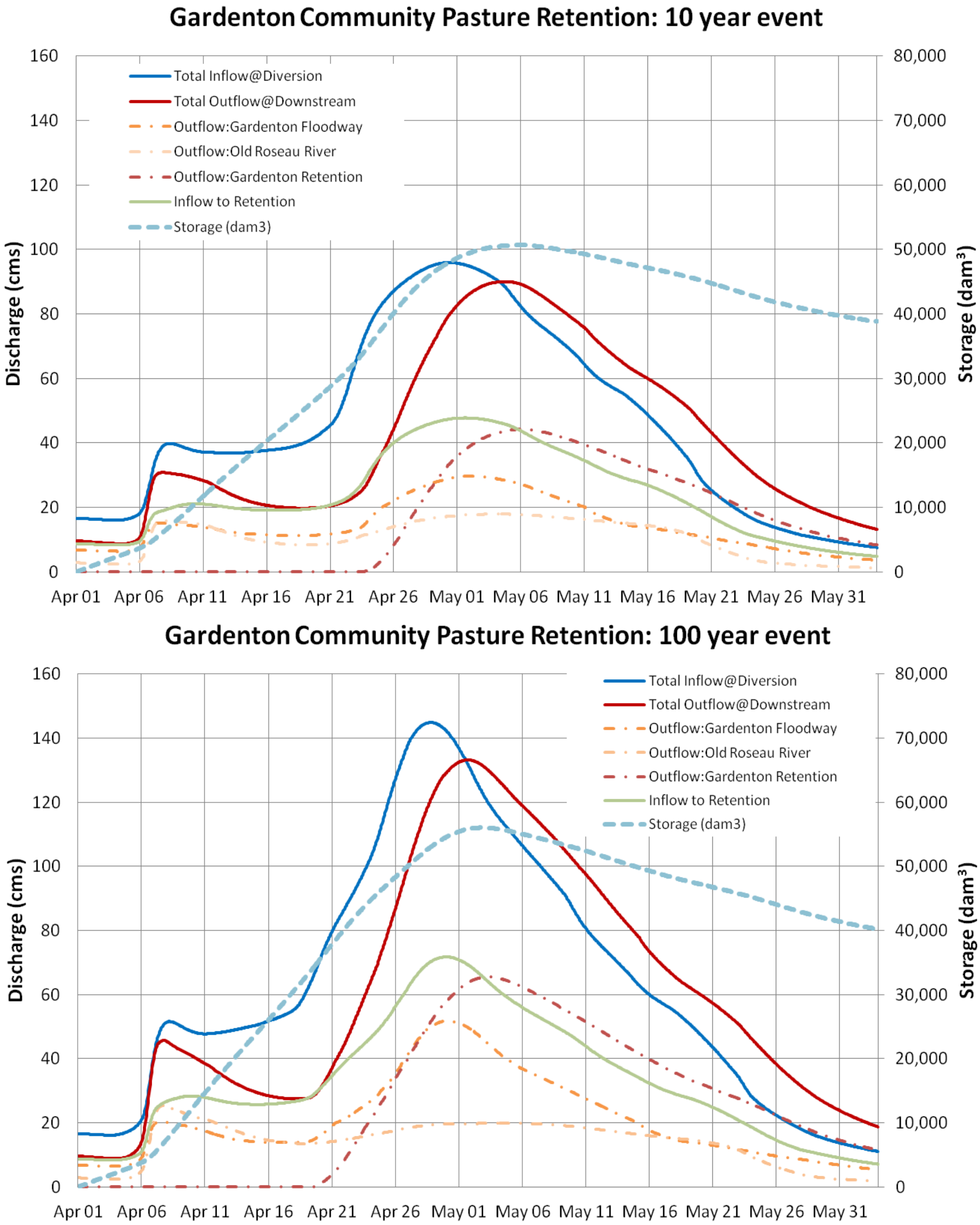


Figure 28: Gardenton Community Pasture and floodway retention effects

Old Roseau River Project

The Roseau River International Watershed Board report (2003) proposed a flood mitigation option that included restoration of flow to the natural river channel which is commonly referred to as the old Roseau River. The old Roseau River is the original river from near the International border to Gardenton and is approximately 18.4 km long. Due to the low channel capacity, less than 20 cms, a wooden control dam was constructed in 1930 to divert the majority of the flow into the Gardenton Floodway. The original dam burned down and a new concrete structure with a stop log system was built in 1965 and is referred to as the Arbakka Dam (Roseau River International Watershed Board, 2003). In 2002, the Arbakka dam gates were closed blocking flows from entering the natural channel except during very high upstream flow. Local agricultural drains from the east, including the Vita South Drain, discharge into the natural channel. Vegetation and organic material have built up within the riverbed reducing the current capacity of the channel to an estimated level below 6 cms. Before the old channel is used again, a clean out to remove the excess vegetation would be necessary to gain more flow capacity.

The old Roseau River could be used as a conveyance channel for recreational purposes and enhancing wildlife and fish habitat. According to the Roseau River International Watershed Board report (2003) and the IWMP public meeting hearing, opening the Old Roseau River channel would allow a variety of year-round recreation activities in the area including fishing, hunting, canoeing, water sports, sailing, snowmobiling, cross-country skiing, ice skating, snowshoeing, tobogganing, hiking, and both wildlife and nature viewing.

The project concept is to construct a 125 m dike built to an elevation of 300 m to block the old Roseau River in NE 31-1-7E, 4.5 km east of Gardenton. The retention would create a storage area of 0.18 km^2 and a storage volume of 190 dam^3. A spillway, riparian outlet and emergency spillway would also be constructed for an estimated cost between \$300,000 and \$450,000. Additionally, the estimated cost of cleaning about 18 km of the Old Roseau River would be \$400,000 to \$600,000.

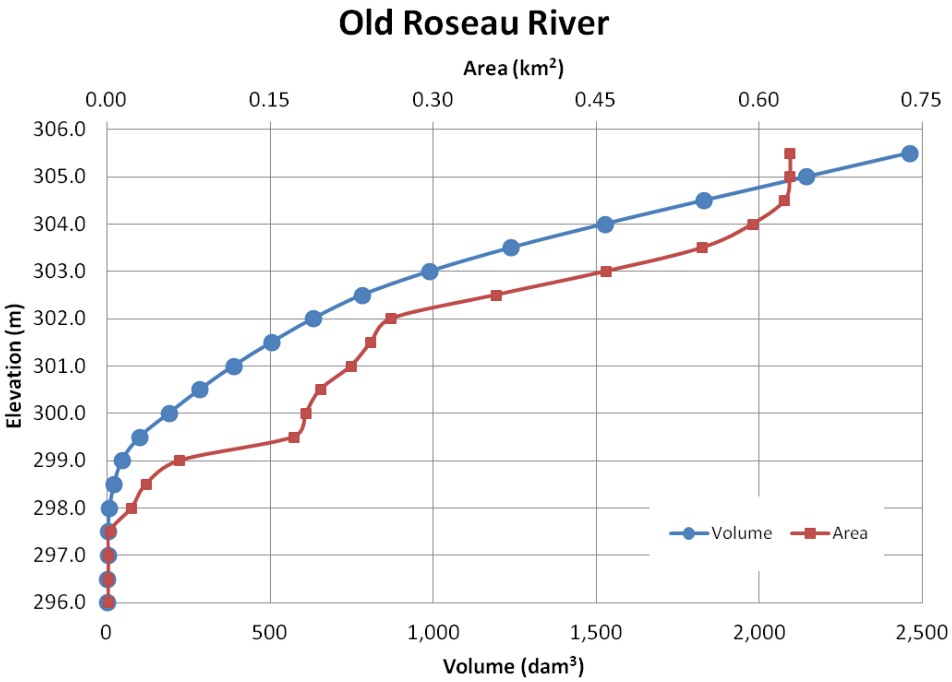


Figure 29: Old Roseau River Retention Elevation-Volume-Area curves

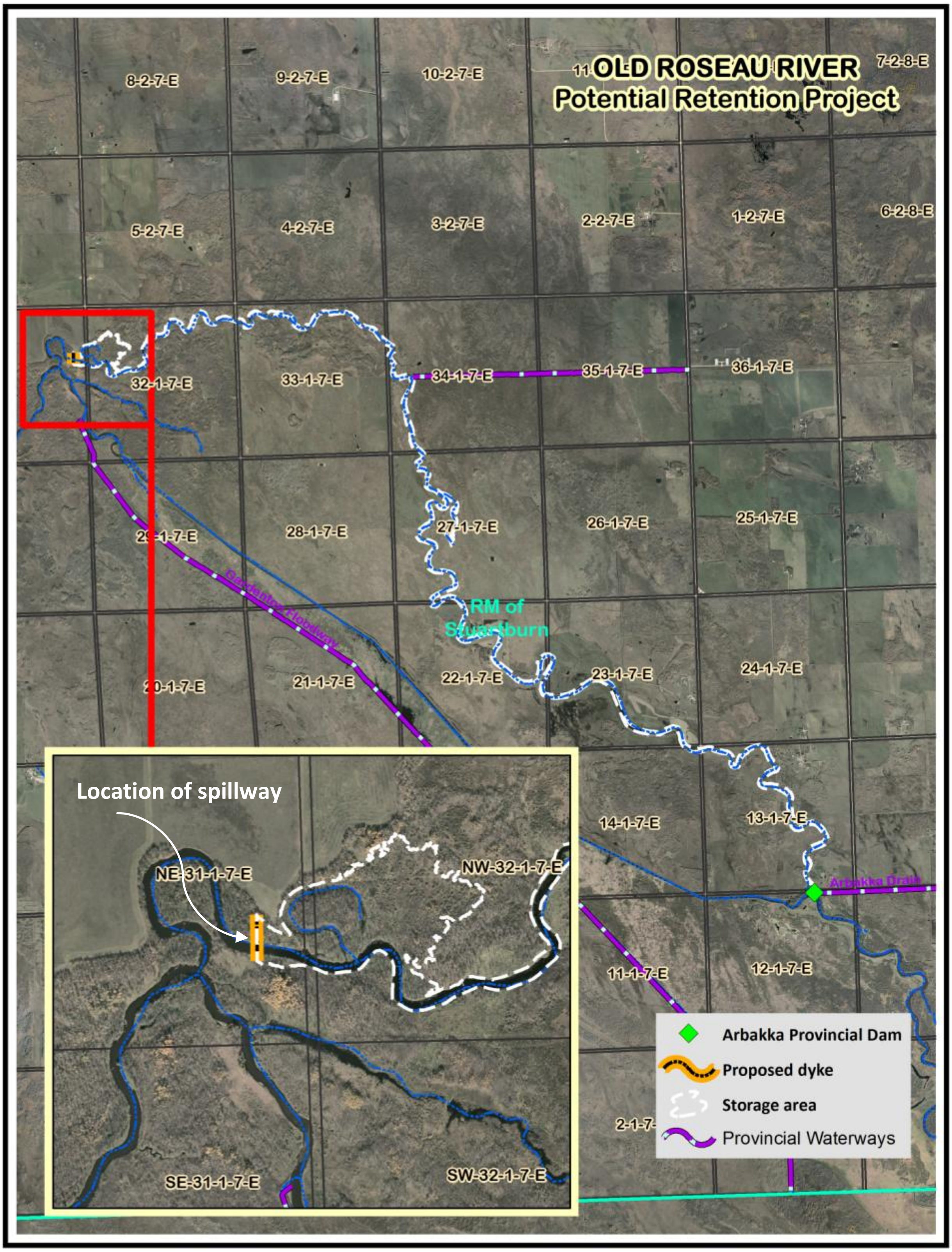


Figure 30: Old Roseau River Project Site Plan

Benefits and potential impacts

The main purpose of the old Roseau River project is to restore the river for recreational use. Given the limited storage volume, limited flow capacity of the old Roseau River channel, and existing properties with buildings adjacent to the river, it is expected to provide no significant peak reduction.

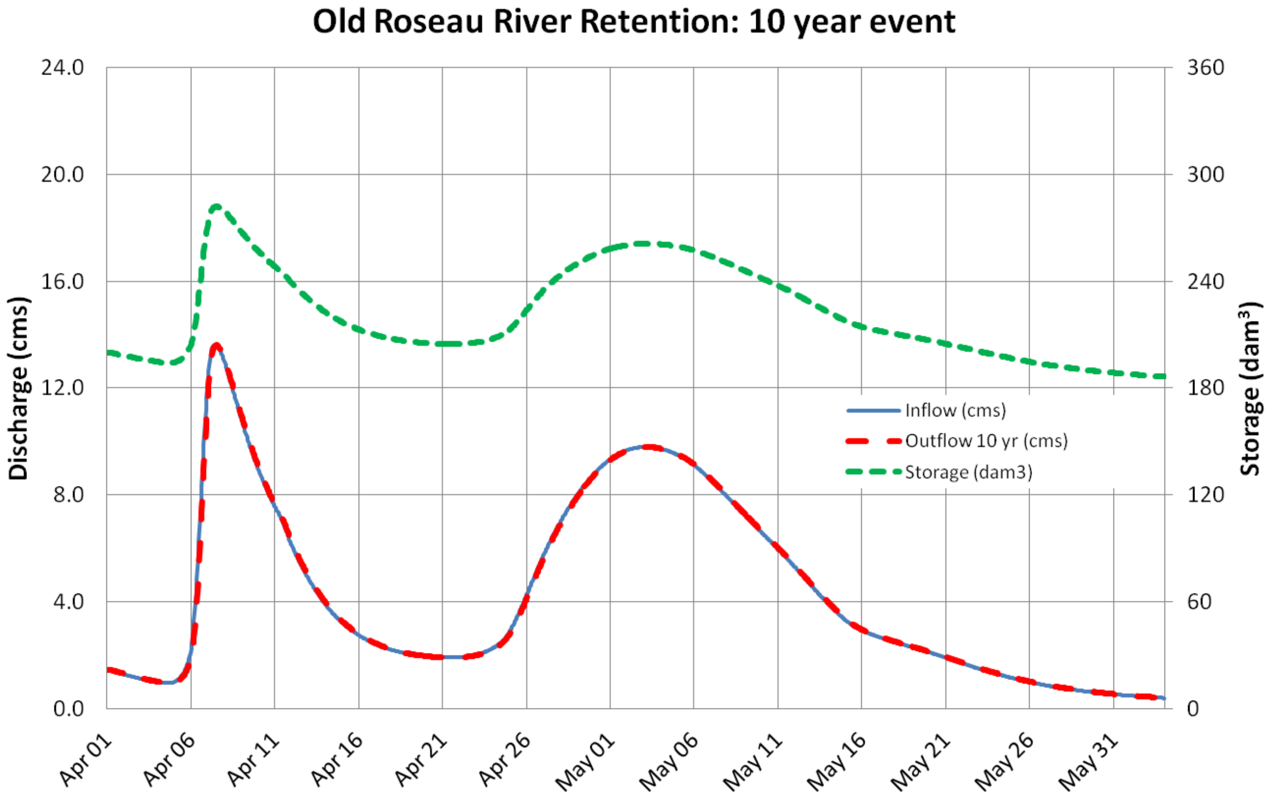


Figure 31: Old Roseau River Retention Effects

Senkiw Dam Project

In connection with a study for the International Joint Commission, Prairie Farm Rehabilitation Administration (PFRA) investigated a proposed recreation dam on the Roseau River located in the NE 7-3-5E, approximately 1.6 km west and 2.4 km north of the Town of Senkiw, Manitoba. Initial design studies were conducted as a tentative embankment design and some required seepage control options (PFRA, 1973). However, the project was never constructed.

Senkiw Dam was also proposed as a flood mitigation option in a Roseau River International Watershed Board report prepared by UMA Engineering Ltd in 2003 (UMA Engineering Ltd., 2003). The report estimated the impoundment's full storage volume at 1,455 dam^3 at a depth of 7.3 m. The dam would create a backwater area extending only 2.4 km upstream due to the steepness of the natural channel and ground. The report concluded the flood storage benefits of the dam would be minimal but it would have recreational benefits.

During the IWMP public meetings, the Senkiw Dam was mentioned as a potential water retention project site for recreational benefits rather than flood reduction. Although this site is located on the main stem of the Roseau River, a preliminary investigation of potential storage at this site was conducted.

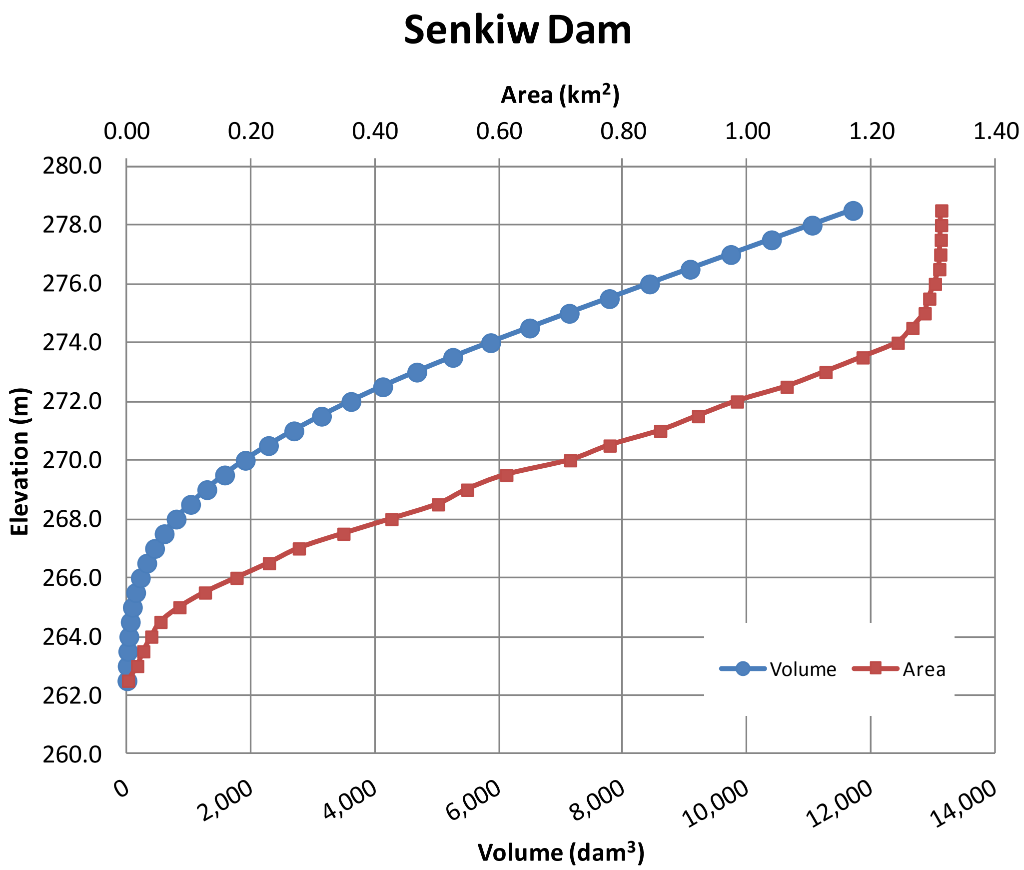


Figure 32: Senkiw Dam Retention Elevation-Volume-Area curves

In the 1973 Senkiw Dam report, PFRA proposed a dam height of 271.5 m. Based on a LiDAR data analysis, this study uses a target level of 275.0 m for the dam height at this site. The proposed dam would be approximately 630 m in length, creating a storage area of 1.3 km^2 and a storage volume of approximately 7,100 dam^3. The project would include a spillway, gated control structure and emergency spillway. Since the project is located on the main stem, the project is much more complicated than the others assessed in this report and a cost estimate was not prepared. A project of this scope could cost tens of millions of dollars. A more rigorous feasibility study or preliminary design would be required to estimate an accurate project cost.

Building a dam on the main stem of the Roseau River would cause much more significant environmental impacts than dams built off channel or on smaller tributaries. Fish passage on the main stem would be a primary concern.

Figure 33: Immediately upstream of the potential Senkiew Dam project site

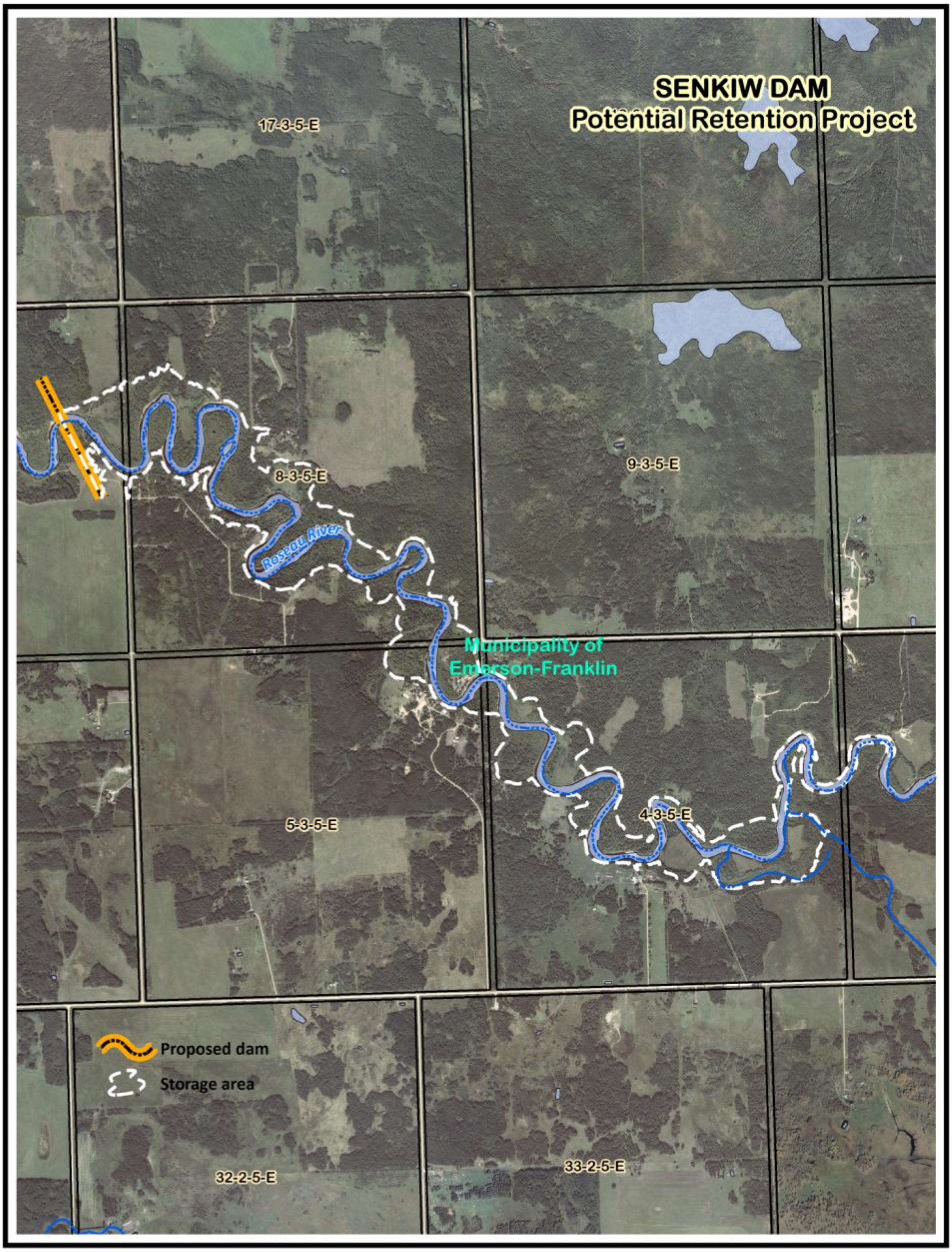


Figure 34: Senkiw Dam Project Site Plan

Benefits and potential impacts

Routing the 10-year event through the proposed dam confirms the assumption that the project would provide no flood control benefit. As the retention project site is located on the Roseau River main stem, 7,000 dam^3 of storage volume would not reduce the peak flow. However, there would be a significant storage volume available which could be used for recreation and wildlife or for water supply if there was a demand.

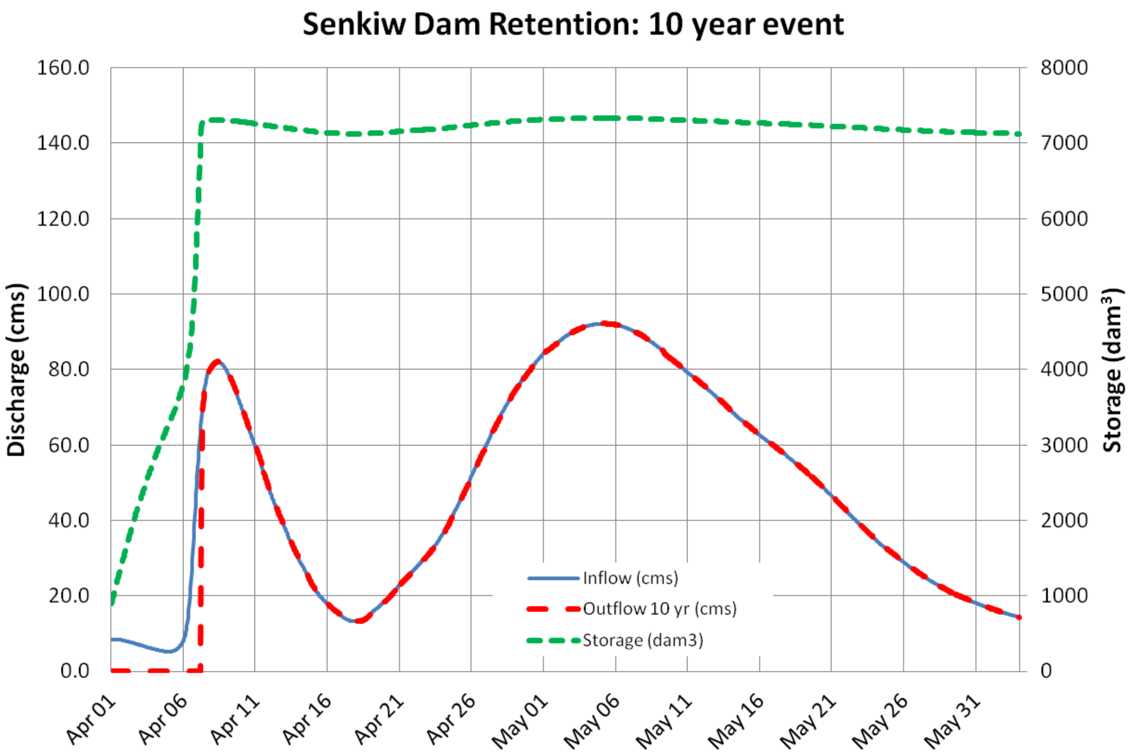


Figure 35: Senkiw Dam Retention Effects

Somme Swamp Project

During the IWMP public meeting some bogs and swamps in the area such as Calitento Bog, Menisino Swamp and Somme Swamp were mentioned as locations to increase retention. To gain a better understanding of developing a retention site in a swamp area, the Somme Swamp was investigated as an example. The Somme Swamp is located just east of the RM of Stuartburn's east boundary, just 5.5 km southwest of the Sundown community. The swamp is situated upstream of Caliento Bog and downstream of Sundown Ridge. During extreme wet conditions, outflow from the Sundown Ridge area and overflow from Sundown Bog would partially drain into the Somme Swamp. Once the swamp is filled up water would flow out to Calitento Bog.

The retention site was selected by considering topography in the area that would provide adequate storage volume with minimum length of dike. The dike is located to divert all flows from Horseshoe Lake, Sundown Ridge and overflow from Sundown Bog into the retention site so it would retain most upstream water flowing into Caliento Bog. A dike would be approximately 11.3 km long and built to an elevation of 320 m creating a storage area of approximately 23.6 km^2 and a maximum storage volume of 26,000 dam^3. A spillway, gated control structure and emergency spillway would also be constructed for a total estimated cost of \$3.6 million and \$5.4 million.

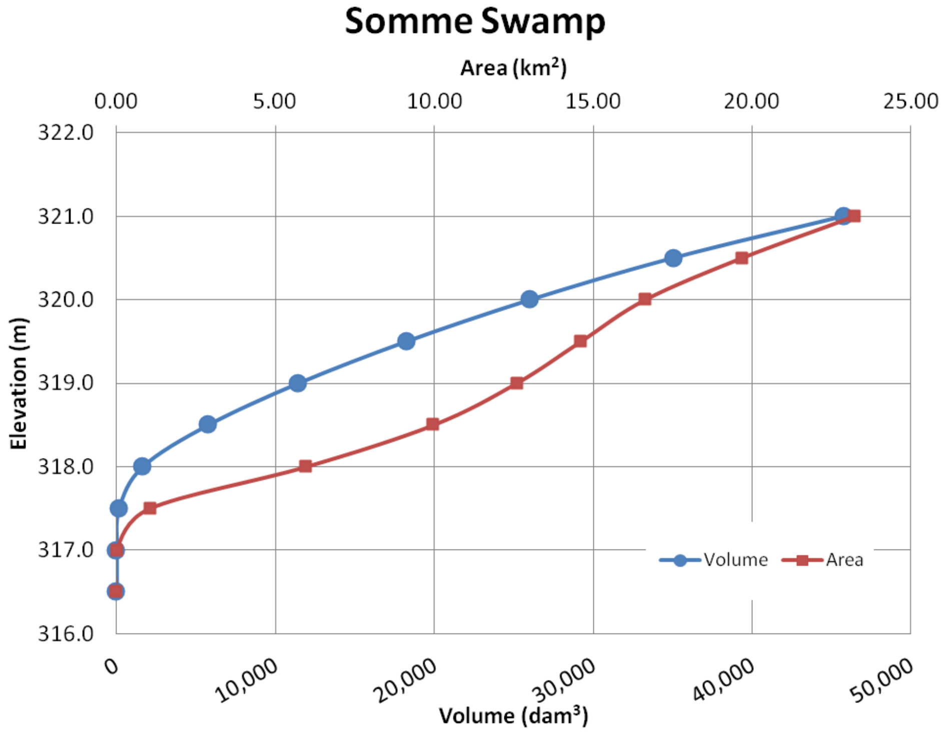


Figure 36: Somme Swamp Retention Elevation-Volume-Area curves

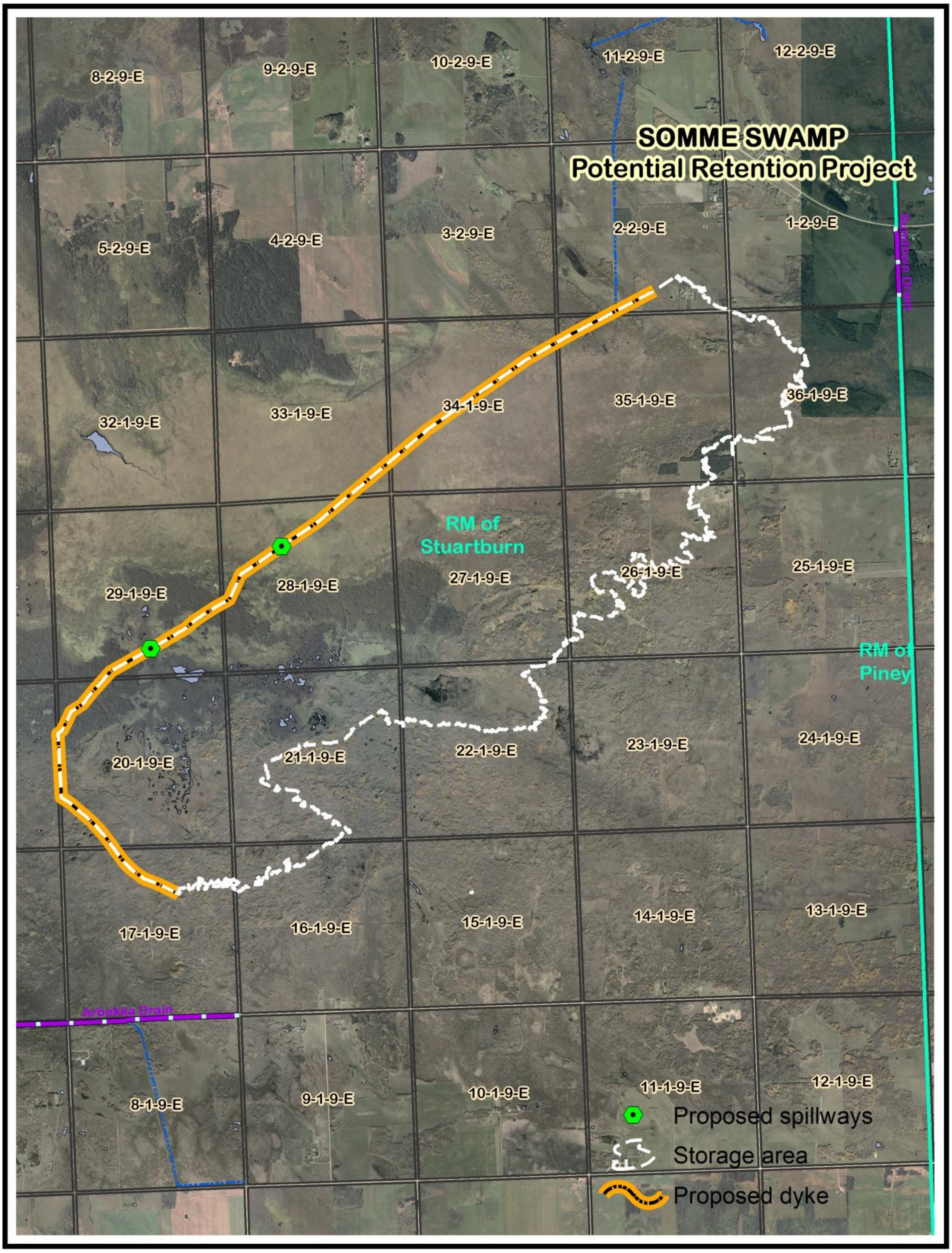
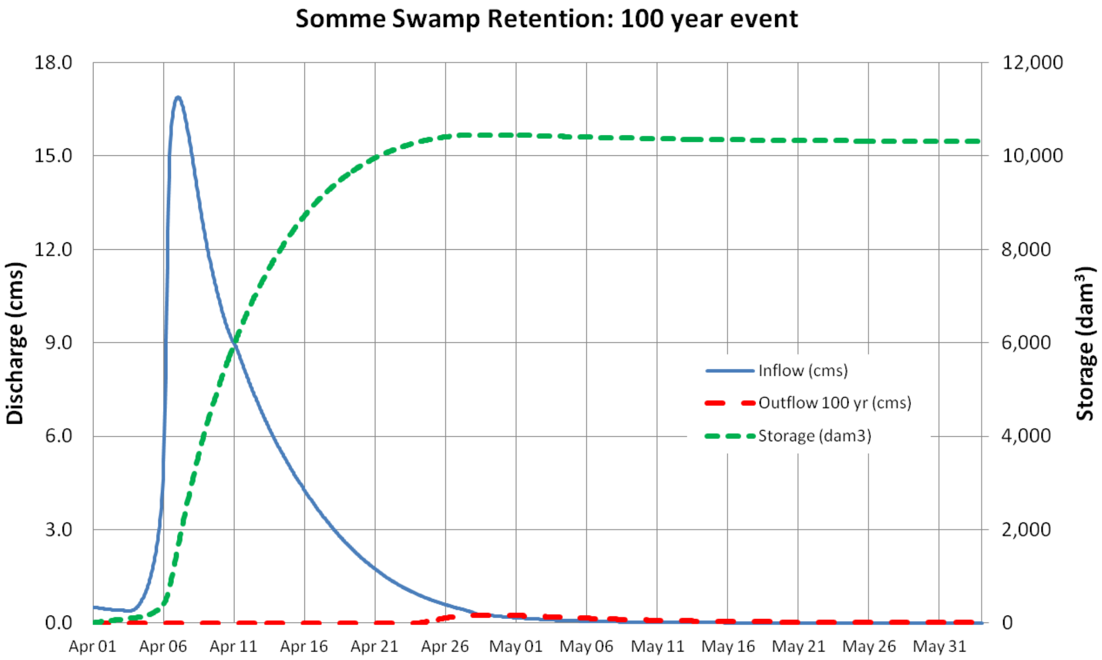


Figure 37: Somme Swamp Project Site Plan

Benefits and potential impacts

The retention would provide almost 98% peak flow reduction for 100-year flood event and retain all flow for 10-year event. If any upstream retention sites, i.e. Horseshoe Lake and Sundown Bog, would be in place and in operation, the Somme Swamp retention would retain all inflow even for 100-year event.



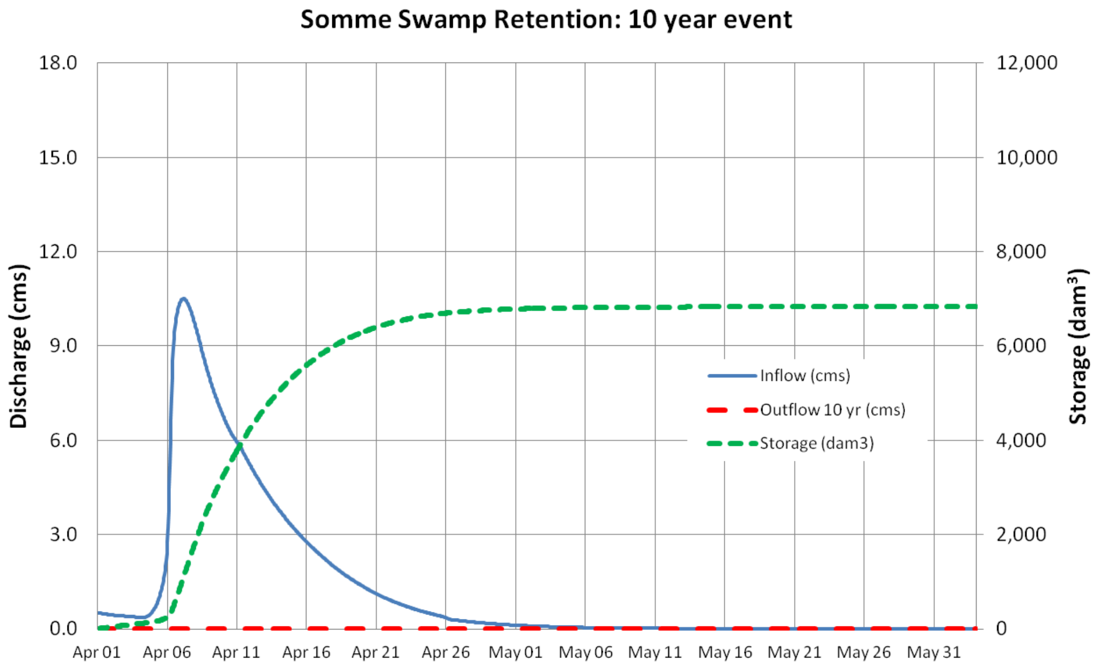


Figure 38: Somme Swamp Retention Effects

Tolstoi Project

The project is located on the border between Emerson-Franklin and Stuartburn municipalities on the NW corner of NW 30-1-6E. A 3,700 m dike, above the existing ridge, would be built to an elevation of 295 m to block the northwest corner of the section to make the reservoir. This project would create a storage area of approximately 1.85 km^2 with a storage volume of approximately 1,860 dam^3. A spillway, riparian outlet, and emergency spillway would also be constructed for a total estimated cost between $1.2M and $1.8M. The adjacent properties located upstream of the site could drain excessive moisture to the retention site without significant impact to the downstream area.

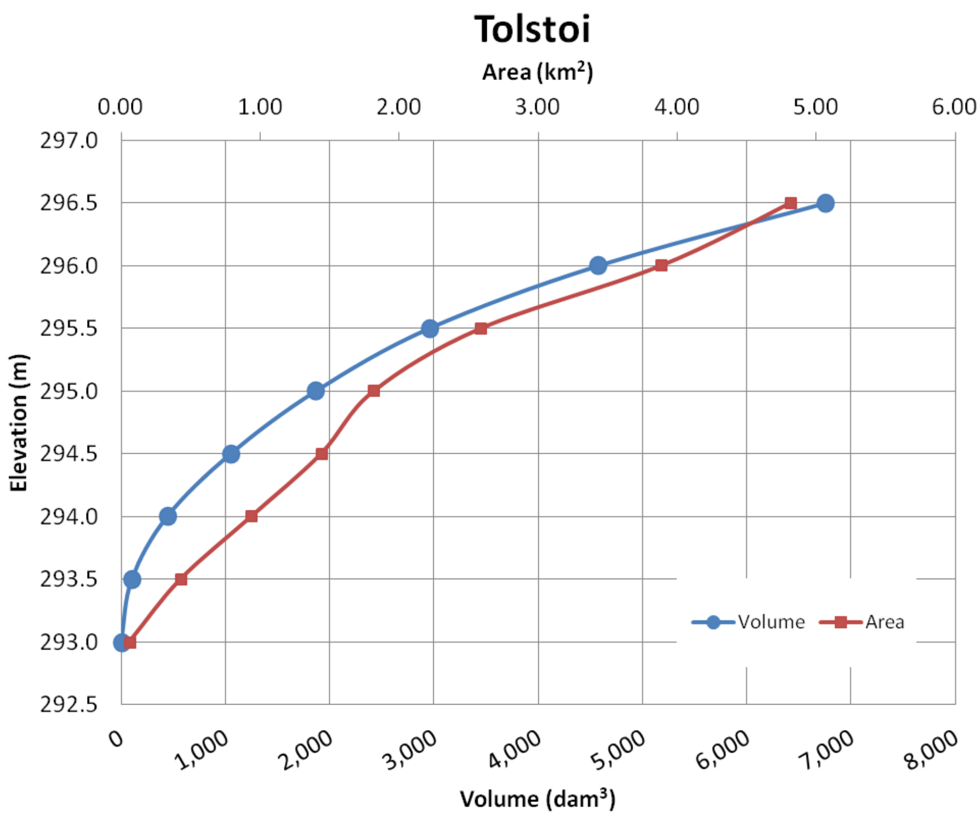


Figure 39: Tolstoi Retention Elevation-Volume-Area curves

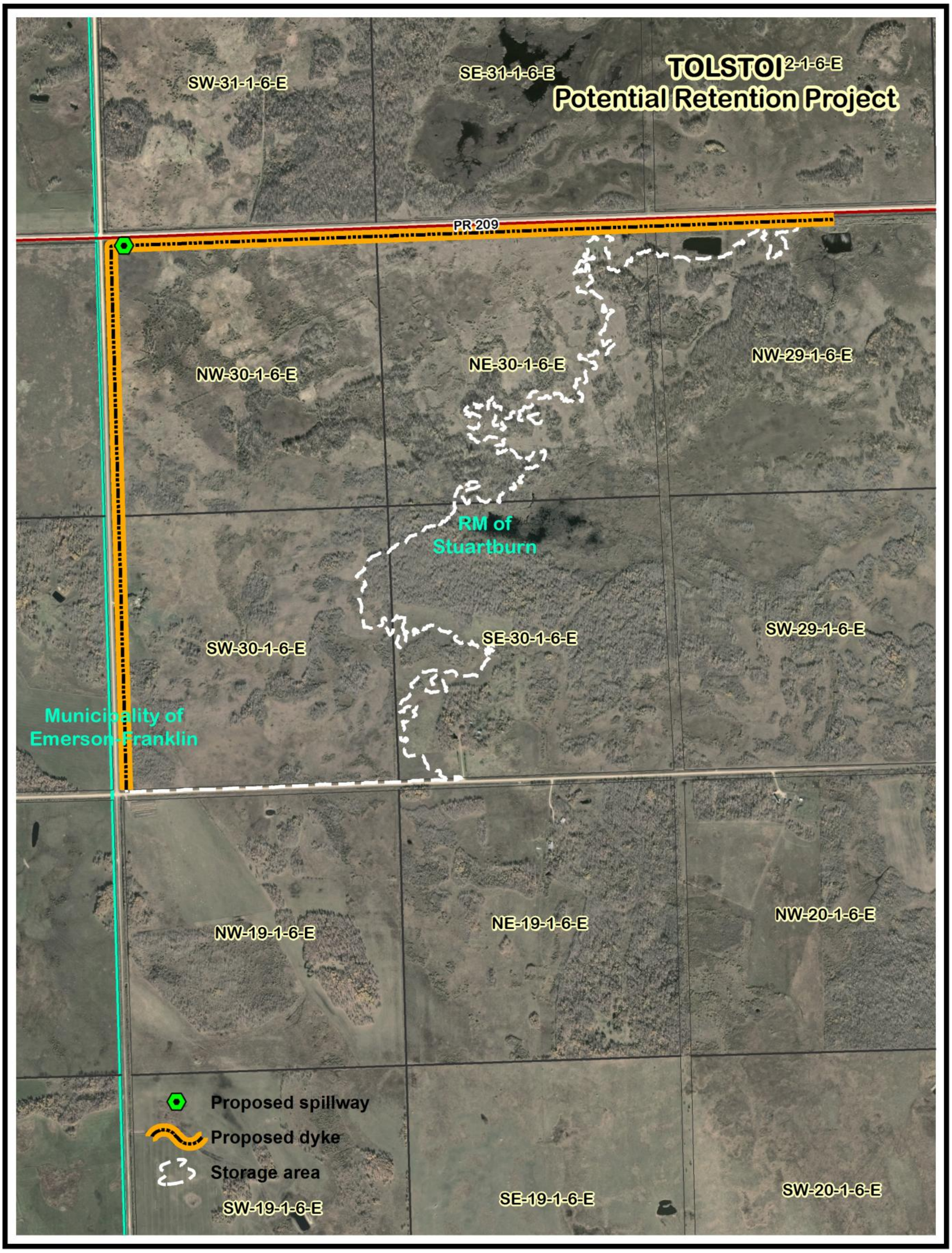
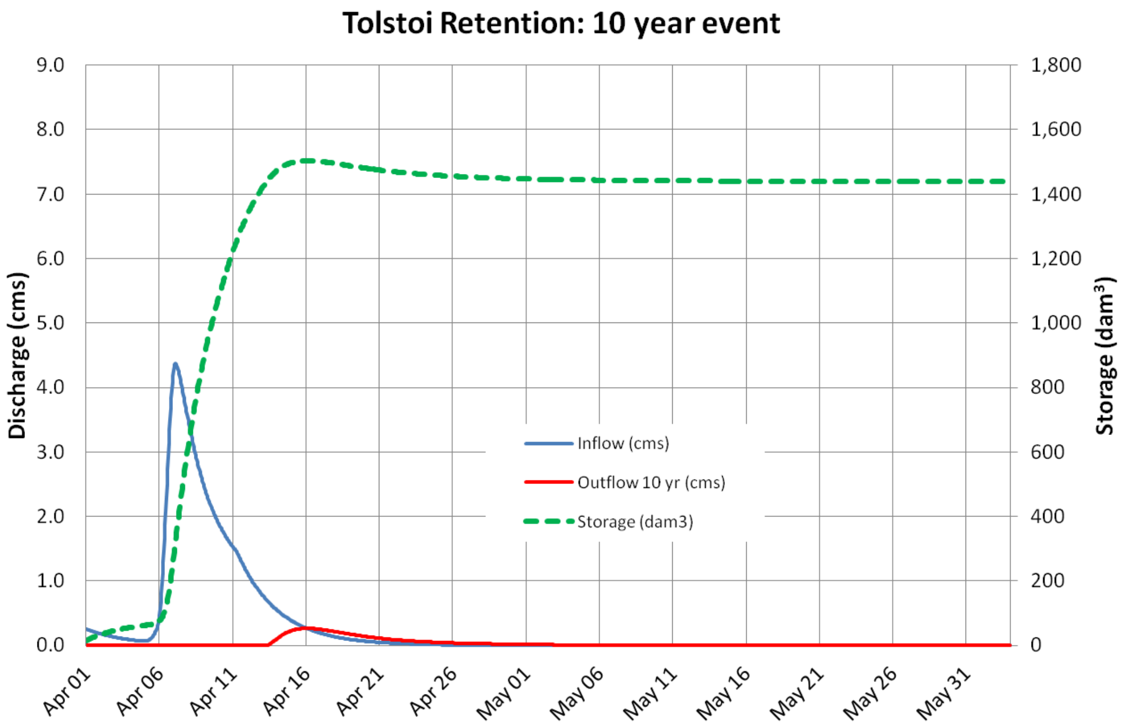


Figure 40: Tolstoi Project Site Plan

Benefits and potential impacts

The retention project would reduce the peak flows for 10-year and 100-year flood events by 94 % and 67 % respectively. The retention project would provide water supply and flood control in the area.



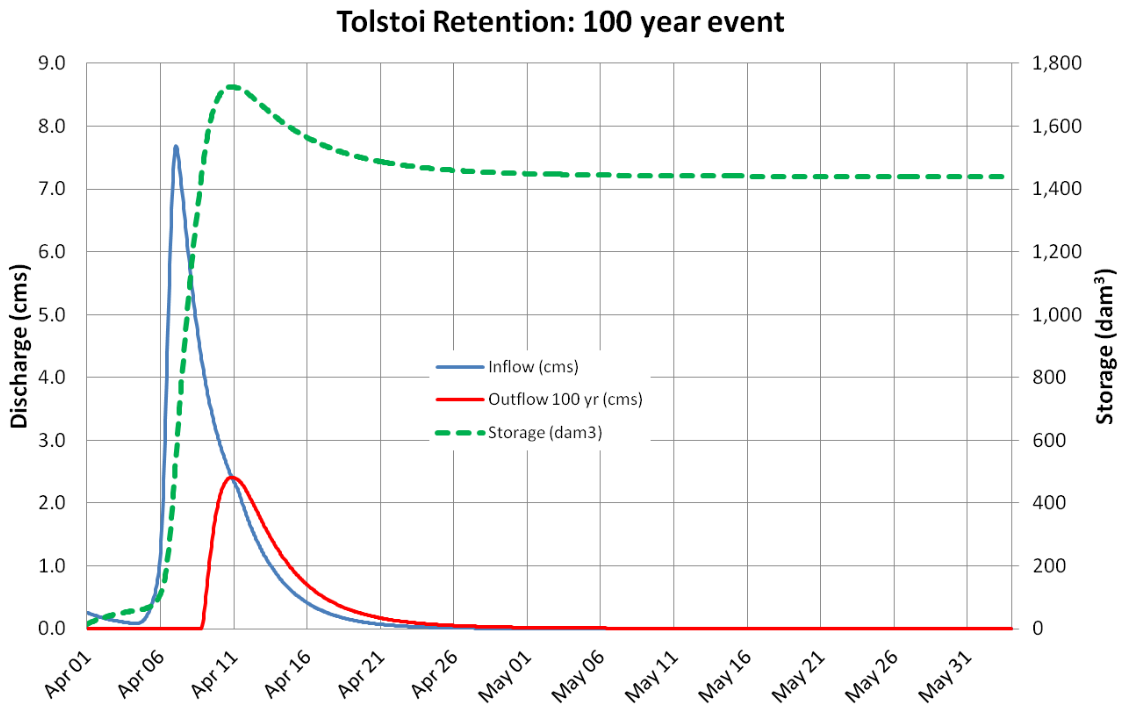


Figure 41: Tolstoi Retention Effects

Sprague Creek Project

The project is situated in township 14E, directly north of the Sprague Drain provincial waterway. The proposed dike is approximately 2 km east of the Sprague community and stretches for 5.5 km across the Mud Creek. Excess moisture issues have been mentioned for the area near Sprague but no specific retention site was recommended through public feedback. The location was identified based on the desktop analysis with all available information. The retention site is mostly located on crown land. The retention project would provide the adjacent areas benefits of flood protection, water supply and wildlife habitat. The project would also provide significant peak flow reduction benefit on the U.S. side of the watershed.

The dike would be a total of 5.5 km in length built to a maximum level of 332 m. The retention would create a 25.3 km^2 storage area with a capacity of 45,000 dam^3. A spillway, gated control structure and emergency spillway would also be constructed for a total cost of between $1.8 million and $2.7 million.

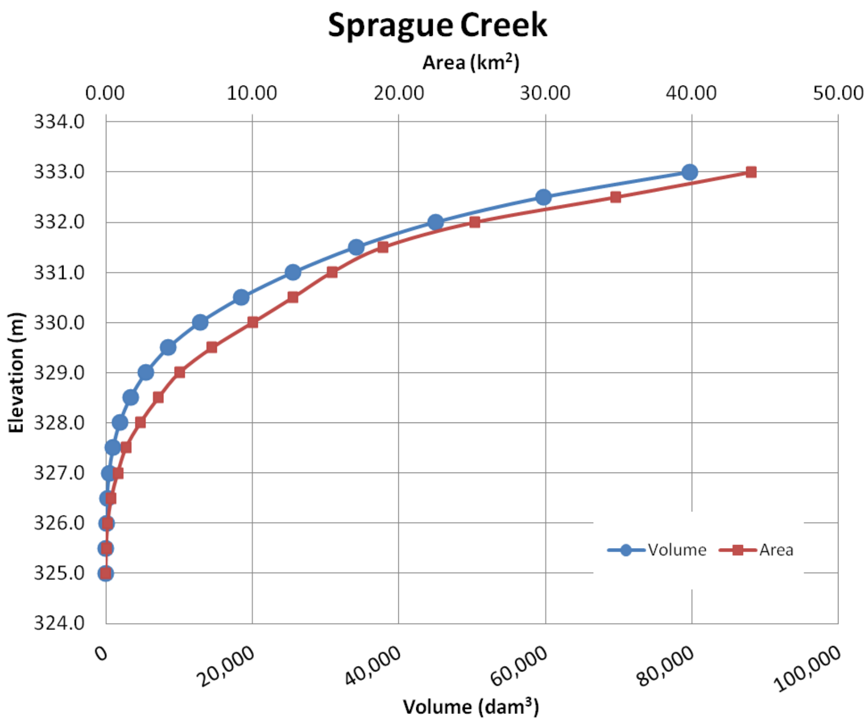


Figure 42: Sprague Creek Retention Elevation-Volume-Area curves

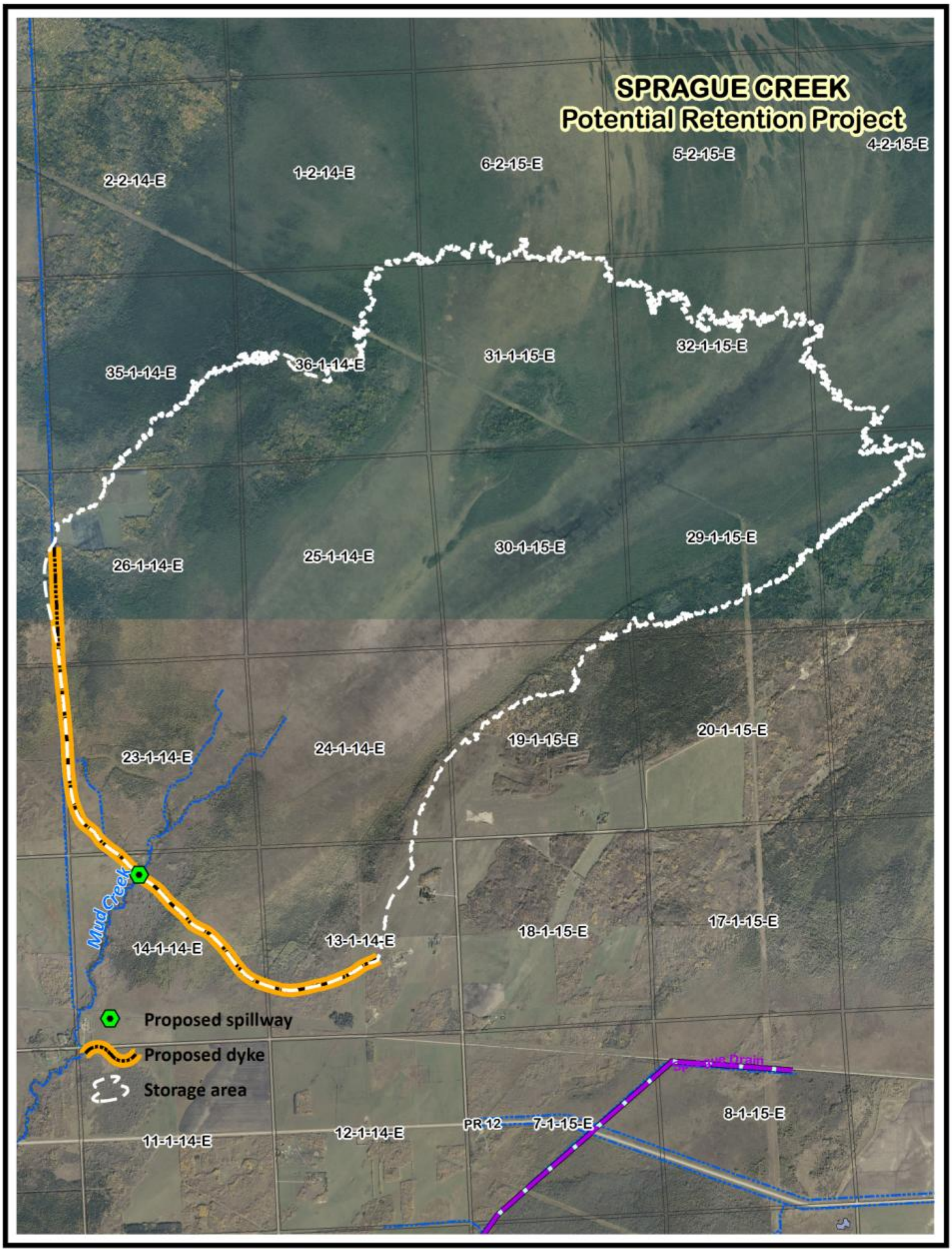
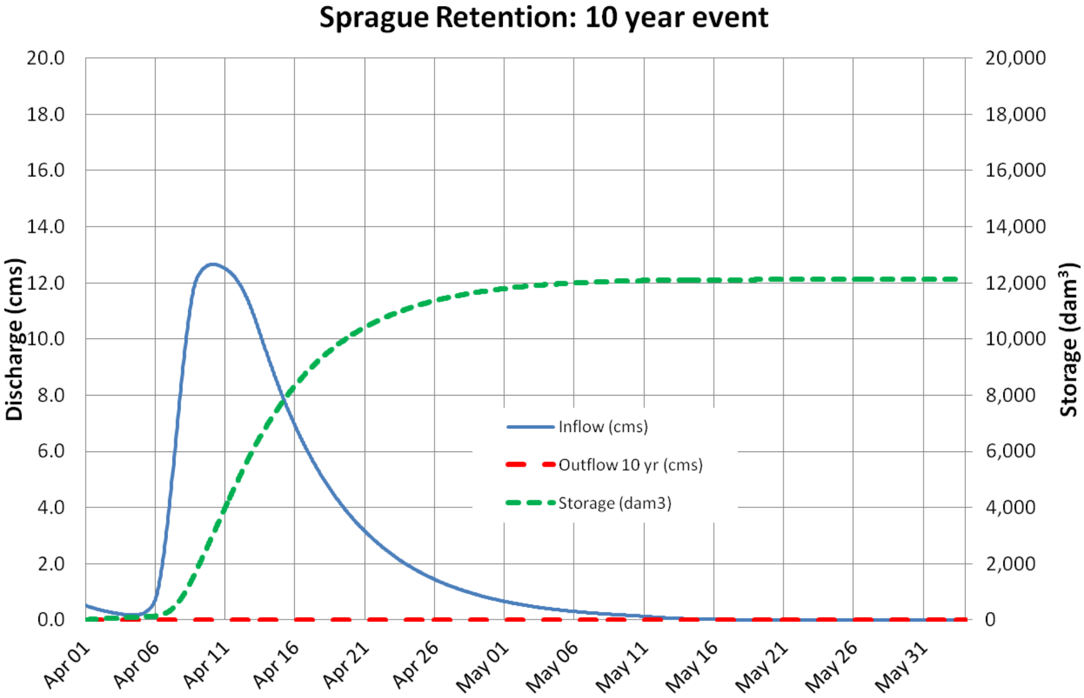


Figure 43: Sprague Creek Project Site Plan

Benefits and potential impacts

The retention project would reduce the 100-year flood events peak flow by 83 % while retaining most of the inflow for 10-year flood events. The significant peak reduction effects at this site would benefit flood control on the Roseau River on the U.S. side. The retention site would also provide a significant storage volume for water supply purpose and additional wildlife habitat.



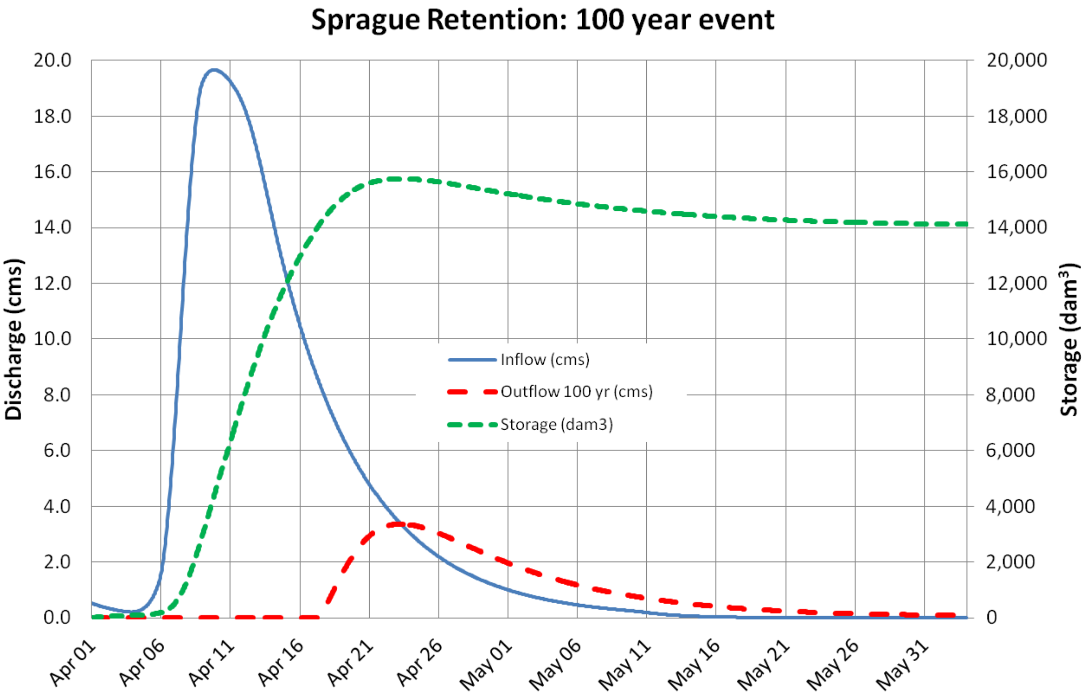


Figure 44: Sprague Retention Effects

5.3 Peak Reduction on the Roseau River by Retention Projects

In addition to assessing the local benefit of individual projects, to assess the peak reduction benefit of all the proposed projects together, each project was included in the HEC-HMS model and simulations were conducted for 10-year and 100-year flood events. As shown on Figure 45, when all retention projects are in operation together, peak reductions for the first peak appears to be about 30 % in both 10-year and 100-year flood events. In the case of the second peak, about 13 % of peak reduction occurs for 100-year events while about 7 % reduction occurs in 10-year events. Based on the HEC-HMS simulation analysis, the ten retention sites would provide significant peak flow reduction that exceeds the RRBC's Long Term Flood Solutions (LTFS) Basinwide Flow Reduction Strategy goal for the first peak, and also provide significant reduction for the second peak.

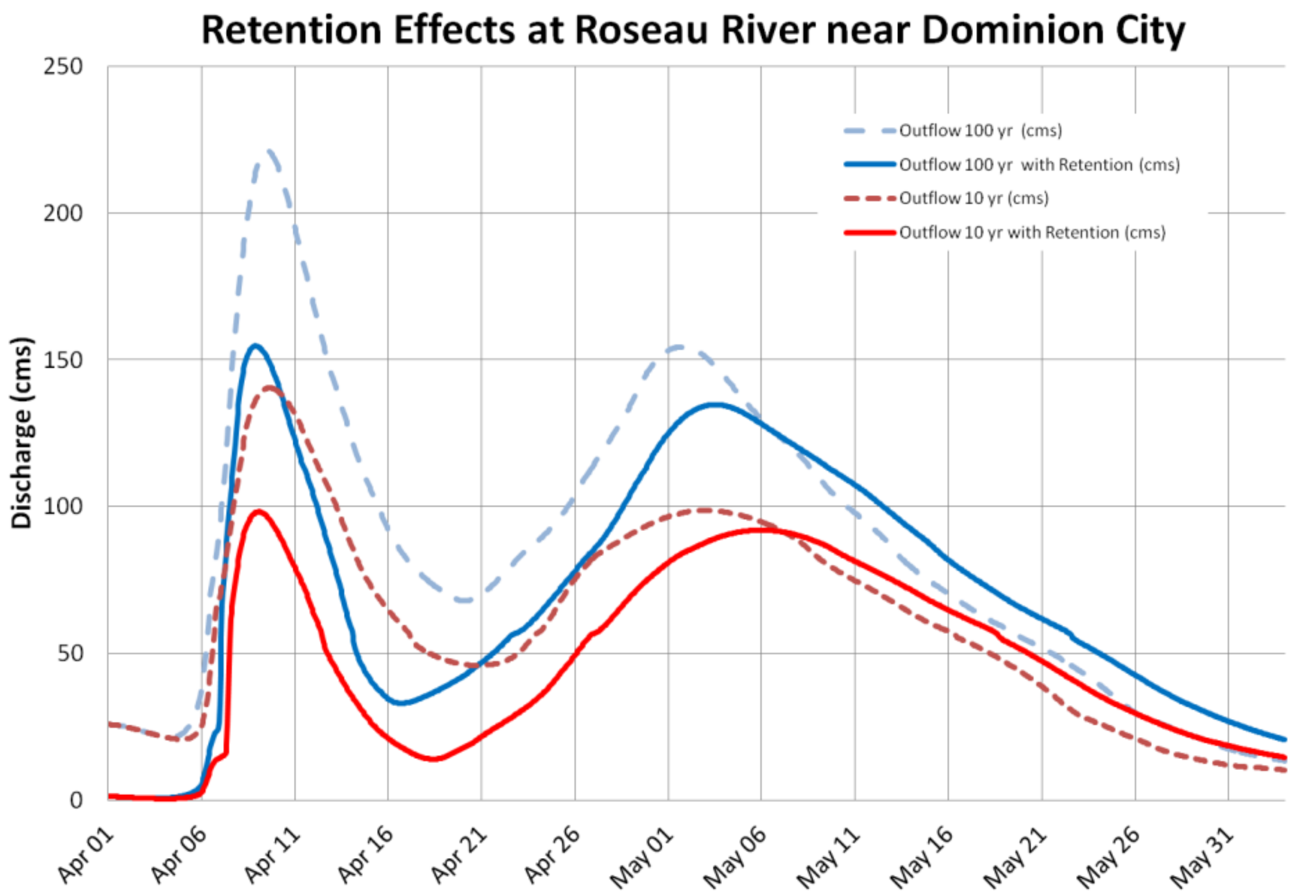


Figure 45: Retention Effects at the Roseau River near Dominion City

As many of the projects were judged to be medium or low priority for various reasons, a HEC-HMS simulation was run with only the five high priority projects. This represents a more reasonable result compared to all projects included. The effectiveness of these five projects, shown in Table 10, are slightly less than the simulation with all projects but do provide flood peak reduction at the basin scale.

Table 10: Peak reduction results comparing all projects and high priority projects

	10-yr Event		100-yr Event	
	1st peak	2nd peak	1st peak	2nd peak
No retention	140 cms	99.0 cms	221 cms	154 cms
All projects	96.8 cms 31 % reduction	92.0 cms 7.1 % reduction	155 cms 30 % reduction	135 cms 13 % reduction
Five high priority projects	108 cms 23 % reduction	92.6 cms 6.5 % reduction	170cms 23 % reduction	143 cms 7.3 % reduction

6. Future Considerations

This study provided an overview of the Roseau River watershed's geography, hydrology, infrastructure and water management issues. Several sources of information were used to assemble a list of potential water retention projects. These projects underwent preliminary assessment to identify potential benefits, storage capacities, hydrologic impact, and construction costs. Based on a variety of considerations and consultation with the Seine Rat River Conservation District and the local watershed planner, the priority of the projects was assessed. High priority projects were judged to have the most merit in the short term. Medium and low priority projects were not suitable for further study at this time for a number of different factors including cost, environmental impact, or private landowner impact. While some of the potential retention projects have substantial costs, their potential benefits in terms of large storage volume, peak flow reduction, water supply, habitat, and water quality are considerable.

The following five projects were determined to be high priority:

- Horseshoe Lake
- Sundown Ridge
- Mueller Farm
- Gardenton Floodway-Community Pasture
- Tolstoi

The next step would be to select projects for more in-depth assessment and conduct a benefit-cost analysis to determine if the projects are feasible.

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Appendix A

Hydrometric Data

Table A1: Monthly Mean Discharge at Roseau River near Caribou, MN

ROSEAU RIVER NEAR CARIBOU (05112000)

Monthly Mean Discharge (cms)													Annual Volume dam^3
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1961	0.833	0.681	4.039	9.031	6.999	0.956	0.173	0.090	1.118	1.524	6.280	2.038	88,747
1962	0.833	0.681	4.039	15.116	35.661	53.273	25.456	26.835	10.925	-	6.280	2.038	477,587
1963	0.833	0.681	4.039	34.635	20.857	23.785	8.630	1.577	0.355	0.763	6.280	2.038	274,022
1964	0.833	0.681	4.039	16.806	22.866	22.964	22.556	2.803	4.561	18.679	6.280	2.038	330,536
1965	0.833	0.681	4.039	34.697	65.686	39.510	23.546	3.670	7.943	19.172	11.407	2.038	562,833
1966	0.833	0.681	4.039	61.377	73.532	37.703	14.506	4.267	3.097	1.788	2.137	2.917	544,906
1967	0.833	0.681	4.039	47.039	63.329	20.450	3.148	0.466	0.050	0.054	0.104	2.038	374,929
1968	0.833	0.681	4.039	18.913	4.415	32.555	46.805	44.658	41.092	-	6.280	2.038	533,149
1969	0.833	0.681	4.039	40.200	55.700	17.700	3.610	3.800	2.010	4.244	2.642	1.430	361,062
1970	0.833	0.681	4.039	23.888	78.374	73.293	34.174	1.262	3.042	2.263	9.735	2.038	616,058
1971	0.833	0.681	0.986	33.093	23.688	7.870	3.776	1.241	0.750	3.338	8.254	2.038	227,322
1972	0.833	0.681	4.119	22.625	31.596	9.813	1.505	0.489	0.596	0.991	1.304	0.449	197,735
1973	0.278	0.248	6.669	2.764	3.075	2.236	0.971	2.344	5.307	14.221	4.029	1.144	114,632
1974	0.441	0.380	0.394	23.604	73.551	55.548	4.974	14.837	12.909	3.558	3.067	1.272	512,722
1975	0.819	0.711	0.521	16.893	65.997	31.365	34.791	2.891	0.838	0.556	0.918	0.579	415,681
1976	0.497	0.464	0.535	28.237	6.397	3.642	2.566	0.277	0.163	0.389	0.394	0.181	114,233
1977	0.107	0.122	0.385	4.439	1.407	1.610	1.599	0.301	1.296	4.429	5.705	3.470	65,454
1978	1.222	0.398	0.195	30.868	42.697	5.245	11.386	5.629	4.767	1.680	1.001	0.672	279,546
1979	0.489	0.348	0.534	19.738	74.766	31.689	3.326	0.479	0.247	0.104	0.624	0.459	351,092
1980	0.431	0.388	0.396	17.242	2.239	0.190	0.019	0.077	0.169	0.704	1.136	0.325	60,727
1981	0.112	0.530	2.092	1.082	1.528	10.236	8.748	1.678	3.676	11.375	6.164	2.605	131,489
1982	0.415	0.385	0.590	23.243	34.567	7.986	8.091	3.633	1.081	16.726	7.166	2.343	281,006
1983	0.861	0.730	12.521	33.551	20.255	16.865	13.355	0.858	1.447	3.082	3.048	1.521	284,583
1984	0.400	0.442	2.633	22.951	7.390	17.819	7.634	0.827	0.053	2.460	2.734	0.682	172,963
1985	0.261	0.171	3.416	25.666	21.941	23.639	33.165	24.706	35.357	20.644	7.325	1.813	522,613
1986	0.991	0.754	4.373	58.352	60.982	22.180	3.986	0.781	0.516	1.358	1.107	0.810	411,047
1987	0.613	0.491	4.967	38.434	8.744	5.757	1.215	0.401	0.065	0.137	0.192	0.215	160,033
1988	0.062	0.026	0.216	10.384	0.762	0.411	1.797	0.177	0.031	0.107	0.178	0.708	38,843
1989	0.052	0.038	0.045	15.229	22.620	12.493	11.892	0.940	0.337	0.178	0.234	0.052	169,261
1990	0.003	0.003	3.053	4.692	3.593	4.168	3.904	0.158	0.008	0.004	0.007	0.015	51,755
1991	0.003	0.002	0.253	1.256	3.277	7.383	32.160	2.719	10.324	8.027	10.298	2.830	207,812
1992	1.298	0.982	6.068	54.897	55.391	10.741	6.959	2.045	14.038	2.872	3.896	2.433	425,409
1993	0.861	0.599	1.184	31.690	10.935	17.507	17.057	44.786	36.017	5.363	8.214	1.766	463,115
1994	0.978	0.560	5.697	17.342	7.658	2.823	12.600	6.514	21.927	18.172	20.159	8.577	323,941
1995	1.331	0.781	22.442	39.197	22.055	5.535	11.927	2.481	1.124	1.896	5.694	1.484	305,898
1996	0.950	0.819	0.779	16.666	81.772	71.415	22.719	9.103	1.172	3.087	11.432	2.730	587,423
1997	2.485	2.135	2.170	46.171	82.914	32.703	20.362	1.825	1.195	14.027	9.782	2.072	575,143
1998	1.097	2.060	21.411	30.933	25.153	27.997	22.013	0.850	0.642	4.786	6.233	2.765	384,665
1999	0.913	0.789	2.544	58.842	61.767	58.182	44.977	3.021	9.806	3.711	2.974	1.236	654,865
2000	0.717	1.673	10.035	7.040	8.597	19.131	27.093	5.008	11.001	9.197	57.266	23.012	472,901
2001	1.465	0.853	1.979	59.393	60.461	45.845	13.237	38.837	4.954	3.200	4.893	2.453	626,140
2002	0.897	0.521	0.453	8.322	20.068	67.890	87.207	20.436	5.936	2.695	2.676	0.934	576,516
2003	0.501	0.334	4.655	10.833	11.938	11.319	3.233	0.789	7.144	5.161	3.657	1.278	160,026
2004	0.802	0.628	1.849	61.189	65.394	86.819	31.202	17.759	20.719	20.586	28.143	2.533	887,118
2005	0.719	0.758	0.936	55.775	41.635	48.847	63.046	17.890	4.478	8.415	20.023	3.763	701,864
2006	2.158	1.350	1.477	68.340	54.284	2.939	0.483	3.458	1.325	3.377	6.994	0.685	386,152
2007	0.258	0.147	3.273	37.446	13.048	33.842	32.280	1.324	0.475	10.004	10.169	1.198	377,139
2008	0.572	0.425	0.470	15.967	23.448	26.949	15.192	5.168	5.113	17.965	25.846	2.713	368,024
2009	1.023	1.277	9.649	76.352	80.886	64.326	19.930	7.308	2.440	1.443	5.239	1.400	713,426
2010	0.739	0.591	28.188	27.296	27.620	58.257	26.302	2.902	13.139	32.637	35.473	10.094	693,308
2011	4.149	2.393	3.911	62.698	69.331	34.719	25.465	2.460	0.585	0.625	1.098	0.454	547,624
2012	0.476	0.484	6.870	7.077	3.133	3.711	0.536	0.486	0.473	1.301	3.223	0.678	74,821
2013	0.378	0.375	0.465	6.188	44.932	50.829	7.067	2.612	1.292	4.051	2.206	0.724	319,085
2014	0.491	0.388	0.352	26.636	68.308	59.635	28.507	5.017	1.940	5.535	3.226	0.805	529,928

Table A2: Monthly Mean Discharge at Roseau River at Gardenton, MB

ROSEAU RIVER AT GARDENTON (05OD004)

Monthly Mean Discharge (cms)													Annual Volume dam^3
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1962	0.204	0.232	-	17.791	40.577	58.840	30.877	23.464	8.665	0.294	3.570	2.300	502,245
1963	0.289	0.235	2.097	36.220	20.226	23.333	8.093	1.477	0.251	0.699	0.767	0.187	246,136
1964	0.034	0.024	-	16.724	21.847	20.330	23.271	2.391	2.695	18.084	8.810	1.060	314,158
1965	0.082	0.037	-	37.066	70.052	42.167	23.499	2.558	5.511	17.639	15.700	7.700	595,564
1966	3.110	1.780	9.540	70.610	79.129	43.447	15.986	4.567	3.704	1.422	1.310	1.550	621,772
1967	0.348	0.136	0.661	55.440	66.268	21.362	3.179	0.240	0.011	0.021	0.275	0.513	390,922
1968	0.204	0.051	0.725	19.727	5.614	32.786	48.810	46.306	44.880	17.613	11.600	2.940	609,964
1969	0.799	0.631	0.998	46.754	61.968	20.273	4.021	3.818	1.714	3.794	2.844	1.714	393,612
1970	1.202	0.662	0.488	23.904	88.474	78.573	37.928	1.587	3.393	2.244	7.162	1.431	651,757
1971	0.147	0.149	0.436	34.758	26.574	8.839	3.682	1.243	0.657	3.445	9.582	1.864	240,049
1972	0.607	0.315	1.706	24.009	32.813	9.916	1.645	0.616	0.435	1.133	1.056	0.202	196,276
1973	0.176	0.167	6.228	2.702	3.338	2.100	0.800	2.172	4.578	15.865	6.310	1.310	121,126
1974	0.439	0.385	0.432	25.354	80.013	56.783	5.378	13.488	13.111	3.915	2.970	1.030	535,931
1975	0.609	0.711	0.817	15.929	65.532	33.060	36.923	3.624	0.864	0.569	0.949	0.413	423,969
1976	0.494	0.352	0.425	28.733	7.574	3.778	2.643	0.357	0.177	0.453	5.049	1.355	134,291
1977	0.494	0.352	0.407	4.754	1.697	1.903	1.695	0.347	1.049	4.996	5.049	1.355	63,354
1978	0.494	0.352	0.261	30.009	43.158	5.645	11.082	5.403	4.432	1.738	5.049	1.355	287,897
1979	0.494	0.352	0.378	19.527	74.635	34.835	3.162	0.453	0.237	0.162	5.049	1.355	371,442
1980	0.494	0.352	0.258	18.034	2.662	0.240	0.028	0.029	0.146	0.656	5.049	1.355	76,365
1981	0.494	0.352	2.681	1.568	1.552	9.425	8.345	2.001	3.816	10.525	5.049	1.355	124,513
1982	0.494	0.352	0.670	29.283	36.161	8.793	8.386	3.677	1.264	17.390	5.049	1.355	298,395
1983	0.494	0.352	26.964	37.827	22.129	18.373	14.263	0.880	1.487	3.003	5.049	1.355	348,509
1984	0.494	0.352	2.165	23.213	7.600	19.368	9.123	1.057	0.114	2.423	5.049	1.355	189,466
1985	0.494	0.352	2.534	25.760	21.477	24.010	32.710	25.873	35.767	21.177	15.167	1.355	544,768
1986	0.494	0.352	5.675	65.130	72.132	25.584	4.934	0.987	0.450	1.295	5.049	1.355	482,913
1987	0.494	0.352	4.959	42.953	9.922	6.220	1.643	0.465	0.108	0.183	5.049	1.355	192,622
1988	0.494	0.352	0.129	9.968	1.014	0.477	1.748	0.129	0.010	0.066	5.049	1.355	54,251
1989	0.494	0.352	0.018	14.972	26.129	13.213	12.869	1.051	0.337	0.264	5.049	1.355	200,844
1990	0.494	0.352	3.423	6.110	3.993	4.733	5.227	0.185	0.015	0.016	5.049	1.355	81,437
1991	0.494	0.352	0.189	1.274	3.462	7.813	36.255	3.675	9.775	8.442	5.049	1.355	207,119
1992	0.494	0.352	7.648	64.733	59.019	12.409	7.546	1.936	14.208	3.077	5.049	1.355	467,871
1993	0.494	0.352	1.402	33.413	11.831	18.018	17.058	44.423	38.340	6.065	5.049	1.355	467,939
1994	0.494	0.352	5.254	19.082	7.492	3.276	12.516	6.288	21.588	19.852	12.500	1.355	289,788
1995	0.494	0.352	26.720	47.873	24.513	6.375	12.887	3.055	1.110	1.816	5.049	1.355	347,165
1996	0.494	0.352	0.873	22.710	84.897	73.443	26.555	10.662	0.857	3.502	5.049	1.355	609,131
2001	0.494	0.352	1.587	64.760	67.265	51.210	14.961	5.502	5.370	5.377	5.049	1.355	587,025
2002	0.494	0.352	0.541	9.163	21.461	74.707	14.961	5.502	5.370	5.377	5.049	1.355	378,341
2003	0.494	0.352	6.251	11.266	13.366	13.363	14.961	5.502	5.370	5.377	5.049	1.355	218,399
2004	0.494	0.352	1.738	66.090	67.816	91.740	14.961	5.502	5.370	5.377	5.049	1.355	697,408
2005	0.494	0.352	1.085	63.827	51.303	61.090	70.771	5.502	5.370	5.377	5.049	1.355	715,602
2006	0.494	0.352	0.766	72.373	58.342	2.923	14.961	5.502	5.370	5.377	5.049	1.355	455,501
2007	0.494	0.352	3.287	38.483	16.113	39.217	14.961	5.502	5.370	5.377	5.049	1.355	355,379
2008	0.494	0.352	0.279	16.150	28.084	29.707	14.961	5.502	5.370	5.377	5.049	1.355	296,848
2009	0.494	0.352	7.361	83.650	88.871	67.987	14.961	5.502	5.370	5.377	5.049	1.355	752,809
2010	0.494	0.352	23.232	30.658	30.252	66.930	30.175	3.502	13.729	35.190	5.049	1.355	635,130
2011	0.494	0.352	3.892	72.520	74.558	39.477	27.139	3.059	0.432	0.655	5.049	1.355	603,060
2012	0.494	0.352	6.354	6.976	3.027	3.511	0.681	0.070	0.020	1.397	5.049	1.355	77,004
2013	0.494	0.352	0.362	5.605	46.623	55.920	8.686	2.940	1.264	3.995	5.049	1.355	349,322
2014	0.494	0.352	0.617	27.597	72.187	65.840	36.513	5.522	2.559	6.030	5.049	1.355	591,446

Table A3: Monthly Mean Discharge at Roseau River near Dominion City, MB

ROSEAU RIVER NEAR DOMINION CITY (05OD001)

Monthly Mean Discharge (cms)													Annual Volume dam^3
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1961	0.141	0.042	2.292	10.565	7.742	1.115	0.265	0.103	0.872	2.099	1.078	0.396	70,351
1962	0.346	0.349	0.132	16.687	42.539	58.803	28.426	23.487	13.289	3.101	3.786	2.724	510,634
1963	0.469	0.351	3.999	38.363	23.887	28.983	12.178	3.095	0.880	0.777	0.967	0.293	299,918
1964	0.071	0.047	0.127	19.401	26.784	24.129	24.814	4.186	4.224	19.425	8.442	1.370	351,408
1965	0.152	0.067	0.092	43.710	71.587	45.957	26.552	5.508	8.281	23.545	14.136	7.958	653,323
1966	3.878	2.127	5.994	92.750	97.077	48.897	19.557	4.490	8.270	1.751	1.553	1.925	758,462
1967	0.555	0.217	1.395	73.347	76.319	25.177	3.893	0.677	0.080	0.294	0.388	0.718	481,699
1968	0.345	0.090	0.601	18.805	5.530	31.670	51.448	45.665	47.023	18.952	10.732	3.397	618,062
1969	1.159	0.846	1.008	45.901	59.503	20.346	4.254	3.574	2.028	4.258	3.074	1.456	388,433
1970	0.994	0.614	0.548	28.484	93.184	81.167	39.109	1.996	3.257	2.120	7.336	1.503	686,669
1971	0.687	0.424	0.621	35.879	27.732	10.348	3.701	1.239	0.627	2.985	11.219	2.414	257,023
1972	0.873	0.490	1.254	22.856	33.616	10.158	2.032	0.640	0.400	1.085	0.890	0.251	196,566
1973	0.301	0.261	6.877	3.157	3.635	2.478	1.072	2.349	4.984	17.071	6.281	1.648	132,697
1974	0.678	0.547	0.482	37.395	100.016	64.293	7.501	13.296	14.436	3.889	3.222	1.336	651,357
1975	0.913	0.939	0.656	18.444	64.761	33.283	37.171	3.743	0.787	0.799	1.166	0.595	432,382
1976	0.506	0.274	0.394	27.643	6.935	3.264	2.719	0.288	0.107	0.247	0.322	0.087	111,817
1977	0.055	0.086	0.404	4.163	1.269	1.613	1.582	0.394	0.986	5.054	4.378	3.623	62,242
1978	1.518	0.507	0.743	34.132	46.481	6.115	10.091	6.082	4.444	1.710	1.316	0.602	300,533
1979	0.500	0.362	0.478	31.692	85.948	39.943	3.163	0.788	0.308	0.179	0.569	0.453	433,924
1980	0.386	0.335	0.290	19.413	2.938	0.337	0.097	0.004	0.453	1.262	0.990	0.307	69,895
1981	0.310	0.503	2.714	2.168	1.385	9.261	8.372	1.908	3.427	10.991	6.262	2.677	131,901
1982	0.585	0.552	1.967	30.379	40.181	11.618	9.745	3.922	1.914	18.633	9.762	4.404	353,219
1983	1.225	0.647	25.559	45.427	25.465	19.313	15.347	0.973	1.703	2.569	2.954	1.857	376,950
1984	0.597	0.496	1.730	25.467	7.888	19.297	8.358	1.362	1.088	3.026	3.392	0.788	192,452
1985	0.329	0.195	2.649	26.720	22.026	24.103	32.542	24.368	37.977	22.994	7.824	1.936	537,090
1986	1.024	0.654	8.302	74.647	82.387	29.099	5.336	0.977	0.479	1.541	1.360	0.775	544,014
1987	0.657	0.520	5.339	49.447	10.676	6.936	1.597	0.561	0.111	0.394	0.450	0.246	201,004
1988	0.064	0.023	0.191	10.685	1.180	0.527	1.611	0.216	0.055	0.133	0.164	0.579	40,334
1989	0.097	0.064	0.043	15.569	24.955	12.184	12.642	1.233	0.451	0.274	0.240	0.147	179,388
1990	0.111	0.070	2.637	7.354	3.725	7.269	5.895	0.314	0.047	0.068	0.075	0.053	72,682
1991	0.041	0.074	0.139	1.752	2.760	9.213	47.310	4.898	10.249	9.631	12.223	2.953	268,260
1992	1.856	1.138	9.251	86.033	66.294	14.333	7.597	1.897	15.115	3.367	3.677	2.632	560,418
1993	0.871	0.830	1.720	35.800	14.730	21.653	18.741	47.284	40.437	6.254	9.554	1.804	525,317
1994	0.942	0.659	5.003	20.297	7.699	3.429	13.236	6.586	22.336	21.168	24.378	11.790	362,087
1995	2.155	1.071	31.660	55.790	24.839	7.632	12.694	3.263	1.221	1.696	5.457	1.744	393,343
1996	1.096	0.787	1.155	31.271	97.297	78.347	26.297	11.203	1.162	3.667	15.139	3.707	715,106
1997	0.664	0.465	2.250	63.451	98.813	41.703	30.165	5.078	1.716	10.572	4.799	1.808	690,590
1998	0.664	0.465	21.968	41.033	37.852	33.993	25.196	1.216	0.613	4.136	4.799	1.808	458,285
1999	0.664	0.465	0.928	61.100	66.842	62.823	48.661	4.750	10.544	4.030	4.799	1.808	704,093
2000	0.664	0.465	12.753	8.323	9.654	25.844	35.088	9.703	14.074	10.480	4.799	1.808	353,279
2001	0.664	0.465	1.565	82.791	73.997	55.610	20.810	49.423	6.593	3.359	4.799	1.808	795,502
2002	0.664	0.465	1.230	9.332	22.087	91.560	95.532	26.304	7.686	3.030	4.799	1.808	698,514
2003	0.664	0.465	6.369	12.399	13.661	17.192	5.227	1.154	6.308	5.724	4.799	1.808	199,304
2004	0.664	0.465	3.687	75.590	75.648	101.690	37.372	19.555	25.270	26.855	4.799	1.808	982,087
2005	0.664	0.465	1.007	67.377	54.897	76.583	86.129	22.966	5.440	9.802	4.799	1.808	875,616
2006	0.664	0.465	1.479	82.783	64.739	5.260	0.728	3.924	1.451	3.029	4.799	1.808	450,080
2007	0.664	0.465	6.265	44.280	22.652	47.770	43.139	1.880	0.454	11.882	4.799	1.808	489,808
2008	0.664	0.465	0.890	21.052	27.235	28.403	16.556	6.920	6.231	22.128	4.799	1.808	362,001
2009	0.664	0.465	8.022	93.207	100.406	76.690	29.145	7.840	3.468	1.735	4.799	1.808	863,667
2010	0.664	0.465	22.851	34.097	38.616	80.857	33.400	4.319	15.438	37.935	4.799	1.808	725,428
2011	0.664	0.465	4.975	89.673	80.661	48.507	28.143	2.698	0.658	0.718	4.799	1.808	693,950
2012	0.664	0.465	6.710	7.216	3.341	3.648	0.779	0.121	0.029	1.201	4.799	1.808	80,966
2013	0.664	0.465	0.494	7.625	50.339	61.447	20.074	2.966	1.174	4.007	4.799	1.808	410,853
2014	0.664	0.465	0.700	28.378	78.284	72.697	46.000	6.913	2.660	6.295	4.799	1.808	659,199

Table A4: Monthly Mean Discharge at Sprague Creek near Sprague Creek, MB

SPRAGUE CREEK NEAR SPRAGUE CREEK, MB (0516000)

Monthly Mean Discharge (cms)													Annual Volume dam^3
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1961	0.035	0.038	0.494	0.988	1.478	0.293	0.021	0.003	0.034	0.071	0.072	0.030	9,399
1962	0.014	0.010	0.025	1.961	8.508	6.269	1.335	4.165	1.158	0.519	0.588	0.256	65,582
1963	0.018	0.019	0.538	7.699	4.260	4.813	0.678	0.080	0.023	0.034	0.039	0.021	47,715
1964	0.008	0.009	0.015	1.814	3.904	4.465	1.642	0.230	2.040	3.479	0.757	0.070	48,584
1965	0.044	0.035	0.051	10.563	10.885	4.957	5.706	0.457	2.498	4.817	1.653	0.809	112,058
1966	0.293	0.113	1.309	17.929	11.610	3.169	1.195	0.397	0.462	0.263	0.171	0.092	97,202
1967	0.035	0.006	0.209	10.890	5.774	0.991	0.755	0.090	0.017	0.037	0.035	0.035	49,525
1968	0.019	0.018	0.790	1.913	1.310	7.529	3.978	4.535	2.222	1.474	0.755	0.154	65,073
1969	0.045	0.035	0.132	11.487	4.174	5.269	0.934	0.703	0.162	0.943	0.408	0.098	63,820
1970	0.048	0.044	0.058	8.190	14.539	7.624	0.666	0.184	0.282	0.371	0.667	0.154	86,463
1971	0.081	0.047	0.062	4.663	2.801	1.829	1.047	0.281	0.177	0.703	1.875	0.185	36,076
1972	0.070	0.032	0.314	6.487	3.806	0.808	0.061	0.086	0.330	0.436	0.441	0.065	33,945
1973	0.026	0.032	0.822	0.791	1.126	1.031	0.778	1.559	2.551	3.443	0.970	0.252	35,371
1974	0.089	0.068	0.063	15.998	13.386	2.919	0.159	2.229	1.217	0.883	0.521	0.106	99,005
1975	0.068	0.066	0.054	5.360	5.851	3.264	1.344	0.139	0.158	0.141	0.152	0.051	43,801
1976	0.046	0.050	0.131	4.014	1.326	1.623	0.587	0.047	0.018	0.030	0.031	0.006	20,681
1977	0.006	0.004	0.035	0.268	0.174	0.250	0.181	0.021	0.548	0.879	0.987	0.380	9,820
1978	0.089	0.045	0.079	8.470	3.692	0.940	1.042	0.207	0.200	0.118	0.092	0.054	39,404
1979	0.037	0.028	0.125	9.503	7.256	2.144	0.159	0.071	0.054	0.046	0.056	0.040	51,256
1980	0.020	0.029	0.049	0.915	0.063	0.003	0.001	0.079	0.094	0.311	0.306	0.053	5,031
1981	0.025	0.075	0.272	0.203	0.471	3.406	0.806	0.706	1.854	3.466	1.296	0.406	34,179
2000	0.051	0.207	0.441	0.395	1.471	7.620	2.929	1.696	1.813	1.952	13.015	0.853	84,872
2001	0.213	0.141	0.175	10.442	7.935	5.433	1.098	3.451	0.371	0.470	0.872	0.298	81,245
2002	0.098	0.055	0.092	1.698	4.133	35.064	5.562	1.614	1.319	0.802	0.396	0.110	133,105
2003	0.076	0.065	0.968	1.484	3.297	2.773	1.067	0.387	2.930	1.745	0.757	0.142	41,319
2004	0.115	0.101	0.605	9.556	17.267	11.003	1.547	2.324	4.487	4.092	3.070	0.334	143,520
2005	0.128	0.142	0.218	8.743	5.740	11.013	9.050	1.376	1.062	2.041	3.532	0.375	114,154
2006	0.364	0.258	0.587	11.618	3.401	0.325	0.061	2.722	0.987	1.575	1.080	0.171	60,723
2007	0.068	0.020	1.764	5.781	4.666	10.445	3.337	0.321	0.139	3.797	2.126	0.225	85,951
2008	0.107	0.072	0.098	2.453	5.703	6.721	3.582	1.187	1.640	3.829	4.239	0.428	79,191
2009	0.147	0.073	1.829	16.023	13.908	6.013	2.104	1.194	0.569	0.342	0.736	0.196	113,492
2010	0.058	0.073	4.096	3.609	9.601	11.823	2.710	0.497	4.565	4.828	4.273	0.972	124,054
2011	0.391	0.180	0.173	14.999	8.195	4.464	1.056	0.059	0.034	0.056	0.053	0.039	77,813
2012	0.044	0.048	0.588	0.581	0.310	0.848	0.102	0.037	0.018	0.596	0.908	0.066	10,892
2013	0.045	0.045	0.103	2.037	12.922	6.752	0.384	0.103	0.253	0.733	0.251	0.086	62,696
2014	0.062	0.060	0.048	6.303	13.879	4.606	1.960	0.160	0.528	1.042	0.321	0.050	76,692

Table A5: Monthly Mean Discharge at Pine Creek Diversion near Piney, MB

PINE CREEK DIVERSION NEAR PINEY, MB (05OD027)

Monthly Mean Discharge (cms)													Annual Volume dam^3
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
1959	0.189	0.160	0.868	1.885	2.157	1.147	0.798	0.441	0.348	1.533	0.628	0.263	27,511
1960	0.167	0.196	0.635	3.321	1.181	1.374	0.436	0.312	0.163	0.361	0.568	0.177	23,296
1961	0.082	0.144	0.265	1.195	0.959	0.254	0.251	0.095	0.259	0.479	0.319	0.125	11,644
1962	0.013	0.049	0.249	2.107	3.772	3.163	0.121	0.307	0.257	0.214	0.215	0.214	28,096
1963	0.058	0.093	1.625	2.780	1.262	3.182	0.272	0.135	0.141	0.193	0.400	0.148	26,974
1964	0.065	0.014	0.117	1.639	2.102	1.588	0.656	0.230	0.672	1.019	0.386	0.179	22,836
1965	0.120	0.106	0.066	1.969	3.347	1.259	2.271	0.343	1.061	1.542	0.685	0.428	34,894
1966	0.178	0.144	0.197	3.442	3.051	0.541	0.591	0.339	0.429	0.537	0.292	0.223	26,240
1967	0.198	0.052	0.509	4.655	1.610	0.453	0.169	0.262	0.153	0.337	0.241	0.238	23,289
1968	0.315	0.241	0.863	1.743	1.241	2.319	2.381	1.756	1.445	0.799	0.638	0.174	36,676
1969	0.202	0.220	0.242	3.840	1.060	1.769	0.619	0.362	0.338	0.586	0.342	0.373	26,061
1970	0.279	0.223	0.285	2.309	4.381	1.588	0.262	0.174	0.364	0.476	0.616	0.291	29,650
1971	0.104	0.157	0.227	2.658	1.281	0.812	0.395	0.237	0.227	0.408	0.593	0.224	19,204
1972	0.163	0.113	0.090	1.781	1.095	0.201	0.113	0.175	0.424	0.375	0.371	0.126	13,191
1973	0.178	0.174	0.713	0.672	0.523	0.640	0.234	0.281	0.641	0.600	0.403	0.238	13,942
1974	0.144	0.196	0.200	3.012	2.574	0.602	0.124	0.632	0.386	0.493	0.337	0.212	23,448
1975	0.234	0.261	0.281	2.331	1.327	1.417	0.493	0.221	0.280	0.298	0.245	0.154	19,765
1976	0.173	0.199	0.570	2.029	0.443	0.905	0.231	0.112	0.120	0.154	0.126	0.108	13,518
1977	0.100	0.113	0.424	0.872	0.865	0.293	0.271	0.162	0.748	0.526	0.575	0.299	13,811
1978	0.222	0.192	0.198	2.775	0.751	0.229	0.277	0.228	0.308	0.278	0.221	0.151	15,261
1979	0.141	0.168	0.267	3.351	1.493	0.635	0.273	0.181	0.173	0.179	0.273	0.182	19,162
1980	0.169	0.160	0.163	1.217	0.296	0.147	0.150	0.192	0.369	0.435	0.243	0.155	9,687
1981	0.123	0.154	0.189	0.446	0.812	1.168	0.243	0.247	1.390	1.244	0.553	0.328	18,126
1982	0.156	0.054	0.449	2.855	1.093	0.547	0.508	0.316	0.289	1.428	0.536	0.710	23,570
1983	0.174	0.093	1.012	1.516	1.460	0.819	0.216	0.256	0.235	0.363	0.437	0.559	18,843
1984	0.373	0.313	0.463	1.202	0.576	1.643	0.355	0.147	0.112	0.532	0.339	0.793	17,979
1985	0.277	0.104	0.567	0.829	1.072	1.417	0.343	0.720	0.941	0.551	0.368	0.203	19,468
1986	0.196	0.197	1.393	2.812	2.318	0.253	0.509	0.221	0.313	0.363	0.266	0.206	23,864
1987	0.205	0.230	0.803	2.463	0.978	0.363	0.232	0.134	0.132	0.225	0.218	0.199	16,223
1988	0.128	0.115	0.141	0.711	0.454	0.291	0.585	0.141	0.146	0.184	0.221	0.164	8,641
1989	0.154	0.170	0.189	1.763	1.014	1.295	1.137	0.240	0.149	0.168	0.185	0.132	17,324
1990	0.147	0.126	0.574	0.989	0.651	0.831	0.258	0.089	0.093	0.140	0.162	0.114	10,967
1991	0.099	0.136	0.251	0.729	1.048	1.848	2.097	0.103	0.449	0.526	0.538	0.291	21,394
1992	0.314	0.263	0.768	3.263	0.924	0.363	0.464	0.268	0.955	0.341	0.374	0.287	22,494
1993	0.218	0.221	0.934	1.535	0.907	1.809	1.914	2.199	0.544	0.442	0.427	0.301	30,239
1994	0.174	0.161	0.545	1.026	0.775	0.502	0.602	0.730	1.118	0.706	1.511	0.309	21,450
1995	0.228	0.197	1.928	0.860	1.281	0.406	0.472	0.187	0.180	0.318	0.313	0.172	17,317
1996	0.246	0.165	0.188	2.967	3.722	0.864	0.382	0.194	0.281	0.760	0.653	0.340	28,368

Table A6: Monthly Mean Discharge at Main Drain near Dominion City, MB

Monthly Mean Discharge (cms)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1961			0.14	0.44		0.00	0.00	0.00	0.00	0.00		
1962				3.29	0.75	0.10	0.13	0.01	0.00	0.00		
1963				0.03	0.01	1.79	0.25	0.03	0.00	0.00		
1964				2.17	1.05	4.32	0.00	0.00	0.25	0.01		
1965				5.34	0.27	0.00	0.03	0.01	1.09	0.88		
1966			0.48	6.11	1.70	0.18	0.84	0.01	0.11	0.00		
1967			1.47	9.44	3.46	0.00	0.00	0.00	0.00	0.00		
1968			1.92	0.78	0.01	0.25	2.15	1.36	3.31	0.17		
1969				3.22	0.28	0.21	0.01	0.00	0.00	0.03		
1970				3.91	1.73	1.02	0.01	0.00	0.06	0.00		
1971				3.07	0.03	0.03	0.00	0.00	0.00	0.00		
1972			0.50	1.31	0.00	0.00	0.00	0.00	0.00	0.00		
1973			0.37			0.15	0.00	0.00	0.14	0.37		
1974				6.65	2.76	0.10	0.00	0.00	0.00	0.00		
1975				1.23	0.17	0.69	0.13	0.00	0.00	0.00		
1976				2.08	0.00	0.05	0.00	0.00	0.00	0.00		
1977			0.03	0.27	0.00	0.00	0.00	0.00	0.00	0.00		
1978			0.74	1.90	0.00	0.00	0.00	0.00	0.01	0.00		
1979				7.96	0.37	0.27	0.01	0.00	0.00	0.00		
1980			0.00	1.00		0.00	0.00	0.00	0.00	0.00		
1981			0.33	0.04	0.01	0.00	0.00	0.00	0.00	0.00		
1982			0.17	1.29	0.01	0.03	0.29	0.03	0.00	0.13		
1983			1.16	2.07	0.10	0.01	0.00	0.00	0.00	0.00		
1984			0.15	0.18	0.00	0.11	0.00	0.00	0.00	0.00		
1985			1.04	0.18	0.04	0.00	0.00	0.11	0.03	0.12		
1986			2.06	1.63	1.21	0.00	0.01	0.00	0.00	0.00		
1987			0.41	3.16		0.00	0.00	0.00	0.00	0.00		
1988			0.01	0.23		0.00	0.00	0.00	0.00	0.00		
1989				1.73	0.01	0.00	0.00	0.02	0.00	0.00		
1990			0.84	1.54	0.01	0.03	0.25	0.00	0.00	0.00		
1991			0.01	0.18	0.07	0.07	0.88	0.00	0.10	0.39		
1992			1.10	5.45	0.09	0.26	0.09	0.00	0.00	0.00		
1993			0.55	0.72	0.01	0.00	0.33	1.51	0.05	0.00		
1994			0.47	0.18	0.00	0.00	0.00	0.00	0.00	0.00		
1995			4.89	0.50	0.07	0.00	0.00	0.00	0.00	0.00		
1996				8.55	0.46	0.00	0.00	0.00	0.00	0.00		
2000			0.20		0.01	0.21	0.00	0.00	0.00	0.00		
2001			0.00	6.92	3.90	1.41	0.00	0.00	0.00	0.00		
2002			0.02	0.18	0.23	7.63	0.00	0.00	0.00	0.00		
2003			0.90	0.06	0.16	0.15	0.00	0.00	0.00	0.00		
2004			1.37	11.02	0.89	5.71	0.00	0.00	0.00	0.00		
2005			0.05	6.50	0.61	14.79	14.12	0.00	0.00	0.00		
2006			0.00	8.42	0.08	0.00	0.00	0.00	0.00	0.00		
2007			1.38	3.18	1.24	1.37	0.00	0.00	0.00	0.00		
2008			0.00	1.64	0.01	0.01	0.00	0.00	0.00	0.00		
2009			0.04	4.09	3.32	1.85	0.00	0.00	0.00	0.00		
2010			1.54	0.47	2.09	5.02	0.11	0.04	0.20	0.11		
2011			0.06	10.08	0.20	0.29	0.07	0.00	0.00	0.00		
2012			0.23			0.03	0.00	0.00	0.00	0.00		
2013				2.41	1.46	0.66	0.02	0.00	0.00	0.00		
2014				3.25	0.46	0.57	1.36	0.03	0.00	0.00		

Note: Annual Discharge Volume has not been calculated because of missing data.

Table A7: Mean Monthly Discharges on the Roseau River (period 1961 to 2014)

	Roseau River near Caribou	Roseau River at Gardenton	Roseau River near Dominion City
	Mean Monthly Discharge (cms)	Mean Monthly Discharge (cms)	Mean Monthly Discharge (cms)
January	0.80	0.52	0.71
February	0.66	0.36	0.48
March	4.19	3.79	4.31
April	28.9	31.5	36.5
May	34.8	37.4	41.3
June	26.7	28.8	32.3
July	16.9	15.7	20.5
August	6.61	5.82	7.60
September	5.95	5.96	6.73
October	6.21	5.91	7.11
November	7.42	5.45	5.02
December	2.23	1.46	1.92
Average Annual Mean Monthly Discharge (cms)	11.8	11.9	13.7
Average Annual Discharge Volume (dam^3)	372,000	375,000	434,000

Table A8: Mean Monthly Discharges on the Roseau River tributaries

	Sprague Creek near Sprague Creek	Pine Creek Diversion near Piney	Main Drain near Dominion City
	Mean Monthly Discharge (cms)	Mean Monthly Discharge (cms)	Mean Monthly Discharge (cms)
January	0.09	0.18	-
February	0.07	0.16	-
March	0.48	0.58	0.68
April	6.27	2.04	3.04
May	6.08	1.47	0.65
June	5.24	1.03	0.97
July	1.66	0.57	0.41
August	0.93	0.35	0.06
September	1.02	0.44	0.11
October	1.40	0.53	0.04
November	1.32	0.42	-
December	0.21	0.26	-
Average Annual Mean Monthly Discharge (cms)	2.06	0.66	0.75
Average Annual Discharge Volume (dam^3)	65,100	20,900	14,400