International Souris River Study Board

A Review of Meteorologic, Hydrologic, and Engineering Studies Completed in the Souris River Basin from 2011 through 2017

International Souris River Study Board Task DW1

July 8, 2020

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
acre-foot (acre-ft)	1,233	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
hectare (ha)	2.471	acre
square kilometer (km^2)	247.1	acre
square hectometer (hm^2)	0.003861	section (640 acres or 1 square mile)
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Volume	
cubic decameter (dm^3)	0.81070	acre-feet
cubic meter (m^3)	0.0008107	acre-foot (acre-ft)
	Flow rate	
cubic meter per second (m^3/s)	70.07	acre-foot per day (acre-ft/d)
meter per second (m/s)	3.281	foot per second (ft/s)
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as °F = (1.8 × °C) + 32.

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as °C = (°F – 32) / 1.8.

Abbreviations

EPA	U.S. Environmental Protection Agency
FIS	Flood Insurance Study
IJC	International Joint Commission
IFD	Inflow Design Flood
ISRB	International Souris River Board
ISRSB	International Souris River Study Board
NDSWC	North Dakota State Water Commission
NWR	National Wildlife Refuge
PAG	Public Advisory Group
PFRA	Prairie Farm Rehabilitation Administration-now Agriculture and Agri-Food Canada
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
RAAG	Resource Agency Advisory Group
SRJWRB	Souris River Joint Water Resources Board
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
WSA	Saskatchewan Water Security Agency

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By International Souris River Study Board

Introduction

The sharing and management of water across the International Boundary between Canada and the United States, including the Souris River Basin (fig. 1), has its origin in the Boundary Waters Treaty of 1909 between the two countries. The Treaty also established an International Joint Commission (IJC) to have jurisdiction over the use, obstruction, or diversion of the waters. Over the decades various binational boards have been established by the IJC to address the management of transboundary waters of the Souris River Basin and its major tributaries. What is referred to as the Souris River in Canada is officially named the Mouse River in North Dakota. However, for convenience the title Souris River will be used throughout this report.

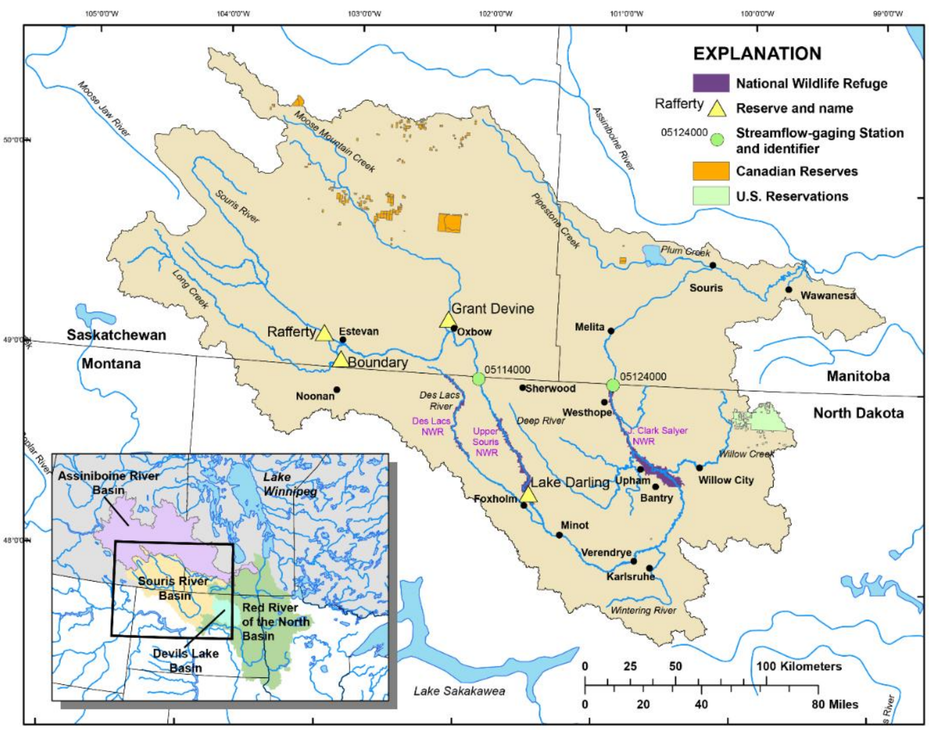


Figure 1. Souris River Basin showing locations of major reservoirs, and National Wildlife Refuges (Modified from Kolars and others, 2016).

In May 1959, the IJC was directed by the U.S. and Canadian Governments that interim measures for cross-border sharing of the waters recommended by the IJC in a report dated 1940 were accepted by Governments. The IJC subsequently issued a directive which: created the International Souris River Board of Control, specified flow apportionment between the states and provinces, and empowered the Board of Control to advise on flow apportionment in the case of severe droughts.

An Agreement between the Government of Canada and the United States for Water Supply and Flood Control in the Souris River Basin was signed in October 1989 (http://ijc.org/files/tinymce/uploaded/documents/reportsAndPublications_2/1989-10-26SourisRiverFloodControlAgreement.pdf). The International Souris River Board (ISRB) is responsible for ensuring compliance for flow apportionment and low-flow measures. Also, the ISRB ensures the terms of the 1989 International Agreement for Water Supply and Flood Control in the Souris River Basin (hereafter referred to as the 1989 International Agreement) are met, including the terms of Annexes A and B of the Agreement and subsequent Amendments to Annexes A and B in 2000, are met.

Unprecedented flooding in the Souris River Basin in 2011 focused attention on review of the Operating Plan contained in Annex A to the 1989 International Agreement. Interests in the basin, particularly in North Dakota, asked that additional flood protection measures be evaluated, above and beyond what is currently provided under the 1989 International Agreement, and that the Operating Plan contained in Annex A of the Agreement be reviewed. In addition, the 1989 International Agreement requires that the Operating Plan be reviewed periodically to maximize the provision of flood control and water supply benefits that can be provided consistent with the terms of the Agreement. In light of these facts, the IJC's ISRB established the 2012 Souris River Basin Task Force in February 2012 to conduct a review of the Annex A Operating Plan contained in Annex A for presentation to the Governments of Canada and the United States.

The first requirement of the Task Force Terms of Reference was to develop a Plan of Study (POS) in 2013 (Souris River Task Force, 2013) to conduct the review. The 2013 POS (Souris River Task Force, 2013) describes the detailed studies that are needed to review the existing Annex A Operating Plan for the reservoirs comprising the Souris Basin Project described in the 1989 Agreement in Saskatchewan and North Dakota and to evaluate alternatives to maximize flood control and water supply benefits. The ISRB submitted the 2013 POS to the IJC in April 2013. The IJC submitted to governments a "Plan of Study: For the Review of the Operating Plan Contained in Annex A of the 1989 International Agreement Between the Government of Canada and the Government of the United States of America" on June 7, 2013.

On July 5, 2017, the governments of Canada and the United States issued a reference for the IJC to undertake the Plan of Study (Canadian Reference Letter - http://ijc.org/files/tinymce/uploaded/documents/Canadian%20LTR%20GAC%20sgnd%20to%20IJC%20-Souris%20River.pdf and United States Reference Letter - http://ijc.org/files/tinymce/uploaded/RNLRCSB/2017%20Souris%20River%20Flooding%20Reference.pdf). In accordance with Article IX of the Boundary Waters Treaty of 1909, the governments of Canada and the United States request that the IJC examine and report on flooding and water supply in the Souris River Basin, and coordinate the completion of the full scope of the 2013 "Plan of Study: For Review of the Operating Plan Contained in Annex A of the 1989 International Agreement Between the Government of Canada and the Government of the United States of America."

On September 5, 2017, the IJC issued a directive to establish and direct the International Souris River Study Board (Study Board) to examine and report to the IJC on matters raised by the Governments of Canada and the United States in the reference dated July 5, 2017 directing the Study Board to aid the IJC in fulfilling the terms of the reference. Under item (1) of the Directive, the IJC directed the Study Board to develop a Work Plan by November 5, 2017 (http://ijc.org/files/tinymce/uploaded/SRSB/2017_Directive.pdf).

The purpose of this Work Plan is to describe all studies needed to assist the IJC in fulfilling the terms of the July 5, 2017 reference.

Each element of the Governments joint reference is addressed in the Work Plan by completing a number of tasks that are grouped under four broad activities:

A. a. Operating Rules Review
B. b. Data Collection and Management
C. c. Hydrology and Hydraulics
D. d. Plan Formulation

One of the tasks under item (b) involves summarizing the available studies, datasets, and modelling setups, that pertain to and are related to the 2013 POS optimal scope option (Souris River Task Force, 2013). In addition, many hydrologic and hydraulic studies completed by Federal, State, Provincial, local agencies and consulting firms since 2013 can be used in development and completion of the tasks outlined in the Work Plan. Thus, the purpose of this report is to summarize all the studies, datasets, and modelling setups completed since 2013 that may be used for completion of some of the tasks.

NOTE: U.S. customary units and the International System of units are used throughout the report. Units are included in the form published in the original report. A conversion table to convert from U.S customary units to the International System of Units or from the International System of Units to the U.S. customary units is included in the front of this report.

Meteorologic Studies

After most major floods in North America, various Federal, State, and Provincial Government agencies are called on to document and describe the meteorological conditions that led to the flooding. In addition, agencies usually complete flood reports to document the flood hydrology including the extent and magnitude of the flood. The meteorologic and hydrologic studies are used as the basis for any structural and non-structural flood protection plans that may be completed as a result of the flood.

Custom Climate Services conducted a study to document and analyze the 2011 spring precipitation over southeast Saskatchewan and to outline the historic significance of the precipitation. A report “Anomalously High Rainfall over Southeast Saskatchewan-2011” by Ron Hopkinson (2011) documents the work completed by Custom Climate Services. The major conclusions from the study outlined in the Executive Summary are:

1. Much of southeastern Saskatchewan received 150 % to over 200 % of normal precipitation in the period April to June 2011.
2. The highest rainfall during the period April to June was along the main stem of the Souris River from Yellow Grass to Estevan.
3. There was a strong negative geopotential height anomaly over northwest USA centered over Idaho. The impact was to depress the jet stream southward and for there to be a

southerly wind vector anomaly component in the upper troposphere facilitating large scale storm movement and moisture advection from the south.

4. There were five events of 20 mm or greater in just over a month before June 17. The Palmer Drought Index for the end of May indicated virtually saturated soil moisture conditions.
5. The rain storm mainly on June 17, 2011 was centered over the headwaters of the Souris Basin in the Yellow Grass area with a one-day rainfall total of 87.6 mm which has a return period of about 50 years.
6. The same storm on June 17 produced 90.7 mm at Assiniboia and this represents a 100-year event relative to the rain30 analysis of daily rainfall. The 12-hour amount of 79.7 mm also represents close to a 100-year event. Shorter duration amounts had return periods of 25 years or less.
7. April to June total precipitation at both Yellow Grass and Weyburn was the highest during the periods of record for 90 and 59 years respectively. For Yellow Grass, the total precipitation of 385 mm appears to exceed the 100-year event while Weyburn's total of 347.9 mm has a return period somewhat in excess of 60 years.
8. It is unlikely that the June 17 storm and subsequent rainfalls over the basin in the few days following would have produced significant runoff if the soil moisture conditions had been normal for the time of year. Another contributing factor was that the maximum rainfall occurred over the main channel of the Souris River near its headwaters.

A report titled "2011 Post-Flood Report for the Souris River Basin" was prepared by the U.S. Army Corps of Engineers (USACE) (2012) documenting the flood operation as specified in the "1989 International Agreement between the Government of Canada and the Government of the United States for Water Supply and Flood Control in the Souris River Basin." This report fulfills a requirement in the Agreement that the USACE prepare a post-flood report in any year in which flood operations are declared under the Agreement. In addition to discussion of the hydrology and hydraulics related to the reservoir operations, the post-flood report includes discussion of the flood meteorology leading up to and including the flood. The report provides a good description of the antecedent soil conditions in the fall of 2010 and in the winter of 2010-11. Snow survey data collected during the late winter and spring of 2011 is provided. The magnitude and geographic extent of individual rain events in May and June are described.

A discussion of the general weather conditions that contributed to the 2011 flooding in the Souris River Basin is provided in a report by Vining and others (2013). The report indicates excessive precipitation produced severe flooding in the Mississippi River and Red River of the North Basins during spring and summer 2011 and documents the 2011 flooding in the Central United States, describes the weather conditions and precipitation in the Mississippi River and the Red River of the North Basins during climatological winter of 2010–11 (December 2010–February 2011), climatological spring of 2011 (March–May 2011), and early climatological summer of 2011 (June–July 2011). The report can be obtained online at (https://pubs.usgs.gov/pp/1798b/).

Kolars and others (2016) used a four-stage process to develop stochastic natural streamflows for selected stream gage locations in the Souris River Basin. In the first stage of the work by Kolars and others (2016), long-term climate variability was analyzed using tree-ring chronologies to hind cast precipitation to the early 1700's and compare recent wet and dry conditions to earlier extreme conditions. The extended precipitation record was consistent with findings from Devils Lake and the Red River Basin. Much of the long-term climate analyses summarized in the report by Kolars and others (2016) is described in detail in a report by Ryberg and others (2016).

A Souris River Basin Hydrometeorological Data Network Improvement workshop was held in February 2013 followed by a webinar in December 2013. The purpose of the workshop was to assess the meteorologic and hydrologic data collection networks throughout the Souris River Basin. The networks were evaluated on the ability to support existing and future needs related to river forecasting, reservoir regulation, and emergency preparedness. Workshop participants also evaluated the dissemination of meteorologic and hydrologic information to the end users. Potential locations for additional streamflow gauges and precipitation stations were prioritized, and data dissemination issues were prioritized (USACE, 2013a). A list of goals to improve all aspects of flood warning and response was prioritized during the webinar (USACE, 2013a).

Several of the meteorologic studies undertaken after the 2011 flood on the Souris River provide information that can be used for some of the data collection and management, hydrology and hydraulics, and plan formulation tasks. As an example, analysis of maximum precipitation events on the Canadian prairies (Hopkinson, 2011) could be used to verify future realizations of precipitation and temperature in the stochastic model outlined as Task HH2 in the Work Plan (2017). The maximum precipitation could also be used to generate and study larger runoff events using the MESH model.

Hydrologic Studies

Rafferty and Grant Devine (formerly called Alameda) projects are located in the Souris River Basin in southeastern Saskatchewan (fig. 1). Rafferty Dam is located on the mainstem of the Souris River 7 km northwest of Estevan, Sask. The dam was competed in 1992, and the reservoir has a capacity of 439,600 dam^3 (356,400 ac-ft) at its full supply level (FSL, elevation 550.5 m or 1806.1 ft). Grant Devine Dam (formerly called Alameda Dam) is located on Moose Mountain Creek 6 km northwest of Oxbow, Sask. Grant Devine Dam was completed in 1995 and Grant Devine Lake has a capacity of 105,500 dam^3 (85,530 ac-ft) at its FSL (562 m or 1843.8 ft).

Record streamflow peaks and volumes occurred at many streamgaging locations throughout the Souris River Basin in the spring and early summer of 2011 including inflows to Rafferty Reservoir. Record floods in 2011 prompted the Saskatchewan Water Security Agency (WSA) to commission a flood-frequency and magnitude study for streamflows and Probable Maximum Flood (PMF) study for streamflow into and out of Rafferty Reservoir and Grant Devine Lake. Hatch Ltd. (Hatch) was retained to develop synthetic hydrographs for various times of the year that represent annual return periods of 10, 2, 1, and 0.1 percent. The methods and techniques used to develop the hydrographs are described in a report by Hatch (2014a). Frequency analysis plots are provided for 1, 3, 7, 14, and 30-day inflow volumes into Rafferty Reservoir and Grant Devine Lake for four seasons (March 1 through May 31, June 1-31, July 1 through August 31, and September 1 through October 31). Seasonal inflow hydrographs are provided for return periods of 10, 2, 1, 0.5, 0.2, and 0.1 percent for Rafferty Reservoir and Grant Devine Lake in the Hatch report (2014a).

Review of the Operating Plan contained in Annex A, and a study of alternatives to maximize flood control and water supply require a hydrologic frame of reference. The USACE (2013b) conducted a study to reconstruct the hydrology of the Souris River to provide streamflow at gauges throughout the Souris River Basin that can be used as the initial frame of reference for studying operation plan alternatives. Various statistical, hydrologic, and hydraulic routing techniques were used to develop daily streamflow estimates, for the period of record 1946 to 2011, at key locations in the Souris River Basin. Three streamflow data sets were produced (USACE, 2013b):

1. Natural streamflows are representative of the streamflow conditions in the Souris River Basin without the Souris River project in place. The effects of Rafferty, Boundary, Alameda, and Lake Darling Reservoirs were removed from the streamflow record.
2. In Situ streamflows are representative of existing conditions in the Basin throughout the period of record.
3. Regulated streamflows are representative of conditions with Rafferty, Boundary, Alameda, and Lake Darling Reservoirs in place for the period of record.

The USACE (2013b) report identified and recommended many future studies to develop better streamflow data sets, and many of the recommendations may be pertinent to hydrologic and hydraulic tasks outlined in the Work Plan (International Souris River Study Board, 2017).

The specific recommendations for future studies are:

1. Hydrologic routing parameters downstream of Sherwood Crossing should be improved utilizing a hydraulic model. This is particularly true of the river reaches between Verendrye, ND and Wawanesa, MB where simplified lag or Muskingum routing was adopted. At minimum, river cross section data should be collected so that this portion of the river can be modeled using physically based Muskingum Cunge routing.
2. The Souris River Project model from the Canadian Reservoirs to Minot, ND should be expanded to include the Des Lacs National Wildlife Refuge (NWR). Modeling the Des Lacs NWR structures would enable modelers to expand the adopted period of record back to 1936.
3. The J. Clark Salyer National Wildlife Structures could be modeled in greater detail if more information was available related to their outlet works and the historic tailwater elevations for each of the refuge structures. Historic elevation data could be utilized to better calibrate the model. Operators could provide a more detailed explanation of how they typically operate the refuge structures.
4. If the effects of the Des Lacs Wildlife Structures and the J. Clark Salyer National Wildlife Structures could be modeled with a greater degree of certainty, true natural flow records could be generated throughout the Souris River Basin. Non-parametric and parametric statistical tests could then be utilized to gauge the homogeneity of flow records throughout the entire Souris Basin.
5. If a more consistent operating plan existed for the Souris River Project (Rafferty, Grant Devine, Boundary and Lake Darling) the HEC-ResSim model could be improved. Because there is no definitive operating plan, the HEC-ResSim model could be further improved by continued coordination with operators in order to develop a model that more closely reflects what is considered typical operation
6. Boundary Reservoir could be modeled in greater detail such that it accurately portrays evaporation losses due to power plant cooling etc.
7. The physical capacity curve for the Boundary to Rafferty Diversion needs to be recomputed because it currently conflicts with the observed data. More definitive operating rules for the diversion would also improve the HEC-ResSim model.

8. The guide curve is difficult to define for Rafferty, Grant Devine, and Lake Darling Reservoirs because the target drawdown elevation varies from year to year and is based on a forecasted parameter that cannot be readily re-generated retrospectively. Further work could be done with operators and model calibration to define a typical maximum drawdown elevation more reflective of what has been done historically or what will be done in response to future flood events.
9. A lot of the tributary flow and local flow in the Souris River Basin was approximated utilizing statistical techniques. These approximations could be verified by developing rainfall-runoff models for historic events that occurred when few gages were active.
10. An automated process could be developed to identify statistically similar long-term gauges to the short-term gauge sites in the Souris River Basin.
11. From comparing modeled and observed flows throughout the basin, it is apparent that during the 2011 event, modeled flows underestimate the magnitude of the 2011 peak flow. A contributing drainage area analysis should be carried out utilizing GIS tools in order to determine the true contributing drainage areas in the Souris River Basin and to investigate whether there is primary and secondary contributing drainage area in the basin. Primary contributing drainage area contributes during the majority of events, while secondary contributing drainage area only contributes during extreme events like the 2011 event.

The WSA commissioned Hatch to conduct a PMF study for streamflow into and out of Rafferty Reservoir and Grant Devine Lake. The purpose of the Hatch study (2014b) was to provide an updated estimate of the PMF. Tasks completed by Hatch (2014b) include:

1. complete a review of available data and previous studies,
2. determine the appropriated Probable Maximum Precipitation (PMP),
3. develop and calibrate a deterministic hydrological model of each watershed,
4. apply the numerical model to investigate various flood scenarios, and
5. recommend a final PMF hydrograph for each project.

The tasks completed by Hatch (2014b) involved a review of the key meteorological variables contributing to flood development at each site, the development and calibration of deterministic hydrological models to synthesize basin runoff, and the use of these models to investigate various PMF scenarios.

Hatch (2014b) concluded the following:

1. The critical summer storm for these two projects has been selected as the event, which occurred in early June of 2002 in South-Eastern Manitoba/North-Western Ontario. This storm provided the greatest maximized depth of precipitation for each basin and is considered to be transposable to the project area.
2. The critical spring storm for these two projects has been selected as the event, which occurred in early May of 1927 in South-Western Manitoba/North Dakota. This storm provided the greatest maximized depth of precipitation for the spring period for each basin and is considered to be transposable to the project area.
3. Various storm positions were tested in the search for a critical basin response for both summer and spring events, and it was found that a storm centered over the mid and lower sections of each basin will result in a maximized overall response.

4. The PMF studies considered both spring and summer PMF scenarios. Spring scenarios involved the accelerated melt of a 1:100-year snowpack, followed by application of the spring PMP event, or the melt of a Probable Maximum Snowpack in combination with a 1:100-year spring rainfall. Summer scenarios involved the application of a 1:10 year pre-storm event, followed by application of the summer PMP shortly thereafter.
5. It was found that for the Rafferty project, the critical PMF event would be generated by a summer PMP event. For the Grant Devine project, both the spring and summer PMF scenarios generated similar peak inflows, but the larger flow volume associated with the spring scenario resulted in the largest reservoir surcharge at the Grant Devine Reservoir. This was caused in part by the spring operating restrictions which limit the initial magnitude of flow releases.
6. The final PMF inflow, outflow, and reservoir elevation hydrographs for the Rafferty project indicate that, for this critical event, the maximum peak inflow to the Rafferty Reservoir would be 1380 m^3/s, and the corresponding maximum outflow would be approximately 710 m^3/s. Given the operating assumptions adopted in this study, the peak level reached on the Rafferty reservoir would be El. 555.35 m which is about 0.35 m below the crest of the main dam.
7. The final PMF inflow, outflow, and reservoir elevation hydrographs for the Grant Devine project indicate that, for the critical summer event, the maximum peak inflow to the Grant Devine Reservoir would be 1760 m^3/s, and the corresponding maximum outflow would be approximately 1310 m^3/s. The peak level reached on the Grant Devine reservoir for the summer event would be El. 567.01 m which is 1.5 m below the crest of the main dam. For the spring event, the maximum inflow is predicted to be 1640 m^3/s, and the corresponding peak outflow would be 1480 m^3/s. The peak level reached on the Grant Devine reservoir for the spring event would be El. 567.52 m which is approximately 1 m below the crest of the main dam.

The original PMF estimates for Rafferty Reservoir and Grant Devine Lake were made in a 1980's study under the direction of the Souris River Basin Development Authority. This study indicated the peak PMF inflow to Rafferty Dam would be 800 m^3/s and the peak PMF inflow to Grant Devine Lake would be 1,200 m^3/s. The more recent study by Hatch, (2014b) indicates that PMF inflows to both Rafferty Reservoir and Grant Devine are substantially greater than the earlier study, and the PMF inflow would be caused by a combined rainfall/snowmelt scenario.

Based on the new PMF inflows, more refined topographic data, and water-surface elevation and streamflow information from the 2011 flood, the WSA commissioned Hatch to update the Inflow Design Flood (IDF) for the Rafferty and Grant Devine projects (Hatch, 2016). The purpose of the study was to provide all the information necessary to select an IDF for the Rafferty and Grant Devine projects. An updated HEC-RAS dam breach model was developed and calibrated using the 2011 flood for the Souris River and Moose Mountain Creek.

Four different floods were modeled:

1. The PMF,
2. a flood that is 2/3 between the 0.1 percent flood and the PMF,
3. a flood that is 1/3 between the 0.1 percent flood and the PMF, and
4. the 0.1 percent flood.

The incremental impacts of a dam failure were assessed for each scenario including:

1. population at risk,

2. incremental loss of life, and
3. incremental costs associated with losses such as third-party losses, water supply etc.

The IDF study (Hatch, 2016) concluded that the selected IDF would not be able to pass through the Rafferty Reservoir without exceeding the maximum allowable flood level. Three options were presented (Hatch, 2016) to allow passage of the IDF. First, the spillway capacity could be increased at a cost of 50-70 million dollars. Second, Rafferty Reservoir could be surcharged above the maximum allowable elevation depending on whether or not the dam can safely handle the elevation. Third, Rafferty Dam operation could be modified to release spring inflows earlier.

Hatch (2016) concluded that the IDF could be passed through Grant Devine Reservoir at a maximum water surface elevation less than the maximum allowable flood level.

The WSA retained XCG Consultants Ltd. (XCG) in 2013 to assist in a review of two reports by Hatch (2014a and 2014b). The Hatch reports (2014a and 2014b) are the revised reports based on the review by XCG. The report "Rafferty and Alameda Reservoirs Probable Maximum Flood" by Hatch (2014a) was reviewed by XCG (2013) for compliance with:

1. World Meteorological Organization (WMO, 2009) manual on estimating PMP;
2. Dam Safety Guidelines (CDA, 2007); and,
3. Alberta Transportation Extreme Flood Guidelines (Alberta Transportation, 2004)

Another potentially relevant study for the hydrologic and hydraulic POS tasks is a PMF study for Boundary Reservoir completed by KGS Group Consulting Engineers (2006). The PMF study consisted of estimating the PMP and PMF runoff hydrographs to assess the ability of Boundary Reservoir to handle a PMF. The spring PMF of 1,329 m^3/s produced the largest inflow to the Reservoir as the summer PMF was 1,200 m^3/s. For comparison, the 2011 maximum peak streamflow at Long Creek near Noonan was 306 m^3 /s or about 23 percent of the PMF.

Two types of time series can be used to test reservoir operating plans (Souris River Basin Task Force, 2013). First, historic streamflow time series can be reconstructed by developing statistical relationships between the longest streamflow records in the Souris Basin with the shorter record locations. Streamflow reconstruction has been completed for many stream gauge locations in the Souris River Basin for the period 1946-2011 from Rafferty, Boundary, and Grant Devine Reservoirs to Wawanesa, Manitoba (USACE, 2013b). The streamflow data were reconstructed to provide a frame of reference for operational review of various water-supply sequences (USACE, 2013b). The streamflow information also can be used for comparing to statistically generated flow sequences. The USACE report (2013b) produced three sets of streamflow sequences:

1. natural flows that represent the flow without the Souris River Project in place;
2. In Situ flows that represent existing conditions throughout the period of record; and,
3. regulated flows that represent conditions with Rafferty, Boundary, Grant Devine, and Lake Darling in place.

The second type of streamflow time series uses stochastic methods developed by Kolars and others (2016). The purpose of the report (Kolars, 2016) is to describe a stochastic natural streamflow model and present the results of model simulations that can be used to evaluate wet and dry periods in the Souris River Basin. The streamflow model was developed in four stages:

1. analysis of long-term climate variability in the Souris River Basin and surrounding region,
2. development of stochastic climate model for simulating climatic inputs,

3. development of a water-balance model for simulating natural (unregulated) monthly streamflow in response to climatic inputs, and
4. development of a natural (unregulated) streamflow routing model for simulating streamflow at a three-per-month (approximately 10-day) time step.

In the second stage, Kolars and others (2016) developed a stochastic climate simulation model of precipitation, temperature, and potential evapotranspiration using recorded meteorological data and extended precipitation records based on the tree-ring analysis.

In the third stage, a water-balance model was developed for simulating natural monthly streamflow based on precipitation, temperature, and potential evapotranspiration at selected gaging stations. Then in stage four, the stochastic climate simulation model was combined with the water-balance model to simulate potential future sequences of 10-day mean streamflow.

The 2011 flood in the Assiniboine and Souris River Basins was the largest flood in more than 100 years, and the flood exposed several weaknesses in the existing flood-control system. The Province of Manitoba retained KGS to conduct engineering studies on a number of measures to mitigate floods with a magnitude similar to 2011. The Province of Manitoba set the flood protect standard to be a 0.5% flood or the largest flood on record if greater than the 0.5% flood (KGS, 2016a and 2016b). KGS (2016a and 2016b) concluded that large dams on the Souris River in Manitoba should not be considered for flood protection due to the significant environmental impacts and high costs. In addition, KGS (2016b) indicates diking is the most feasible flood protection option for communities along the Souris River.

Stantec (2011) developed a hydrologic model for the Assiniboine River Basin to assist Manitoba with a climate change adaptation strategy. The Danish Hydraulic Institute MIKE-SHE (Danish Hydrologic Institute, 1998) model was used to assess the potential impacts of climate change on surface-water flow and soil moisture in the Assiniboine River Basin. The study compared modeled historic data (including historic meteorological inputs) to modeled climate change scenarios data including meteorological inputs generated by a regional climate model (Stantec, 2011). Streamflow collected at the Souris River at Wawanesa gaging station was one of five locations used to calibrate the model. Stantec report (2011) conclusions regarding the impacts of climate change on streamflow in the Assiniboine Basin are:

1. Low flows (one in ten-year or 10th percentile) are predicted to be about the same in future as they have been and should not impact Assiniboine River water available for water supply or wastewater assimilation. There is not enough information to predict potential changes to other more extreme low flow conditions.
2. Future extreme floods may be slightly higher than in the past. Future soil moisture is predicted to be lower in fall, which should generally balance spring flood risk caused by predicted higher winter and spring precipitation. However, if unusually wet fall conditions occur, giving high fall soil moisture, the risk of an extreme spring flood would be greater than today due to predicted higher winter and spring precipitation.
3. Historic year to year and decade to decade variation in flow has been large. Future flow variation is predicted to be large, but not much different than in the past. When 30-year future predicted flow scenarios (2011 to 2040, 2041 to 2070, 2071 to 2099) are compared to historical periods of record (1913 to 1944, 1945 to 1976, 1977 to 2009), it is not possible to separate natural variability from climate change.
4. An earlier spring melt due to generally higher temperatures in March and April is predicted to cause an earlier spring freshet. There is no indication that the melt rate will be any faster than current conditions.

5. When predicted future monthly flows are compared against historical monthly flows, there is variation, but it is both increasing and decreasing for most months. Average flows at Headingley show no discernible change in the future. Brandon 50th percentile flows also show no discernible change in the future

The report by Kolars and others (2016) describes the stochastic model simulation for precipitation, temperature, and potential evapotranspiration that will be used to drive the water-balance model. The water-balance model will be used in Task HH2 to generate streamflow traces. The probabilistic inflow estimates (Hatch, 2014a) can be used as check on the range of extreme values produced in the regional and reconstructed streamflow competed as part of Task HH1.

Post Flood Reports

A report titled "2011 Post-Flood Report for the Souris River Basin" was prepared by the USACE (2012), and the report documents the flood operation as specified in the 1989 International "Agreement between the Government of Canada and the Government of the United States for Water Supply and Flood Control in the Souris River Basin." The report documents difficulties operating the reservoirs while implementing the 1989 Agreement. Also, several recommendations have implications for several of the hydrology and hydraulic tasks outlined in the Work Plan. The USACE report (2012) recommendations are:

1. Implement Recommendation 2 from the 2001 Souris River Post Flood Report – "The "Designated Entities" should establish a continuing review process to discuss runoff forecasting techniques and deficiencies, striving to ensure availability of the best possible forecasts for operational decision-making."
2. Implement Recommendation 3 from the 2001 Souris River Post Flood Report – The "Designated Entities" should resolve outstanding issues and be prepared to resolve any new issues that might arise with respect to the interpretation of Annex A of the 1989 International Agreement. These issues include, but are not limited to, "Target Flow" and "Maximum Controlled Flow".
3. Implement Recommendation 4 from the 2001 Souris River Post Flood Report – "The "Designated Entities" should undertake a thorough review of the operating plan in Annex A and establish policies to ensure periodic future reviews consistent with the provisions of Article V of the 1989 International Agreement." Annex A needs to be updated and re-written, so that the wording is easy to understand, and its meaning is clear. In addition, a revised Annex A needs to incorporate provisions for control of flooding from summer rainfall events.
4. In developing an updated operating plan, testing should be done for the period of record. The use of a systematic reservoir regulation approach using index levels and reservoir balancing is certainly desirable for use in the Souris River basin.
5. In considering any changes to the Souris Basin Project flood control regulation plan contained in Annex A, it must be taken into account that Annex A is part of a treaty between the United States and Canada. As such, any changes to Annex A (or to the regulation of the flood control portion of the Souris Basin Project) would need to be developed through a bilateral effort of U.S. and Canadian regulators or "Designated Entities" as defined in the 1989 Agreement. Also, implementing any change to Annex A would require the approval of governments through the U.S. State Department and

Canadian Department of External Affairs. The ISRB and its expertise and the IJC would also need to be involved in this effort.

6. In any effort to revise Annex A, it must be recognized that the Souris Basin Project primarily provides water supply benefits to Canada, while flood control is the primary benefit to the United States. It must also be recognized that within the bounds of the regulation plan contained in Annex A, Canadian regulators have wide latitude to make flow release decisions from the Canadian dams to meet their objectives, but that do not always align with desired U.S. objectives. The regulation plan contained in Annex A relies heavily on the concept of "target flows" at Sherwood Crossing and Minot as a key feature of project regulation. Certainly, more rigorous regulation schemes using index levels and system reservoir level balancing would likely produce better results for overall project flood control regulation, but there would need to be binational agreement to this concept.
7. Update Souris River basin hydrology (Past, Current and Forecast). The overall hydrology used to develop "Annex A" is outdated and inadequate. A probabilistic approach using stochastic analysis looking at a wide range of areal distributions of runoff of possible snowmelt and storm rainfall runoff needs to be done. Statistical analysis of the updated hydrology should be undertaken to update frequency curves, duration curves, etc.
8. Investigate additional flood control storage possibilities within the basin at existing flood control reservoirs and on the Des Lacs River and Long Creek. The 2011 flood event in the Souris basin revealed the critical role that Long Creek and the Des Lacs River play in producing large flood events, particularly from summer rainfall events. The contributions of both of these watersheds to an extreme flood event in the Souris basin are underestimated in "Annex A". A basic HMS model has been developed for the Des Lacs basin, but needs additional work (USACE, 2012).
9. Install additional streamflow and rainfall gauging stations for the Souris River, Long Creek and Des Lacs River as dictated by modeling requirements and regulation needs.
10. Update Hydraulic Modeling for the Souris River basin. The majority of the Souris River hydraulic modeling to date was accomplished as part of the original design studies for the Souris River Flood Control Project including Lake Darling Dam and other United States Fish and Wildlife Service (USFWS) refuge improvements. Minimal updates to the models were made as part of Flood Insurance Study (FIS) updates for McHenry and Ward Counties in 2000, and 2002, respectively as well as during the 2011 flood event.

A report titled "2013 Post-Flood Report for the Souris River Basin" was prepared by the USACE (2014) documenting flood operation as specified in the 1989 International Agreement. The report provides a description of the dry antecedent precipitation in the fall of 2012, and much above normal winter precipitation in the Saskatchewan part of the Souris River Basin. Winter precipitation ranged from about 75 to 150 percent of normal in the United States and Manitoba parts of the Souris River Basin. Favorable melt conditions allowed substantial infiltration to occur and streamflow throughout much of the Basin was less than expected. As in other USACE flood reports, recommendations were made to improve all aspects of flood forecasting and warning. The recommendations made in the USACE report (2014) are:

1. Implement Recommendation 1 from the 2011 Souris River Post Flood Report (USACE, 2012) - "The "Designated Entities" should establish a continuing review process to discuss runoff forecasting techniques and deficiencies, striving to ensure availability of the best possible forecasts for operational decision-making."

2. Implement Recommendation 2 from the 2011 Souris River Post Flood Report (USACE, 2012) - The "Designated Entities" should resolve outstanding issues and be prepared to resolve any new issues that might arise with respect to the interpretation of Annex A of the 1989 International Agreement. These issues include, but are not limited to, "Target Flow" and "Maximum Controlled Flow".
3. Implement Recommendation 3 from the 20ll Souris River Post Flood Report (USACE, 2012) - "The "Designated Entities" should undertake a thorough review of the operating plan in Annex A and establish policies to ensure periodic future reviews consistent with the provisions of Article V of the 1989 International Agreement. Annex A needs to be updated and re-written, so that the wording is easy to understand, and its meaning is clear. In addition, a revised Annex A needs to incorporate provisions for control of flooding from summer rainfall events."
4. Implement Recommendation 4 from the 2011 Souris River Post Flood Report (USACE, 2012)- "In developing an updated operating plan, testing should be done for the period of record. The use of a systematic reservoir regulation approach using index levels and reservoir balancing is certainly desirable for use in the Souris River basin."
5. Implement Recommendation 5 from the 2011 Souris River Post Flood Report (USACE, 2012)- "In considering any changes to the Souris Basin Project flood control regulation plan contained in Annex A, it must be taken into account that Annex A is part of a treaty between the United States and Canada. As such, any changes to Annex A (or to the regulation of the flood control portion of the Souris Basin Project) would need to be developed through a bilateral effort of U.S. and Canadian regulators or "Designated Entities" as defined in the 1989 Agreement. Also, implementing any change to Annex A would require the approval of governments through the U.S. State Department and Canadian Department of External Affairs. The ISRB and its expertise and the IJC would also need to be involved in this effort."
6. Implement Recommendation 6 from the 2011 Souris River Post Flood Report (U SACE, 2012)- "In any effort to revise Annex A, it must be recognized that the Souris Basin Project primarily provides water supply benefits to Canada, while flood control is the primary benefit to the United States. It must also be recognized that within the bounds of the regulation plan contained in Annex A, that Canadian regulators have wide latitude to make flow release decisions from the Canadian dams to meet their objectives, but that do not always align with desired U.S. objectives. The regulation plan contained in Annex A relies heavily on the concept of "target flows" at Sherwood Crossing and Minot as a key feature of project regulation. Certainly, more rigorous regulation schemes using index levels and system reservoir level balancing would likely produce better results for overall project flood control regulation, but there would need to be binational agreement to this concept."
7. Implement Recommendation 7 from the 2011 Souris River Post Flood Report (USACE, 2012) - "Update Souris River basin hydrology (Past, Current and Forecast). The overall hydrology used to develop "Annex A" is outdated and inadequate. A probabilistic approach using stochastic analysis looking at a wide range of areal distributions of runoff of possible snowmelt and storm rainfall runoff needs to be done. Statistical analysis of the updated hydrology should be undertaken to update frequency curves, duration curves, etc."

8. Implement Recommendation 8 from the 2011 Souris River Post Flood Report (USACE, 2012)- "Investigate additional flood control storage possibilities within the basin at existing flood control reservoirs and on the Des Lacs River and Long Creek. The 2011 flood event in the Souris basin revealed the critical role that Long Creek and the Des Lacs River play in producing large flood events, particularly from summer rainfall events. The contributions of both of these watersheds to an extreme flood event in the Souris basin are underestimated in "Annex 4". A basic HMS model has been developed for the Des Lacs basin but needs additional work."
9. Continue to Implement Recommendation 9 from the 2011 Souris River Post Flood Report (USACE, 2012)- "Install additional streamflow and rainfall gauging stations for the Souris River, Long Creek and Des Lacs River as dictated by modeling requirements and regulation needs." A workshop was conducted by the USACE, in February of 2013.
10. Continue to Implement Recommendation 10 from the 2011 Souris River Post Flood Report (USACE, 2012)- "Update Hydraulic Modeling for the Souris River basin. The majority of the Souris River hydraulic modeling to date was accomplished as part of the original design studies for the Souris River Flood Control Project including Lake Darling Dam and other USFWS refuge improvements. Minimal updates to the models were made as part of FIS updates for McHenry and Ward Counties in 2000, and 2002, respectively as well as during the 2011 flood event." Since 2011 models have been added and updated, however, there is still not a model that contains all four flood control reservoirs, their basins and their downstream control points.

Recently, a report titled “2017 Post-Flood Report for the Souris River Basin” was prepared by the USACE (2018) documenting the flood operation as specified in the 1989 International Agreement. The report provides a good description of the antecedent precipitation in the fall of 2016 and winter of 2016-17. Flood forecasts issued by the WSA and the National Weather Service in March 2017 indicated a high likelihood of minor to moderate flooding throughout the Souris River Basin (USACE, 2018). Favorable melt conditions lead to significant infiltration of melt water. Thus, little flooding was reported in Saskatchewan and North Dakota. Flood runoff from Willow Creek and Deep River in the United States and local drainages in Manitoba produced a flood event with an annual return period between 2 to 5 percent. Two recommendations in the USACE report relevant to Work Plan tasks are:

1. The need to evaluate topsoil conditions while conducting manual snow surveys prior to the initial forecast, and
2. The need to collect and compile LiDAR data for the entire basin.

Engineering Studies

After the 2011 flood, the public and local officials requested the North Dakota State Water Commission (NDSWC) investigate solutions to reduce flood damages along the Souris River. The NDSWC contracted with a consulting team lead by Barr Engineering Company to develop a Souris River flood protection plan. The primary objective of the plan is to reduce the risk of flood damages for Souris River streamflow similar the flow recorded in 2011.

A Preliminary Engineering Report by Barr and others (2012) which outlined flood risk reduction measures for areas along the Souris River from Burlington to Velva was the first report completed. The Barr and others report (2012) provides a description of several flood risk reduction studies and planning that have been conducted since the 1930’s. The Barr and others report (2012) also describes the current (2012) flood risk reduction features such as reservoir storage, levees, channel modifications, and pump stations that are in place. In an effort to guide the project, Barr and others (2012) outlined a statement of purpose and need as:

1. Reduce the risk of property damage due to future flooding along North Dakota's Souris and Des Lacs rivers, or otherwise encourage the removal or relocation of at-risk structures from the 2011 floodplain.
2. Maintain operation of critical elements of the public transportation system during and after a flood event like the 2011 flood.
3. Implement risk mitigation strategies that would facilitate an increase in the peak release target out of the reservoirs to shorten the duration of overland flooding in agricultural areas throughout the Souris River Basin.
4. Assist in the development of policy objectives that reduce the risk of property damage to flooding within the 2011 floodplain.

The Barr and others report (2012) outlines various flood reduction alternatives ranging from a no-action approach to complete removal of damaged properties in the 2011 flooded area. A list of potential alternatives and consideration for implementation are listed in table 1.

Table 1. Potential Alternatives for Flood Risk Reduction for Mouse River Valley (From Barr and others, 2013a)

Alternative	Implementability Considerations
Upstream Flood Storage	
Construction of New or Additional Storage	
Canadian Dams	Unlikely - High cost, Large land requirement, Environmental Impacts
Souris River in US	Unlikely - High cost, Large land requirement, Environmental Impacts
Des Lacs River in US	Unlikely - High cost, Large land requirement, Environmental Impacts
Operational Modifications of Existing Dams	
Alameda, Rafferty & Boundary Dams	Possible -Limited effectiveness, Impacts on other reservoir storage purposes
Lake Darling Dam	Possible - Limited effectiveness, Impacts on other reservoir purposes, Environmental Impacts
Diversions	
Upstream Diversions	
49th Parallel Diversion	Unlikely - High cost, Large land requirements, Environmental Impacts
Lake Darling Diversion	Unlikely - High cost, Large land requirements, Environmental Impacts
Local Site Diversions	
Minot North Diversion	Unlikely - High cost, Limited effectiveness, Large land requirements
Minot South Diversion	Unlikely - High cost, Limited effectiveness, Large land requirements
Minot Tunnel (South)	Unlikely - High cost, Limited effectiveness
River Loop High Flow Diversions	Likely - Supplement to levees, Reduced land impact
Levees and Floodwalls	Likely - Cost effective, Land required is generally most prone to flooding
Channel Modifications	Unlikely - High cost, Limited effectiveness, Environmental Impacts
Removing Drains in Upstream Basin	Unlikely - Limited effectiveness, Landowner opposition
Floodproofing	Unlikely - Limited effectiveness, Social acceptance and livability Issues
Relocation/Buyouts	Unlikely - High cost, Large land requirements, Local acceptability issues
Increased Floodplain Regulations	Possible - Limited effectiveness, Only addresses future development
No Action - Maintain current levee, channel modification and flood storage system	Possible - Does not achieve objective, Low cost option, Allows rebuilding in existing flood-prone locations

The Barr and others report (2012) describe the development of the hydrologic and hydraulic models that can be used to evaluate floodplain management alternatives in the Souris River Valley. As stated in the Barr and others report (2012), the objectives of the study are to develop:

1. A hydrologic model to simulate runoff from ungauged portions of the Souris River watershed for use in the hydraulic model.
2. A baseline hydraulic model simulating movement of water through the Souris River Valley for existing conditions.
3. A second hydraulic model representing future conditions after construction of the levee-floodwall project.

The initial HEC-RAS hydraulic model for the Souris River was developed in the 1970's and underwent updates throughout the years. The new existing conditions HEC-RAS model was updated with data such as LIDAR, as-built records, and field survey data to create a continuous model from Lake Darling downstream to Velva. The new HEC-RAS model was calibrated to within an average deviation of less than one-tenth of a foot from 2011 high water surface elevations (Barr and others, 2012). The 2011 flood of record was used as the design flood for the levee-floodwall Project described in detail in the Barr and others report (2012).

After the Preliminary Engineering Report was completed (Barr and others, 2012), outlining alternatives for flood risk reduction along the Souris River from Burlington, ND to Velva, ND, all other rural reaches from Sherwood, ND to Westhope, ND were investigated. In addition to outlining flood risk reduction alternatives, Barr and others (2013a) evaluated areas with significant potential for sediment and erosion along the Souris River. The study approach (Barr and others, 2013a) was:

1. to seek input from stakeholders to identify rural flood issues and alternatives to be studied,
2. to develop hydrologic and hydraulic models for the entire study area, and
3. to evaluate alternatives using stakeholder criteria and modeled flood scenarios.

The three questions investigated (Barr and others, 2013a) were:

1. What are the effects of implementing the Project elements in the report by Barr and others (2012) when compared to existing conditions?
2. Are the proposed rural flood risk reduction alternatives effective in reducing flood impacts to agriculture and/or infrastructure?
3. Are the rural alternatives implementable?

Twelve alternatives were identified by stakeholders as having merit in reducing the flood risk. The twelve alternatives are described in table 2. The alternatives were evaluated based on their ability to reduce flood impacts using historic floods and computer simulations for specific flood conditions. Based on analyses of all major floods since 1937, Barr and others (2013a) concluded:

1. Snowmelt combined with coincidental or subsequent rain was the primary cause of the majority of the largest floods, but over 25 percent of the floods on the Souris River at Verendrye, ND were the result of rain.
2. Drainage area upstream of Lake Darling Dam was the major contributor to most of the largest floods, but about 25 percent of the largest floods were generated primarily from drainage areas downstream of Lake Darling.

3. Measures that reduce flood runoff from all parts of the drainage area upstream of Velva must be considered to provide successful flood risk reduction for reaches downstream of Velva.

Table 2. Rural Flood Risk Reduction Alternatives (From Barr and others, 2013a)

ALTERNATIVE 1	ADVANCED DISCHARGE FROM LAKE DARLING Modify the operating plan of Lake Darling Dam to drawdown pool level to the maximum drawdown level (El. 1,591) prior to spring flood events.
ALTERNATIVE 2	INCREASED TARGET DISCHARGE AT MINOT Modify the operating plan of Lake Darling Dam to allow discharges up to 10,000 cfs at Minot.
ALTERNATIVE 3	NON-STRUCTURAL FLOOD STORAGE INCREASE IN LAKE DARLING Increase the storage capacity of Lake Darling by lowering the maximum allowed drawdown level by 7 feet (to El. 1,584).
ALTERNATIVE 4	STRUCTURAL FLOOD STORAGE INCREASE IN LAKE DARLING Increase the storage capacity of Lake Darling by raising the dam. (Increase maximum flood storage level by 10 feet to El 1,611.)
ALTERNATIVE 5	RING DIKES Provide ring dikes around homes, businesses, and farmsteads in rural areas.
ALTERNATIVE 6	BOUNDARY DIVERSION Provide a high-flow diversion from Sherwood to Westhope to divert high flows away from the Mouse River Valley in North Dakota.
ALTERNATIVE 7	CHANNELIZATION IMPROVEMENTS DOWNSTREAM OF VELVA Provide increased channel flow capacity through channelization in select areas downstream of Velva.
ALTERNATIVE 8	BRIDGE MODIFICATIONS Raise or enlarge openings of select bridges over the Mouse River to allow key transportation corridors to remain open during flood events and to provide increased conveyance capacity at bridges.
ALTERNATIVE 9	MODIFY J. CLARK SALYER REFUGE DAM OPERATIONS Modify the operations of JCS NWR dams so that all water control structures remain open during events like the 2009, 2010, and 2011 historic events.
ALTERNATIVE 10	MODIFY J. CLARK SALYER REFUGE HYDRAULIC STRUCTURES Modify the physical parameters of the five JCS NWR dams to re-create conditions that existed prior to dam reconstruction work in the early 1990s.
ALTERNATIVE 11	REMOVE TRAPPED FLOODWATER AFTER THE FLOOD RECEDES Improve drainage of low-lying overbank areas to remove trapped floodwater from the floodplain after the flood recedes.
ALTERNATIVE 12	FLOOD STORAGE ON TRIBUTARIES TO THE MOUSE RIVER Provide floodwater storage in tributary watersheds.

Barr and others (2013b) completed a study to assess the potential impacts of a flood risk reduction Project outlined in Barr (2012) on sedimentation and erosion. Geomorphic analyses were used to develop an evaluation of sediment and erosion impacts from the Project that include:

1. changes in river meandering upstream and downstream of the Project features,
2. increased sedimentation in the channel and/or floodplain upstream or downstream of channelized reaches,
3. increased erosion within channelized reaches; and,

4. increased channel erosion or sedimentation upstream or downstream of Project features.

The objectives of the study (Barr and others, 2013b) were to:

1. provide an initial characterization of the processes of erosion, transport, and deposition of river sediment based on available data,
2. use the initial characterization as the basis for conducting a preliminary qualitative evaluation of the projects potential to result in undesirable erosion and sedimentation,
3. identify the modeling and additional data needed in the next phase of the study to quantify the Project's potential impacts and to propose options to minimize adverse geomorphic impacts from Project implementation.

The study (Barr and others, 2013b) is based largely on historic data and stream classification methods to characterize the sediment transport and geomorphological processes in the Souris River Basin. The Barr report (2013b) indicates although modifications have been made to some reaches along the Souris River, no widespread erosion or sedimentation impacts occurred during the 2011 flood. The authors (Barr and others 2013b) conclude "distinct portions of the Mouse River behave differently in response to differences in local variables such as slope and channel sediment." Also, the authors conclude "there is not sufficient information available to quantify the likely magnitude of erosion or sedimentation impacts that may result from the Project."

Barr (2013b) outlined the additional data collection, hydraulic modeling, and geomorphic analysis needed to quantify the erosion or sedimentation impacts from the Project:

1. collect suspended sediment concentrations, bed load concentrations, and bank material gradation,
2. collect channel cross-section surveys,
3. obtain U.S. Geological Survey cross-section measurements; and,
4. conduct sediment transport modeling.

The USACE received funding in 2016 to start a feasibility study to determine measures that can reduce flood risk on the Souris River in the Minot area and improve the aquatic ecosystem (USACE, 2017). The project study area included all the Souris River Basin in the United States. National objectives for the study are to maximize the National Economic Development and restore ecosystem functions, and the specific objectives are:

1. reduce flood risk and flood damages to structures in the urban and rural areas due to peak flows,
2. reduce the risk to life, health, public safety and critical infrastructure due to flooding,
3. reduce the risk of property and agricultural damage due to peak flows,
4. reduce the risk of property and agricultural damage due to extended duration of flows,
5. improve ecosystem functions and values in areas impacted by existing federal projects or in conjunction with nonstructural flood risk management measures,
6. in conjunction with flood risk management, and associated with improving ecosystem functions and habitat, improve the public's access to and use of outdoor recreational opportunities,
7. increase community resilience and ability to fight and recover from flood events throughout the basin.

Several types of measures and alternative plans to reduce flood risk were analyzed in the feasibility study and they include:

1. no action, but continue emergency measures,
2. nonstructural measures,
3. flood barriers including levees,
4. increased conveyance including diversion channels,
5. flood storage.

Hydraulic analyses indicated the potential benefits from flood storage options and increasing conveyance would not be greater than the costs of constructing the options. Thus, the options did not receive further consideration (USACE, 2017). The no action, nonstructural, and flood barrier options were the only options considered in greater detail (USACE, 2017).

The recommended plan (Maple Diversion concept) in the USACE report (2017) includes a high flow bypass channel, on North levee (west bank), and West Tieback levee. All the features are in Minot, ND.

Data Sets and Model Setups

A complete summary of hydraulic data used for various modeling activities has been compiled by Michelle Larson (personal communication) of the USACE St. Paul District.

Table 3. Summary of Survey Data

Type	Location	Date	Source	Notes
Topographic Maps & Cross Section Plots from field surveys	Souris River – Saskatchewan agricultural areas from Weyburn to the ND/SK border	1940s	PFRA (Prairie Farm Rehabilitation Administration, now: Agriculture & Agri-Food Canada)	
Topographic Maps & Cross Section Plots from field surveys	Souris River – Saskatchewan, 44 cross sections Upstream of ND/SK border near Sherwood, ND	November – December 1970	PFRA (Prairie Farm Rehabilitation Administration, now: Agriculture & Agri-Food Canada)	
Maps, Cross Section Plots, Bridge Survey Drawings	Souris River – North Dakota	1969-1978	USACE – HEC2 data files (and maps & plots)	For modeling and study of original flood control projects
Surveying – (Wet) Channel	Souris River & Long Creek - see Estevan HEC-RAS model for reaches included	1994	WSA	Data was entered into the HEC-RAS model
Surveying – Overbank & Channel	Lake Darling Bathymetry	1994	USFWS	Before pool raised with raising of dam
Top of Levee Survey Data	Burlington to Minot communities	2011 flood	Ackerman – Estvold for SRJWRB/NDSWC	Emergency flood fight
Top of Levee Survey Data	Sawyer levees, Velva levees	June 2011	Ackerman – Estvold for SRJWRB/NDSWC	Emergency flood fight
Surveying – Overbank & Channel	Souris River - Renville County Park; Bridge surveys – Minot and Burlington	October 2011	Barr Engineering (By Ackerman-Estvold)	NDSWC Project
Surveying – Overbank &	Souris River DS of Lake Darling Dam (Pond 87A)	2011/2012	Houston Engineering	For Ward County FIS

Channel	through Ward Co (DS of Sawyer)			
Surveying – Overbank & Channel	Des Lacs River – Baden to Burlington	Dec 2011 – Feb 2012	Ackerman-Estvold (Houston Engineering)	For Ward County FIS
Hydrographic Surveying of Channel	Souris River at Minot, US Hwy 83 Bypass to just US of Water Treatment Plant	November 2014	Ackerman-Estvold	NDSWC Project
Surveying – Overbank & Channel	Minot – Labeled Areas 1, 2 & 3; Areas 1 & 2 – at sharp bends in golf course; Area 3 – Tierricita Vallejo outlet DS of US Hwy 83 Bypass	November 2014	Ackerman-Estvold	NDSWC Project
Surveying – Overbank & Channel	Downstream of Warner's Road to upstream of Short Creek (Between Estevan & Roche Percee)	April 2012	WSA	Post 2011 Flood
Surveying – Overbank & Channel	Souris River – from Burlington to Minot, Minot	April – May 2012	USACE	For model updates
Surveying – Overbank & Channel	Souris River – Post river bank repairs at Tierrecita Vallejo community (just US of Minot)	Winter 2012-2013	USACE	For model updates
Top of Levee Survey Data (xyz)	City of Minot Levees – Left and Right Banks	April 2013	City of Minot	Emergency Levee Elevations Left in Place
Top of Levee Survey Data (xyz)	Johnson's Addition (Burlington)	Winter 2013-2014	Souris River Joint Water Resources Board (Ackerman – Estvold)	Modified previous alignment
Top of Levee Survey Data (xyz)	Burlington to Minot communities – King's Court & Rostad Addition and Tierrecita Vallejo	Winter 2013-2014	Souris River Joint Water Resources Board (Ackerman – Estvold)	Post levee repair work
Surveying – Overbank & Channel	Souris River – sparse XSs from Saskatchewan border to just DS of Renville County Park	August – September 2013	USACE	For model updates – filling in data gaps
Surveying – Overbank & Channel	Souris River – sparse XSs Burlington to Minot, Minot	May – June 2013	USACE	For model updates – filling in data gaps

Hydrographic Survey – sparse	Souris River – DS end of Eaton Ponds (near Towner) to “Johnson Bridge” just US of Willow Creek (near Bantry)	June 2014	NDSWC	For model updates – filling in data gaps
Surveying – Overbank & Channel	Souris River – 1 XS in Minot, sparse XSs between Minot & Sawyer, Sawyer, sparse XSs between Sawyer & Velva, Velva, sparse XSs between Velva & just DS of Verendrye Gauge	Summer 2015	USACE	For model updates – filling in data gaps

Table 4. Summary of DEM Datasets (LiDAR)

Location	Date	Resolution	Source	Notes
Saskatchewan	November 2011	3 meters	SGIC	Obtained by WSA
Renville County	October – November 2013	1 meter	http://lidar.swc.nd.gov/	Obtained by NDSWC
Ward County and City of Velva	September – October 2010	5 feet	http://lidar.swc.nd.gov/	Obtained by NDSWC
City of Minot	June 2015	5 feet	http://lidar.swc.nd.gov/	Obtained by NDSWC
McHenry County	October – November 2011, April 2012	1 meter	http://lidar.swc.nd.gov/	Obtained by NDSWC
Bottineau County	April 2012	1 meter	http://lidar.swc.nd.gov/	Obtained by NDSWC

Table 5. Summary of High-Water Data (for calibration)

Type	Location	Date	Source	Notes
Gauges	Minot 4NW, Souris near Foxholm	1948	USGS	
Gauge	Verendrye	1949	USGS	
Gauges	Oxbow & Roche Percee	1969 Flood	Environment Canada	discontinued
Gauges	Minot 4NW, Souris near Foxholm, Logan, Verendrye, Bantry, Dam 332, Souris near Westhope	1969	USGS (gauges)	
Surveyed HWMs	Minot area downstream to border near Westhope	1969	USACE (HWMs)	
Gauges	Minot 4NW, Verendrye	1970	USGS (gauges)	
Surveyed HWMs	Burlington, Minot, Sawyer, Velva, Towner	1970	USACE (HWMs)	1 HWM at each City
Gauges	Sherwood, Lake Darling Pool, Souris near Foxholm, Minot 4NW, Verendrye, Bantry, Souris near Westhope	1974	USGS (gauges)	
Surveyed HWMs	Sherwood border area downstream to Towner	1974	USACE (HWMs)	
Gauges	Sherwood, Lake Darling Pool, Souris near Foxholm, Minot 4NW, Logan, Verendrye, Bantry, Dam 332, Souris near Westhope	1975	USGS (gauges)	
Surveyed HWMs	Sherwood border area downstream to Westhope border area	1975	USACE (HWMs)	
Gauges	Sherwood, Lake Darling Pool, Souris near Foxholm, Minot 4NW, Logan, Verendrye, Bantry, Dam 332, Souris near Westhope, Dam 357, Melita, Above Hartney Dam, Souris (MB), Wawanesa	1976	USGS (gauges), Environment Canada (gauges)	
Surveyed HWMs	Sherwood border area downstream to Westhope border area	1976	USACE (HWMs)	
Gauge	Souris near Foxholm, Minot 4NW	1979	USGS (gauges)	

Gauges	Above Napkina Dam, Above Hartney Dam, Souris (MB), Wawanesa	1995	Environment Canada	
Gauge	Verendrye	1996	USGS	
Gauges	Above Napkina Dam, Above Hartney Dam, Souris (MB), Wawanesa	1999	Environment Canada	
Gauges	Verendrye	2009	USGS	
Surveyed HWMs	Sherwood border area downstream to Westhope border area	2009	USACE (HWMs)	
Surveyed HWMs	Burlington to Minot, Minot	2011	FEMA	
Gauges	Sherwood, Lake Darling Pool, Souris near Foxholm, Minot 4NW, Minot – Broadway Bridge (RD), Logan (RD), Verendrye, Towner (RD), Bantry, Upham, Dam 332, Souris near Westhope, Rafferty Reservoir, Below Rafferty Reservoir, Alameda Reservoir, Boundary Reservoir, Melita, Souris (MB), Wawanesa	2011	USGS (gauges), Environment Canada (gauges)	RD = Rapid Deployment
Surveyed High Water Marks	US of Hwy 18 near Estevan to DS of Hwy 39 near Roche Percee; Hwy 9, Hwy bridge near Oxbow, Sherwood gauge, Renville County Hwy 2	2011 Flood (June)	WSA	
Souris River Gauges	Estevan, near Sherwood, near Foxholm, Minot4NW, Verendrye, Bantry, Upham, near Westhope (rapid deployment – Tolley, Minot Broadway Bridge, Logan, Towner)	2011 Flood	USGS	
Des Lacs River Gauges	Foxholm, (rapid deployment – Burlington)	2011, 2013, 2017	USGS	
Surveyed Water surface elevations	Minot	2011 Flood, Early April - June	City of Minot	
Surveyed HWMs and Water surface elevations	Des Lacs River, Souris River downstream of the Des Lacs River to just downstream of	2011 Flood, Early	Anderson Engineering	Under Contract with

	Velva, ND	April - June		USACE
Gauge	Logan	2011, 2013, 2017	USGS	Rapid Deployment
Souris River Gauges	Sherwood, Lake Darling Pool, Souris near Foxholm, Minot 4NW, Minot – Broadway Bridge (RD), Logan (RD), Verendrye, Towner (RD), Bantry, Upham, Dam 332, Souris near Westhope	2013	USGS	RD = Rapid Deployment
Gauges	Souris River near Tolley, ND	2013	USGS	Rapid Deployment
Des Lacs River Gauge	Baden	2017	USGS	Rapid Deployment

Table 6. Summary of River Profiles (From Reports)

Type	Location	Date	Source	Notes
Profiles for 1976 Flood, 1% & 0.2% events, and low flows for existing conditions & Channel Improvements	Estevan	1977-1978	Souris River Basin Study	Also includes Flood Hazard Areas (10%, 4%, 2%, 1% & 0.2%) @Estevan: 1976 is 10,400 cfs; 1% is 8,800 cfs; 0.2% is 16,000 cfs
Profiles for 1976 Flood, 1% & 0.2% events, and low flows for existing conditions & Channel Improvements	Roche Percee	1977-1978	Souris River Basin Study	Also includes Flood Hazard Areas (10%, 4%, 2%, 1% & 0.2%) @Roche Percee: 1976 is 7,390 cfs; 1% is 9,900 cfs; 0.2% is 18,000 cfs
Profiles for 1976 Flood, 1% & 0.2% events, and low flows for existing conditions & Channel Improvements	Oxbow	1977-1978	Souris River Basin Study	Also includes Flood Hazard Areas (10%, 4%, 2%, 1% & 0.2%) 1976 is 14,400 cfs; 0.2% is 26,000 cfs; 1% is 14,500 cfs 2% is 10,700 cfs

Table 7. Summary of Hydraulic Models

Type	Location	Date	Source	Notes
HEC-RAS (originally HEC-2)	Estevan – Souris River and Long Creek	1999, 2003 revision – modeled complexities at Long Creek Souris River confluence	WSA	Used 1974 floodplain geometry and updated channel geometry (and flows) following the construction of the Rafferty Reservoir
HEC-RAS	Roche Percee		WSA	
HEC-2	US of Sherwood gauge		USACE files	
HEC-2	North Dakota	1970s	USACE files	Based data for the flood control projects
HEC-RAS	Lake Darling to Logan	2009, 2011, 2014, 2016	USACE & Houston	New LiDAR and New surveys
HEC-RAS	DS of Rafferty to Sherwood Gauge	2012	URS (USACE contract)	Unsteady
HEC-RAS	Burlington to Velva, Mouse River Park	2012	Barr	For Preliminary Engineering Report
HEC-RAS	North Dakota – border to border,	2013	Barr	Unsteady. For Enhanced Flood Protection Plan
HEC-RAS	Ward County & Des Lacs River		Houston	For FIS Update
HEC-RAS	Burlington to Logan	2016	USACE	Minot Levee Breach Modeling. Unsteady & 2D
HEC-RAS	DS of Rafferty to Westhope & Des Lacs River	2016-2017	USACE	Unsteady
HEC-RAS	DS of Lake Darling to Central Ave, just upstream of Wintering River	2017	USACE & Barr	408 Project / Feasibility Study for Minot Flood Protection

Table 8. Summary of Bridge Drawings in Saskatchewan

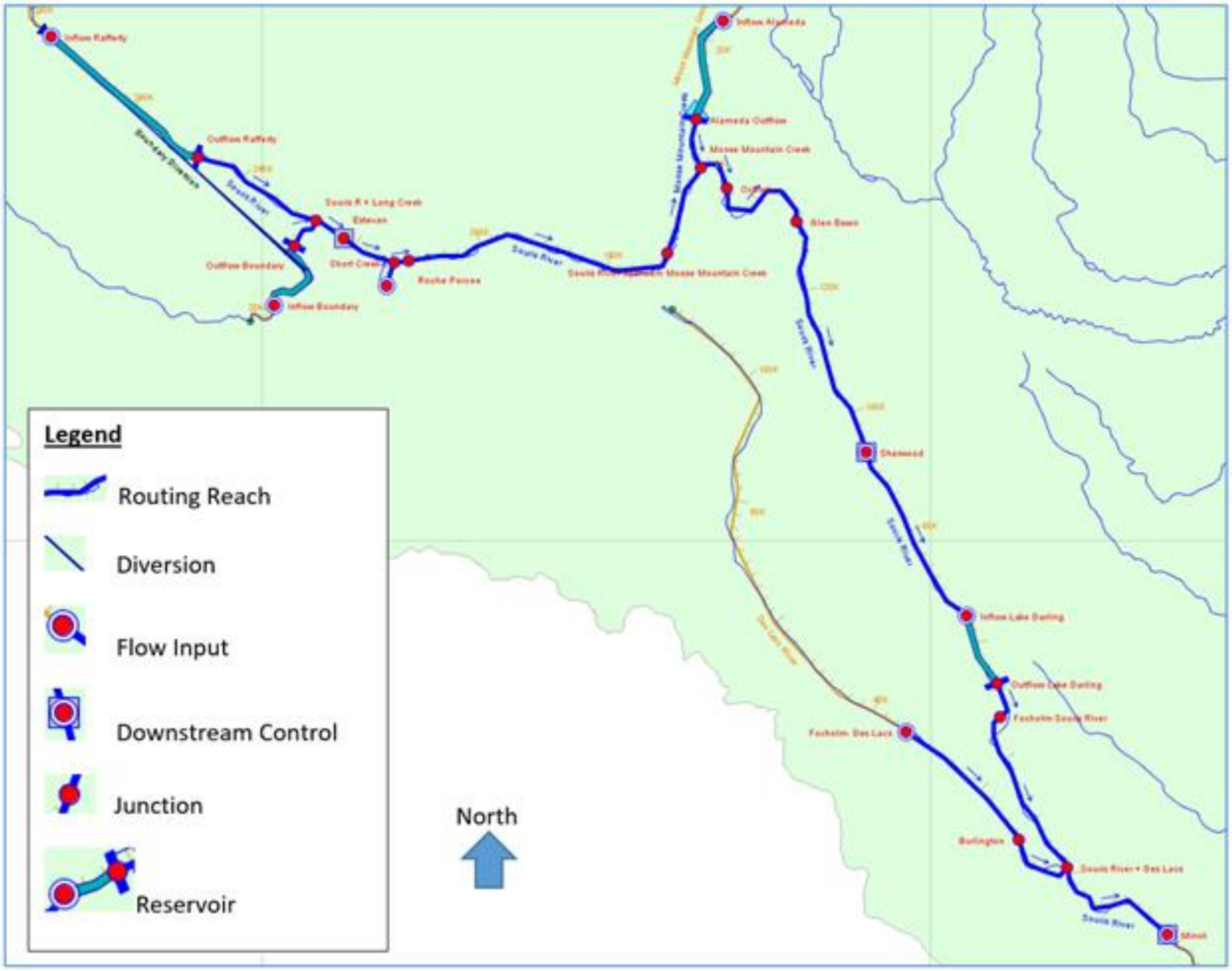
Location	Date	Source	Notes
RM of Coalfields No. 4, Bridge Plans No. M340 (2 miles east of Roche Percee)	Approved October 2001	Saskatchewan Highways and Transportation	Obtained by WSA
RM of Coalfields No. 4, Bridge Plans No. 46 (7 miles north of North Portal, SK)	August 1962	Municipal Road Assistance Authority	Obtained by WSA
RM of Enniskillen No. 3, Bridge Plans No. 90 (At Oxbow)	August 31, 1962, not confirmed	Municipal Road Assistance Authority	Obtained by WSA
RM of Enniskillen No. 3, Bridge Plans No. 104 (At Glen Ewen)	April 1968	Municipal Road Assistance Authority	Obtained by WSA
RM of Estevan No. 5, Bridge Plan NO. M407	April 2010	Municipal Bridge Services	Obtained by WSA
RM of Mount Pleasant No. 2, MRAA Bridge Plan No. 34 (10 miles south of Glen Ewen)	July 31, 1961	Municipal Road Assistance Authority	Obtained by WSA
Hwy 9 (5 miles north of Northgate, SK)	Approved June 13, 1983		Obtained by WSA
Hwy 18 (At Estevan)	July 10, 1975	Saskatchewan Department of Highways	Obtained by WSA
Hwy 39 Plan No. 1764 (1.5 miles east of Roche Percee)	No Date		Obtained by WSA
Old Hwy 39 Superstructure Plan No. 1189 (At Roche Percee – concrete arch)	April 1929, not confirmed	Saskatchewan Department of Highways	Obtained by WSA
Hwy 47 Plan No. 2324 (At Estevan)	Approved May 31, 1991	Saskatchewan Highways and Transportation	Obtained by WSA
Coal Haul Road Crossings (3) Sketches & Photos, one crossing with real elevations	1991, 1997 1999	Prairie Coal ltd.	Obtained by WSA
Coal Haul Road – Costello Mine (added 2nd bridge to easternmost crossing)	1997	Stanley Consulting	Obtained by WSA
Additional Bridges without drawings	Information includes picture(s), bridge name, coordinates, surveyed low chord, and open span distance		Obtained by WSA

HEC-ResSim

The HEC-ResSim modeling software (v. 3.1) was used by the USACE to model reservoirs in efforts to support an ongoing USACE Flood Risk Reduction Feasibility Study for the Souris River Basin (USACE, 2017) and to develop naturalized flows that can be used to evaluate reservoir operation (USACE, 2013b). ResSim is a widely used modeling platform and is approved by FEMA for floodplain modeling. In 2012, Houston Engineering, Inc. on behalf of FEMA also developed a HEC-ResSim model to support the 2011 Ward County Risk Map Project (Houston Engineering, Inc., 2012). The model developed by the USACE was generated independently from Houston Engineering's efforts but uses modeling conventions consistent with the assumptions incorporated in the model developed by Houston for FEMA. The USACE ResSim model is a fairly accurate numerical model of the reservoir system and applies USACE standards of practice for reservoir modeling.

A ResSim model was used to simulate the operation of Rafferty Reservoir, Boundary Reservoir, Boundary to Rafferty Diversion, Grant Devine Lake, and Lake Darling. A schematic of the model is shown in figure 2. The model extends from the upstream end of the reservoirs downstream through Verendrye, ND, including the Des Lacs River from Foxholm, ND to its confluence with the Souris River. Downstream maximum allowable release control points are inserted at the following key locations critical to reservoir operation: Estevan, Sherwood, and Minot. Downstream control points allow for operational rules that depend on downstream conditions and ensure the reservoirs operate as a system.

Figure 2. ResSim model schematic for Rafferty Reservoir, Boundary Reservoir, Grant Devine Lake, and Lake Darling in the Souris River Basin



Summary

Unprecedented flooding in the Souris River Basin in 2011 focused attention on review of the Operating Plan contained in Annex A to the 1989 International Agreement. In June 2013 the IJC submitted a Plan of Study to review the Operating Plan, and in July 2017 governments responded with a request that the IJC evaluate and make recommendations regarding the Operating Plan. Also, the IJC was asked to investigate flood protection and water supply measures in the Souris River Basin. In September 2017 the IJC established the ISRSB to carry out the terms of reference and delivery recommendations in early 2020.

The ISRSB developed a Work Plan to answer the questions raised in the terms of reference and the study objectives are:

1) Review operating rules and improve the language of the Operating Plan,
2) Collect and analyze date,
3) Improve hydraulic and hydrologic modelling; and,
4) Propose alternative approaches and recommendations.

One of the tasks under item 2 involves summarizing the available studies, datasets, and modelling setups that are pertinent to the 2013 POS (Souris River Task Force, 2013). The purpose of this report is to summarize all the studies, datasets, and modelling setups completed since 2013 that may be used as reference or background material for some of the tasks outlined in the Work Plan (ISRSB, 2018).

Previous studies were reviewed and discussed in Meteorologic, Hydrologic, and Engineering Studies sections of the report. Several Federal, State, and Provincial Government agencies completed reports that documented and described the meteorological conditions that led to the 2011 flood in the Souris River Basin. The key findings and recommendations are described in the Meteorologic section. A wide range of hydrologic studies, ranging from flood-frequency and magnitude to reconstruction of the streamflow records at key locations are summarized the Hydrologic Studies section. Studies described in the Engineering section generally are focused on alternatives to reduce flood risk to private property and public transportation.

Data sets are summarized and listed as survey data (table 3), DEM datasets (table 4), high-water data (table 5), river profiles (table 6), and bridge drawings (table 8). A list of hydraulic models, including the location and source, are listed in a separate table (table 7).

References Cited

Alberta Transportation, 2004, Guidelines on Extreme Flood Analysis, 87 p., plus Appendices.

Barr Engineering, Ackerman-Estvold Engineering, Moore Engineering, and CPS, Ltd, 2012, Mouse River Enhanced Flood Protection Preliminary Engineering Report: Prepared for the North Dakota State Water Commission, 190 p., plus Appendices.

Barr Engineering, Ackerman-Estvold Engineering, Moore Engineering, and CPS, Ltd, 2013a, Mouse River Enhanced Flood Protection Plan Rural Risk Reduction Alternatives Evaluation: Prepared for the North Dakota State Water Commission, 139 p., plus Appendices.

Barr Engineering, Ackerman-Estvold Engineering, Moore Engineering, and CPS, Ltd, 2013b, Mouse River Erosion and Sedimentation Study: Prepared for the North Dakota State Water Commission, 127 p., plus Appendices.

CDA, 2007, Dam Safety Guidelines: Canadian Dam Association/Association Canadienne des Barrages, Edmonton, Alberta xx p.

Danish Hydraulic Institute, 1998, MIKE-SHE Water Movement—User Guide and Technical Reference Manual

Hatch, 2014a, Final Report for Rafferty and Alameda Dams-Probabilistic Inflow Estimates: Report prepared for Saskatchewan Water Security Agency, Moose Jaw, Saskatchewan, 18 p, plus Appendices.

CDC, 1999, Dam Safety Guidelines: Canadian Dam Association/Association Canadienne des Barrages, Edmonton, Alberta xx p.

Hatch, 2014b, Final Report for Probable Maximum Flood-Rafferty and Alameda dams: Report prepared for Saskatchewan Water Security Agency, Moose Jaw, Saskatchewan, 126 p, with Appendices.

Hatch, 2016, Final Report for Alameda and Rafferty Dams IDF Study: Report prepared for Saskatchewan Water Security Agency, Moose Jaw, Saskatchewan, 117, with Appendices.

Hopkinson, Ron, 2011, Anomalously High Rainfall over Southeast Saskatchewan-2011: prepared by Custom Climate Services Inc., Regina, Saskatchewan, for the Water Security Agency, Moose Jaw, Saskatchewan, 35 p.

International Souris River Study Board, 2017, Draft Work Plan for the Souris River Basin: Prepared for the International Joint Commission, Ottawa, Ontario, Canada and Washington, DC, 32 p.

KGS Group, 2006, Dam safety Review of Boundary Dam-Estimation of Probable Maximum Precipitation and Probable Maximum Flood: Prepared for SaskPower, Regina, Saskatchewan, 26 p., plus appendices.

KGS Group, 2016a, Assiniboine River & Lake Manitoba Basins Flood Mitigation Study: Prepared for Manitoba Infrastructure and Transportation, Winnipeg, Manitoba, 890 p., plus appendices.

KGS Group, 2016b, Assiniboine River & Lake Manitoba Basins Flood Mitigation Study-Executive Summary: Prepared for Manitoba Infrastructure and Transportation, Winnipeg, Manitoba, 22 p.

Kolars, K.A., Vecchia, A.V., and Ryberg, K.R., 2016, Stochastic model for simulating Souris River Basin precipitation, evapotranspiration, and natural streamflow: U.S. Geological Survey Scientific Investigations Report 2015–5185, 55 p., http://dx.doi.org/10.3133/sir20155185.

Ryberg, K.R., Vecchia, A.V., Akyuz, F.A., and Lin, W., 2016, Tree-ring-based estimates of long-term seasonal precipitation in the Souris River Region of Saskatchewan, North Dakota and Manitoba, Canadian Water Resources Journal / Revue canadienne des ressources hydriques, 17 p., http://dx.doi.org/10.1080/07011784.2016.1164627.

Stantec, 2011, Assiniboine River Basin Hydrologic Model—Climate Change Assessment: Prepared for Manitoba Conservation Climate Change Branch, Winnipeg, Manitoba, 140 p., plus appendices.

Souris River Basin Task Force, 2013, Plan of Study: For the Review of the Operating Plan Contained in Annex A of the 1989 International Agreement Between the Government of Canada and the Government of the United States of America: Prepared for the International Souris River Board, 76 p.

U.S. Army Corps of Engineers, 2012, 2011 Post-Flood Report for the Souris River Basin: U.S. Army Corps of Engineers, St. Paul District, Water Management and Hydrology Section, 70 p.

U.S. Army Corps of Engineers, 2013a, Souris River Basin Hydrometeorological Data Network Improvement Workshop Report: U.S. Army Corps of Engineers, St. Paul District, Water Management and Hydrology Section, 23 p., plus plates.

U.S. Army Corps of Engineers, 2013b, Regional and Reconstructed Hydrology of the Souris (Mouse) river: U.S. Army Corps of Engineers, St. Paul District, 157 p., plus appendices.

U.S. Army Corps of Engineers, 2014, 2013 Post-Flood Report for the Souris River Basin: U.S. Army Corps of Engineers, St. Paul District, Water Management and Hydrology Section, 70 p.

U.S. Army Corps of Engineers, 2017, Souris River Basin Flood Risk Management Feasibility Study and Integrated Environmental Assessment Bottineau, McHenry, Renville, and Ward Counties, North Dakota Draft Report: U.S. Army Corps of Engineers, St. Paul District, 96 p.

U.S. Army Corps of Engineers, 2018, 2017 Post-Flood Report for the Souris River Basin: U.S. Army Corps of Engineers, St. Paul District, Water Management and Hydrology Section, 33 p., plus appendices.

Vining, K.C., Chase, K.J., and Loss, G.R., 2013, General weather conditions and precipitation contributing to the 2011 flooding in the Mississippi River and Red River of the North Basins, December 2010 through July 2011: U.S. Geological Survey Professional Paper 1798–B, 22 p.

World Meteorological Organization, 2009, Manual on Estimation of Probable Maximum Precipitation (PMP): WMO-No. 1045, World Meteorologic Organization, Geneva, Switzerland, 257 p.

XCG Consultants Ltd., 2014, Review and Assessment of Probable Maximum Flood and Probabilistic Inflow Estimates for Rafferty and Alameda Reservoirs: Report prepared for Water Security Agency, Moose Jaw, Saskatchewan, 69 p.