International Souris River Study Board

Managing Water Supply and Flood Control in the Souris River Basin:

Review of the 1989 International Agreement between the Government of Canada and the Government of the United States of America for Water Supply and Flood Control in the Souris River Basin

A report to the International Joint Commission

Prepared by the

International Souris River Study Board

September 21, 2021

Letter of Transmittal

The International Souris River Study Board is pleased to submit its final report to the International Joint Commission, **Managing Water Supply and Flood Control in the Souris River Basin**.

We believe the report responds in a practical and comprehensive manner to the challenge issued by the Governments of Canada and the United States to identify opportunities to improve flood control and water supply security in the international basin. We believe our report both reflects and reinforces our two countries' long history of sound, cooperative management of the Souris River.

The Study Board expresses its sincere appreciation to all the individuals who contributed to the preparation of this report. From its beginning, the Study benefited from the engagement, ideas, and enthusiasm of the many interests in the Souris River basin.

First, the report is the product of a close collaborative binational effort involving more than 50 researchers in both countries. Technical teams of experts cooperated on the extensive data collection, modeling and analysis that formed the foundation of our findings and recommendations.

We acknowledge and thank the members of the Study's Public Advisory Group, who helped prepare and carry out the Study's engagement and outreach activities so that the Study could better understand and respond to the concerns of the basin's residents and communities. The many members of the public who participated in public meetings, workshops, webinars, and other activities improved our understanding of the challenges in the basin and how governments could better address those challenges.

The Resource and Agency Advisory Group, made up of representatives of federal, state, and provincial water management and other agencies with responsibilities in the basin, worked to ensure that the Study's analysis and recommendations are realistic and compatible with their mandates and resources.

The Study Board is also grateful to Tribes, First Nations, and the Métis Nation in the basin for helping enrich our understanding of their connection to and interests in the basin's waters and their concerns about the future of those waters. We are united in our belief that the openness and communication that were nurtured during the Study must continue as governments consider new approaches to water management in the basin.

An Independent Review Group established by the IJC helped ensure the scientific integrity of the Study's methodology and analysis through its peer review and comment.

Finally, we want to thank the IJC for the opportunity to serve on the Study Board. Throughout the Study, we have listened to and learned from one another. We submit our report and its recommendations unanimously. Our work has only renewed our belief that an open and cooperative approach is essential to protecting the Souris River basin that our two countries share.

International Souris River Study Board

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Acknowledgements

The Study team thanks all participants who contributed their valuable time and resources to this project. The study has required broad input from diverse participants in Canada and the United States:

- Citizens, groups, and organizations (e.g., watershed groups)
- Members of the public
- Indigenous Nations
- Rural and urban communities
- Conservation areas
- Municipalities
- Counties
- Stakeholders
- Technical experts
- Federal/state/local agencies

All participants have provided valuable input with their vested interests, concerns, and desire to achieve effective water management in the Souris River basin.

The International Souris River Study Board expresses thanks to all who provided input to the study, and expressly identifies:

- Public Advisory Group members and contributors
- Indigenous Nations, with special thanks to Marci Riel, Lisa Lone Fight, Carol Davis, Richard Aisaican, Morrissa Boerchers, Jasmine Langhan and Stewart Klyne

***Thank you -
your contributions and input
have enriched this study.***

Special note:

The International Souris River Study Board appreciates the committed interest of all those who have participated in this Study. The Board thanks everyone for their in-person contributions throughout the Study, and for their continued interest during the time in-person meetings have not been possible. Since February 2020, when COVID-19 began its dramatic global impact, this Study and its contributors have made every effort possible to encourage and participate in open dialogue and technical contributions using remote on-line meeting platforms. This challenge has not been easy as COVID-19 has prevented face-to-face meetings of all participants, including the technical teams, for over 19 (nineteen months). Despite this challenge during a critical phase to complete the Study, we believe the material presented in this report offers significant insight into options for future consideration for managing water supply and flood control in the Souris River basin. Thank you to all contributors. Thank you to all technical participants.

Executive Summary: International Souris River Study Board

Managing Water Supply and Flood Control in the Souris River Basin is the final report of the International Souris River Study Board (Study Board) to the International Joint Commission (IJC) on its evaluation of water management operations under the *1989 International Agreement between the Government of Canada and the Government of the United States of America for Water Supply and Flood Control in the Souris River Basin* (the 1989 Agreement).

The report presents the analysis, findings, conclusions, and recommendations of the Study Board regarding opportunities to improve the 1989 Agreement and strengthen the provision of flood control and water supply benefits to interests in the international basin.

The Challenge

The Souris River basin covers about 61,900 km^2 (23,900 mi^2) in the provinces of Saskatchewan and Manitoba in Canada and the state of North Dakota in the United States (Figure A). With a total population of about 157,000, the basin's economy is relatively diversified, with a mix of agriculture, coal mining and energy production, service industries, and tourism.

Long, cold winters in the basin tend to retain snowfall until the spring melt, which provides most of the Souris River's annual flow. Much of the basin is part of the prairie pothole region, characterized by the presence of shallow potholes or kettle lakes that are remnants of the last period of continental glaciation in North America.

The combination of climate and terrain contributes to highly variable flows in the basin, from season to season and from year to year.

Since 1940, Canada and the United States have worked together through the IJC to jointly manage the transboundary waters of the Souris River. Today, the waters of the Souris River basin are extensively managed for flood control and water supply by dams, diversion canals and other water resource infrastructure to meet the needs of communities, agriculture, industry, recreation, and ecosystems. The current Operating Plan has been in place since 1989, part of the 1989 Agreement.

In 2011, the Souris River basin experienced an unprecedented flood, far exceeding the scale of any other flood event in the more than 100 years for which instrumental data and records are available. Extremely wet conditions in the preceding years, combined with an above average snowmelt and heavy spring and substantial summer rainfall, resulted in a series of flooding events that significantly affected homeowners, businesses, and properties throughout the basin. Water management and control structures were severely tested as never before.

The 2011 flood focused renewed attention on the existing Operating Plan under the 1989 Agreement. Members of the public, as well as several government flood protection and water management agencies, requested that options for additional flood protection measures be evaluated. Across the basin, there were also emerging concerns related to security of water supply, water quality and environmental protection.

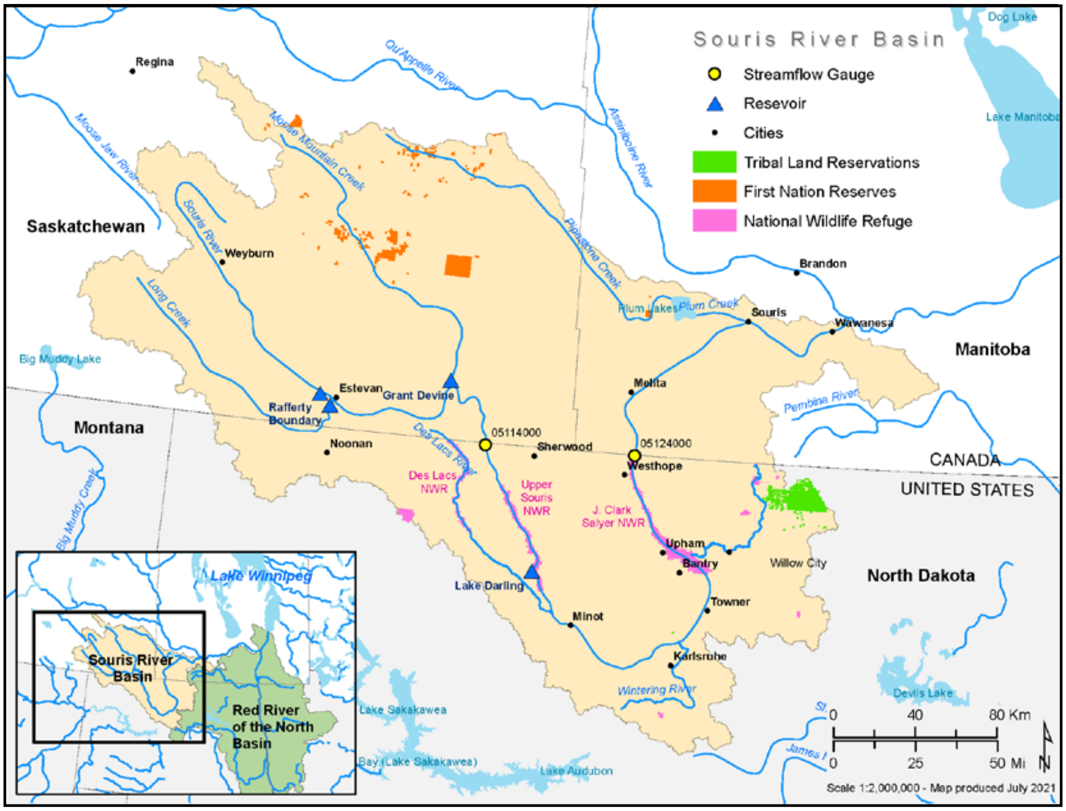

Figure A   Souris River basin

The International Souris River Study

The International Souris River Study was a direct response of the Governments of Canada and the United States to the 2011 flooding event. In addition to the concerns expressed following the 2011 flooding, the 1989 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. As a result, the International Souris River Board (ISRB), a permanent board established by the IJC responsible for oversight of transboundary water issues in the basin, including flood operations and apportionment of river flows, established the 2012 Souris River Basin Task Force to develop a Plan of Study (POS) proposing a review of the Operating Plan contained in Annex A for the consideration of the Governments of Canada and the United States. The Souris River Project includes three reservoirs in Saskatchewan and one in North Dakota (i.e., water storage reservoirs used for flood protection and water supply purposes).

The Task Force's 2013 POS document describes the studies needed to review the existing Annex A of the 1989 Agreement's Operating Plan for the reservoirs 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 the 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. The IJC recommended the full scope of the POS be conducted.

On July 5, 2017, the Governments of Canada and the United States issued a Reference for the IJC to undertake the POS. In accordance with Article IX of the *Boundary Waters Treaty of 1909*, the governments requested 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 POS.

On September 5, 2017, the IJC issued a Directive to establish and direct the 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.

Specifically, the Study was directed to undertake analysis and make recommendations regarding:

- the Operating Plan contained in Annex A to the 1989 Agreement; and,
- how the provision of flood control and water supply benefits in the basin might be maximized.

The Study organization (Figure B) consisted of:

- a Study Board of five members each from Canada and the United States responsible for providing overall direction and management of the Study, including reporting formally to the IJC on a regular basis;
- technical teams responsible for undertaking the extensive data collection, analysis and modeling that formed the basis of the Study's findings and recommendations;
- an independent binational Public Advisory Group (PAG), established by the IJC, responsible for helping plan and implement the Study's engagement and outreach plan;
- a binational Resource and Agency Advisory Group (RAAG), representing key resource management agencies and industry;
- a binational Climate Advisory Group (CAG) with expertise in hydrology and climate science was established; and,
- an Independent Review Group (IRG), established by the IJC, to provide independent scrutiny and guidance throughout the Study.

Brief summaries of the reports of the technical task teams are presented in Appendix 5. The reports are available on the Study's website: www.ijc.org/en/srsb.

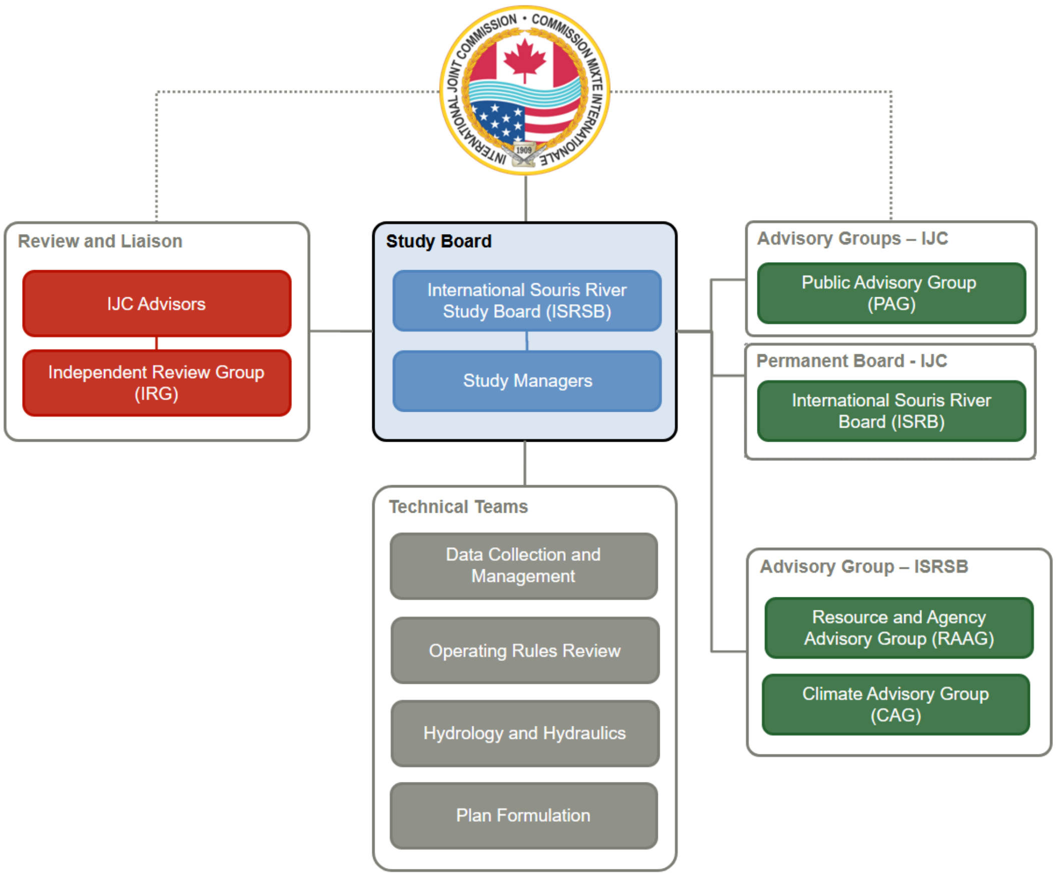

Figure B International Souris River Study organizational

Engagement and outreach in the Study

The IJC was committed to ensuring that the Study process was open, inclusive, and fair, and that the public, stakeholders and Indigenous Nations in the region were aware of the Study and of the opportunities to participate. Over the course of the Study, teams undertook a wide range of engagement and outreach activities with:

- the public;
- representatives of government resource and regulatory agencies and industry; and,
- Indigenous peoples with current and/or ancestral interests in the Souris River basin.

The binational PAG played a key role in helping develop and implement the Study's engagement and outreach activities. PAG members were responsible for:

- advising the Study Board on public consultation, involvement, and information exchange;
- involving the public by bringing information from the Study Board to their various networks throughout the community, as well as bringing back views from the community for consideration by the Study Board;
- reviewing and providing feedback on the Study's approaches, reports, products, findings, and recommendations; and,
- advising the Study Board on the responsiveness of the Study process to public concerns.

The RAAG was established by the Study Board early in the Study to act as a conduit for input from federal, provincial, state, and municipal agencies, and from the electric power industry over the course of the Study. The group worked to ensure that any recommendations made by the Study Board with respect to the existing Operating Plan or alternative measures would be compatible with the mandates and resources of the agencies. RAAG membership consisted of about 20 members from federal agencies and agencies in Saskatchewan, Manitoba, and North Dakota.

The Study Board recognized that Tribes, First Nations, and the Métis Nation have current and/or ancestral interests in the Souris River basin, and that their interests can be affected by the changes in water levels and flows in the basin. The Study worked to establish lines of communication and build relationships with these Indigenous Nations so that their interests could begin to be considered and the Study could benefit from their Indigenous Knowledge. As this engagement has only started, continued engagement with Indigenous Nations is expected beyond the Study, to determine how Indigenous interests can be included and addressed in management of the Souris River.

ISRSB Work Plan and Tasks

Based on the IJC Directive, the Study team developed a work plan to guide the work of the Study Board and various task teams in the execution of the Study. The work plan identified key data requirements, tasks (Table A: ISRSB's main study tasks and task groups), and resources required to fulfill the Directive. Stand-alone reports are available for most tasks at the Study website www.ijc.org/en/srsb.

Table A ISRSB's main study tasks and task groups:

Core Activity	Technical Task Teams
Operating rules review	OR 1: 1989 Agreement Language Review
Data collection and management	DW 1: Projects and Report Progress since 2011 DW 2: Bathymetry and LiDAR Data DW 3: Hydro meteorological Network Review DW 4: Data Collection for Performance Indicators
Hydrology and hydraulics	HH 1: Regional and Reconstructed Hydrology HH 2: Stochastic Hydrology HH 3: Artificial Drainage Impacts Review HH 4: Flow Simulation Tools Development HH 5: Climate Change Analysis HH 6: Reservoir Flow Release Modeling (HEC-ResSim) HH 7: Reservoir Flow Release Modeling (HEC-RAS) HH 8: PRM Model Development (HEC-ResPRM) HH 9: Model System Integration HH 10: Flow Forecasting Assessment
Plan formulation	PF 1: Workshops and Engagement PF 2: Run and Evaluate Alternatives PF 3: Dam Safety PF 4: Apportionment, Water Quality and Ecosystem Health

Review of the 1989 Operating Plan Annex A language

The unprecedented flooding in the Souris River basin in 2011 challenged operations as never before. For the operators of the dams, the flooding highlighted long-standing language ambiguities in the 1989 Agreement and the need to clarify some provisions of the Agreement.

As a result, the operators commenced a cooperative review of the language used in the 1989 Agreement, with oversight from the ISRB. Their objective was to update provisions of the Agreement for clarity, relevancy, and completeness. In 2017, this work was brought into the Study as one of its primary objectives.

Building on the earlier work of the operating agencies' committee, a Study team identified a range of issues that needed to be addressed to update and improve the clarity of the language of the 1989 Agreement. The team worked with reviewers from the dam operating agencies and the ISRB to find consensus on proposed changes. The team's proposals were then reviewed by the Study Board, the PAG and the RAAG.

Those areas that the Study Board reached consensus on revised language need to be submitted to the governments for legal review of the language and a decision made for implementation.

The Study Board identified six issues that need guidance, direction, and legal analysis from the Parties to the Agreement.

The review identified two sets of findings:

- specific proposed changes in language in the 1989 Agreement that will help improve the clarity and ongoing relevance of the Operating Plan and ensure consistency in its implementation; and,
- a set of six outstanding issues for which no consensus was reached among the operating agencies; resolution of these issues may involve policy considerations and require the attention of the IJC and the Governments of Canada and United States.

Table B summarizes these outstanding issues and the Study Board's conclusions regarding next steps.

Table B Review of Operating Plan language: summary of outstanding concerns

1989 Operating Plan Item	Study Team Proposal	Outstanding Concerns	Study Board Conclusion
1. Section 4.3.1 Flood Operating Plan	Revised language to address runoff during periods outside of spring snowmelt	Proposed revision could change the original intent of the 1989 Agreement	Retain existing language Reconsider if or when there are substantive updates to the 1989 Agreement
2. Section 4.3.3 Drawdown during spring freshet	New language proposed to address existing gap in Operating Plan procedures regarding drawdowns during the spring freshet	Proposed addition could be seen as a basic change to the 1989 Agreement	Proposed language should not be included as part of its recommended revisions to the 1989 Operating Plan Reconsider if or when there are substantive updates to the 1989 Agreement
3. Section 4.3.4 Drawdown after spring freshet	Revised language to clarify existing language regarding drawdowns after the spring freshet	The additional language assigns reservoir operating rules that are not in the original 1989 Operating Plan, and therefore, could be considered a change in the 1989 Agreement	Proposed language should not be included as part of its recommended revisions to the 1989 Operating Plan Reconsider if or when there are substantive updates to the 1989 Agreement
4. Section 4.3.5 Significant spring and summer rainfall	Revised text to provide more details on operational procedures during significant spring and summer rainfall events	Proposed text may add unintentional ambiguity	Revert to the 1989 Agreement language, given that the proposed new language could be viewed as a change in procedures of the 1989 Agreement
5. Section 4.3.6 Flood operation steps	Reviewed an editorial change to the 1989 Agreement made prior to 2017 that sought to simplify procedures during a flooding event	The 1989 Agreement language had been changed at some period prior to the study being established in 2017.	Retain the changed language Reconsider if or when there are substantive updates to the 1989 Agreement considered
6. Section 4.3.6 Flood operation steps - reporting	Reviewed an editorial change to the 1989 Agreement made prior to 2017 that sought to remove redundancy	The 1989 Agreement language had been changed at some period prior to the study being established in 2017.	Revert to the original language of the 1989 Agreement; that is, re-insert “part c” of section 4.3.6”

Evaluation of the performance of the 1989 Operating Plan

The first key step in considering the potential for improving water supply and flood control benefits in the basin was to first evaluate how well the existing Operating Plan has performed.

The Study analyzed and compared three hydrologic model simulations over a period from 1930-2017 to understand how the 1989 Agreement affects flood control, water supply and other key areas:

- a *baseline simulation*, incorporating the existing 1989 Agreement and its Annex A and Annex B, as if it had been in place the entire 1930-2017 period; this simulation includes Rafferty, Boundary, Grant Devine, and Darling reservoirs throughout the entire simulation;
- a *pre-Agreement simulation* that includes only the operational plans in place prior to 1989 for the Boundary and Darling reservoirs; the Rafferty Reservoir and Grant Devine Lake were removed from the model for this simulation; and,
- an *unregulated simulation* representing a condition close to the “state-of-nature” for the Souris River basin from 1930-2017, with all four reservoirs removed from the model. It should be noted, however, this simulation is not truly a natural state, as J. Clark Salyer National Wildlife Refuge was not removed from the model, nor was all built infrastructure within the Souris River basin removed from the model (towns, cities, roads, rail, landscape/land use modifications, etc.).

The 1989 performance evaluation simulation runs included analysis for 13 key locations or reaches along the Souris River, to understand flow for all three regions (Saskatchewan, North Dakota and Manitoba).

Based on the analysis, the Study Board found that, overall, the 1989 Operating Plan has performed well in providing water supply and flood control benefits. In particular, the analysis showed:

- The baseline simulation reduces the number of bankfull overflows (exceedances) compared to the pre-Agreement and unregulated simulations at all locations downstream of the Rafferty and Grant Devine Reservoirs, with one exception at Bantry, North Dakota.
- The addition of Grant Devine, Rafferty and Boundary Reservoirs and Lake Darling to the Souris River System provided protection for the spring snowmelt in 2011; however, when high rainfall events occurred throughout the basin in May and June, all remaining flood storage was used, and basin-wide flooding occurred. Analysis showed that even if the reservoirs were empty before the flood (dry dam scenario), a flood of similar magnitude to the 2011 extreme summer flood could not be mitigated. The reservoirs provide significant to modest flood protection from the Estevan, Saskatchewan reach to as far downstream as Westhope, North Dakota, and into Manitoba for floods similar in magnitude to the major floods experienced in 1969 and 1976.

- Mean monthly streamflows in the baseline simulation generally were less during the spring and summer than in the pre-Agreement and unregulated simulations as a result of water being stored in each of the four reservoirs. Mean monthly streamflows in winter generally were greater in the baseline simulation as the result of water being released from storage, resulting in a more uniform distribution of streamflow throughout the year.
- In addition to the direct benefits to flood control and water supply, the presence of the Souris River Project reservoirs, as modeled under the baseline simulation, resulted in benefits and impacts on secondary effects on environmental resources, socio-economic components, historic and cultural sites, water quality and recreation.
- The existing plan under the 1989 Agreement works well in relation to water supply and flood control. There are no major operational changes that will result in significant improvements in both water supply and flood control benefits across the basin.

Development of alternative Operating Plan measures

Alternatives are defined as a change or series of changes to how the basin's reservoir system is operated – that is, the levels of reservoirs and the timing of releases affecting flows, or a physical change to one or more of the reservoirs. By varying water levels and flow rates, reservoir operators can affect flood storage, outflow releases, water supply conditions and river and riparian conditions.

The Study addressed the need to develop a range of alternative Operating Plan measures through the integration of several key areas of work by the technical teams: data collection and management; development of runoff sequences; the application of performance indicators (PIs); and iterative rounds of modeling and evaluation. The evaluation of alternatives included engagement activities to obtain the input of the public, Indigenous Nations, government water and resource management agencies, and industry.

A first step was to review existing hydrological and meteorological studies and collect, update, and analyze key data on the basin's hydrology and meteorology needed to support the modeling of alternatives. This included physical data on the Souris River basin, data on each reservoir's elevation, storage, volume and outflow, and climate and bathymetric information (for reservoir depth and topography).

Study teams also developed a set of runoff sequences as input to the modeling and testing of alternatives. These included scenarios of historical water supply conditions in the basin, going back to 1930.

The next step was to integrate the runoff sequences, basin data and PI data into models to formulate a range of alternative Operating Plan measures. The plan formulation process to investigate possible alternative Operating Plan measures was carried out over five phases. Each phase built on the findings of the previous phase, with new or modified alternatives being formulated at each phase. As this work advanced to its later phases, a hydrological visualization tool allowed users to compare simulation results at specific locations in the Souris River basin.

Figure C illustrates how the initial ideas on the evaluation of operational changes in the early phases supported the formulation of new alternative Operating Plan measures in the subsequent phases of analysis. Six of the initial set of operational changes were modeled primarily to provide insights into the limits and constraints to managing water supplies in the basin and thereby support additional modeling in subsequent phases. Some of these areas of operational change, such as those associated with minimum flows or spring drawdown, were rejected, as they failed to meet flood management and water supply criteria or resulted in unacceptable impacts on one or more PIs. Other operational changes, such as those associated with normal drawdown targets, spring maximum flow limits and summer operating rules, proved more promising and were refined through further modeling. As a result, they formed the basis of the final set of five alternative Operating Plan measures that have the potential to provide improved flood control and water supply benefits to the interests in the Souris River basin.

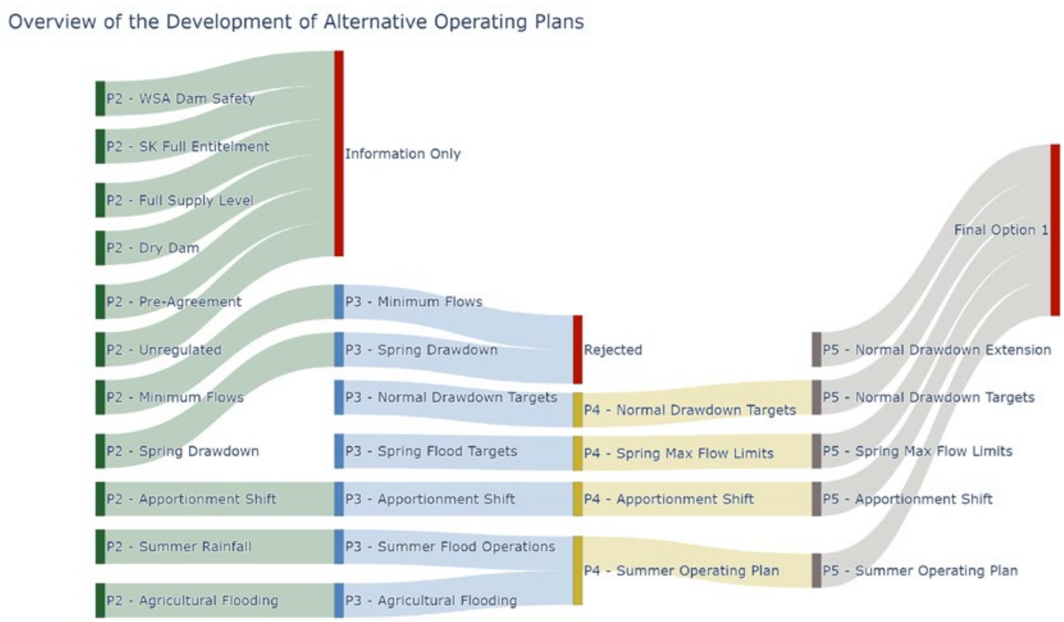

Figure C Overview of the development of alternative Operating Plans

Evaluation of alternative Operating Plan measures

The existing plan under the 1989 Agreement works well in relation to water supply and flood control. There are no major operational changes that will result in significant improvements in both water supply and flood control benefits across the basin.

However, the Study identified a short list of five Operating Plan measures that could be considered as viable alternatives to the existing provisions in the 1989 Operating Plan. These measures were largely developed as responses to specific seasonal conditions, (Table C).

Table C Summary of alternative Operating Plan measures

Alternative Operating Plan Measure	Objective
1. Winter Drawdown Elevation Targets (two options)	Allows for changes in winter storage in reservoirs, for improved operations that account for antecedent soil moisture and watershed basin conditions
2. Winter Drawdown Extension to March 1	Extends reservoir drawdown date from Feb 1 (1989 Agreement) to March 1, providing additional river flow for improved environmental benefits during February
3. Lower Spring Maximum Flow Limits	Reduces the spring flow limits during small/moderate flood years and non-flood years to reduce flood peaks and agricultural flood risk in riverine reaches in North Dakota
4. Summer Operations (two options)	Provides operators guidance for reservoir storage and river flow to maintain lower flow limits during targeted summer flood events to mitigate flood risk
5. Apportionment Year Shift to a Water Year	Changes the apportionment calculations from a Calendar Year (Jan. 1 to Dec. 31) to a Water Year (Nov. 1 to Oct. 31) to ensure flood protection releases in November and December are credited towards apportionment

The alternative Operating Plan measures were evaluated in detail, through a series of workshops with members of the Study Board, the PAG and RAAG, using the visualization tool. The in-depth analysis and comparison included evaluating the alternative Operating Plan measures under a wide range of water supply conditions. Figure D shows how the most promising Operating Plan measures may be sequenced in comparison to the 1989 Agreement.

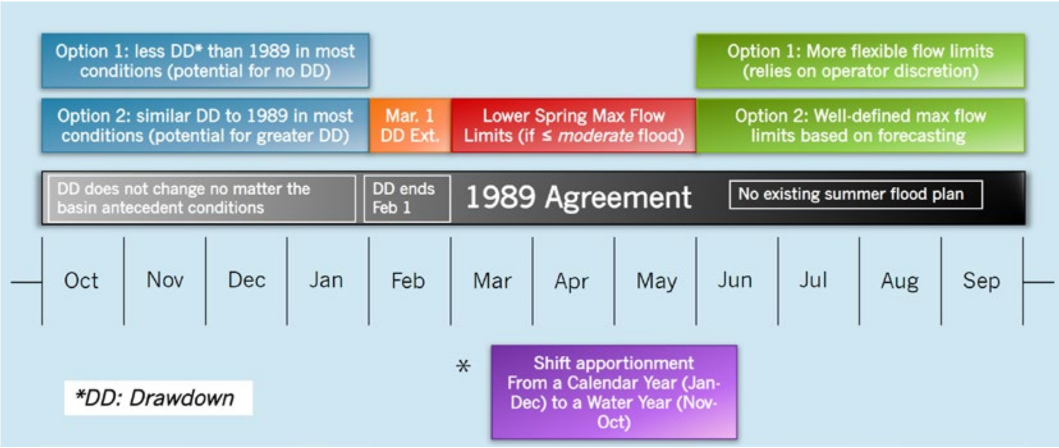

Figure D Sequencing and timing of alternative measures compared to operations under the existing 1989 Agreement

Based on its evaluation of the alternatives, the Study Board made the following key findings:

Alternative Measure 1:
Winter Drawdown Targets – Options 1 and 2

The analysis of **Alternative Measure 1** showed that:

- Antecedent soil moisture conditions can be used for operational decisions on winter drawdown target elevations, adjusting for Dry, Normal or Wet basin conditions, with trade-offs to the amount of water stored in reservoirs
- Depending on the option selected, benefits could be accrued to water supply or to river water quality
- Reservoir storage would still require flood risk management

Alternative Measure 2:
Winter Drawdown Extension to March 1

The analysis of **Alternative Measure 2** showed that:

- Extending the reservoir drawdown target date from February 1 to March 1 draws water down from the reservoirs over a longer winter period, improving river water quality and aquatic habit

Alternative Measure 3:
Lower Spring Maximum Flow Limits

The analysis of **Alternative Measure 3** showed that:

- Lowering of the spring maximum flow limits reduces flood risk of agricultural lands downstream of Minot, North Dakota, with a trade-off of storing water at higher levels in the reservoirs
- This approach reduces flood risk for small to moderate flood events (peak flows of approximately 57-85 m^3/s (2,000-3,000 ft^3/s) at Minot, North Dakota)
- The trade-off is that storage used for these smaller floods may not be available should a larger flood event occur (i.e., increased risks could occur)

Alternative Measure 4:
Summer Operations - Options 1 and 2

The analysis of **Alternative Measure 4** showed that:

- Establishing a more robust summer flood Operating Plan that provides clearer operator guidance in managing summer floods
- Both options use reservoir storage and require careful management to reduce reservoir impacts and manage risk related to the passage of higher flood events should they occur

Alternative Measure 5: Apportionment Year Shift to a Water Year (November to October)

The analysis of **Alternative Measure 5** showed that:

- Changing apportionment rules to be calculated from November to October ensures winter releases of water from Canadian reservoirs supporting flood risk management are credited to Canada as apportionment to the United States; this would result in more gradual releasing of flood water and assist in water supply storage and management in Canada
- The volume of apportioned water is not changed. However, the trade-off in changing the apportionment rules to a Water Year from a Calendar Year (January to December) results in a shift of timing for the apportioned water delivered to the United States, and slightly decreases the storage at Lake Darling in the United States

Climate variability and change in the basin

There is significant evidence pointing to a high degree of natural variability in the Souris River basin's hydrometeorology. Both natural climate variability and the potential future impacts of human-driven climate change poise a formidable challenge to formulating an enduring water management plan for the basin. To better understand and plan for climate variability and change, the Study team reviewed recently published, regionally relevant scientific research characterizing the effects of human driven climate change on hydrometeorology. As part of this literature review, the Study team also summarized studies which investigated naturally occurring climate variability, as apparent within paleo-flood records collected in the vicinity of the Souris River basin. After performing a literature review, the study team performed basic statistical analyses of observed, hydrometeorological records collected throughout the Souris River basin. In addition to evaluating observed records, the Study team also conducted a comparative analysis of global climate model (GCM) based historical simulations versus projected, climate-changed simulations of precipitation and temperature.

It was found that although future climate change may fall within the historic natural variability experienced in the basin, it is also possible that climate change may have an effect on the timing/seasonality, variability, intensity, frequency and duration of streamflow events. There is evidence of increasing temperatures in both the historic record and projections of future meteorology. There is more uncertainty and less consensus in observed and projected precipitation trends, however, in general the frequency and intensity of extreme precipitation events and annual precipitation is anticipated to increase. There is little consensus in the literature reviewed or observed records analyzed concerning trends in observed or projected annual streamflow.

The Study team was originally scoped to model sequences of climate-changed hydrology specific to the Souris River basin. Generating climate-changed hydrology involves the development of a hydrologic model calibrated and configured for continuous simulation. To fulfil this need, a MESH model (Modélisation Environnementale, Surface et Hydrologie) of the Souris River basin was produced. MESH is able to capture distributed storage effects and the physical processes associated with snow accumulation and melt. To derive climate-changed hydrology, outputs derived from GCMs are required to force the hydrologic model. Raw GCM outputs must be downscaled and bias-corrected prior to being adopted in support of water resources modeling and decision making. This process is resource intensive. Only one off-the-shelf downscaled and bias-corrected product is available for the Souris River basin. This product is derived using a single carbon emissions pathway and a single GCM. Due to the considerable uncertainty associated with the assumptions required to produce climate-changed hydrometeorology, to appropriately characterize the effects of climate change on hydrology, results must be based on an ensemble of GCMs. Thus, for the current Study, the team was limited to developing a workflow process and conducting a proof-of-concept run demonstrating how GCM based meteorological outputs could be used to derive climate-changed hydrology using MESH and HEC-ResSim (Hydrologic Engineering Center's Reservoir System Simulation Model). As new GCMs and mechanisms for downscaling and bias corrections become available, these data sources can be used along with the workflow process defined as part of this Study effort to further improve the Study Board's understanding of future hydroclimatic conditions in the basin.

To further characterize how human driven climate change and natural climate variability will impact water management in the Souris River basin, it is suggested that resources be dedicated to continued monitoring of observed hydrometeorology, improving the MESH model and the generation of GCM based assessments of projected climate-changed hydrology. To address the residual risk that climate variability and change poise to future water management as part of the Study, it is recommended that adaptive management be incorporated in the Operating Plan being proposed for the Souris River basin.

Other water management considerations in the basin

Over the course of the Study, the Study Board addressed a number of important emerging water management issues in the basin.

Impacts of artificial drainage

There are public concerns that the drainage of marshes, prairie potholes and other wetlands – undertaken to allow for increased or more efficient agricultural production – has increased the severity of flooding in the basin. As a result of these concerns, a review of the possible impacts of artificial drainage from the basin was added to the Study's work plan.

The Study concluded that artificial drainage has increased the basin's effective drainage area (the portion of the basin that may contribute runoff), although the change is not uniform throughout the basin. The Study was not able to quantify the extent of artificial drainage across the entire Souris River basin due to a lack of complete, comparable data sets. The existing wetland inventories in the three jurisdictions are incomplete, use different classifications and are based on different imagery dates. (For a more complete analysis, please see: HH3: Souris River Basin Artificial Impacts Review)

During extreme floods, such as in 2011, wetland drainage has a minor to insignificant impact, as all the wetlands are filling and spilling. However, based on the available data, it is likely that wetland drainage has the greatest impact in the basin in average to moderate runoff events and floods, resulting in more frequent occurrences of a 1:10-year flood.

Wetland drainage is potentially deteriorating water quality in the Souris River basin. However, it is not possible within the scope of the Study to separate out and quantify this impact, given the ongoing impacts of other activities on water quality, such as changing land management practices.

Since post-European settlement, the Souris River basin continues to experience extensive modifications through land use changes (e.g., urban and rural development, agriculture and industrial development, road and rail transportation networks). While the natural variability of floods and droughts in the basin will continue, there is a need to better understand the impacts of land use changes and climate change in the region.

Water quality

Water quality of the Souris River was identified as an important issue during the Study's public engagement process. In response, the Study developed a series of water quality PIs to help evaluate potential alternative operating measures. The United States Geological Survey (USGS) undertook an analysis of the Souris River water quality in relation to flow under the guidance of the Study Board.

The analysis was conducted at three locations in North Dakota: Sherwood, Minot, and Westhope. The Study found that variability in concentration for chloride, sodium, sulfate, and total dissolved solids is largely explained by the variability in flow and can be used to evaluate minimum flow thresholds for each season. The variability in other constituents such as total iron, total suspended solids and nutrients was explained largely by other factors, including seasonality. The implications of minimum flow thresholds were not possible to evaluate with limited data.

The ISRB has a mandate to report yearly on compliance with the established water quality objectives for the two international border crossings near Sherwood and Westhope, North Dakota. Under this mandate, the ISRB has developed a two-year International Watersheds Initiative (IWI) project for evaluating water quality trends for the entire Souris River basin. The ISRB IWI project has run in parallel to the Study. The findings of this project, which began in 2020, could be used to enhance the water quality PIs developed under the Study. The improved water quality PIs will help assess the effectiveness of the operational changes with respect to water quality conditions.

Given the public interest in water quality conditions in the basin, the Study Board concludes that water-quality monitoring should be continued as a basin-wide, long-term activity. It is expected that such an activity would capture a full range of hydrological conditions, including changes on the landscape and reservoir operations. The resulting long-term dataset will be critical for evaluating changes in water quality as well as improving knowledge of interconnections between hydrological conditions, landscape changes and reservoir operations on water quality.

Aquatic ecosystem health

Although the Study did not directly investigate aquatic ecosystem health, it did develop several PIs that provide a measure of the influence that a proposed operational change may have. Similar to the water quality trends analysis being conducted by the ISRB, the Study recognized that the continuous dissolved oxygen (DO) monitoring investigation being conducted by the ISRB as an IWI project will contribute greatly to improving understanding of processes affecting DO concentrations in the Souris River.

The Study Board concludes that the findings of this continuous DO monitoring study will be useful in improving the aquatic ecosystem health PIs developed under the Study and in assessing the effectiveness of the operational changes with respect to aquatic ecosystem health conditions.

In addition to the improvements in the aquatic ecosystem health PIs developed under the Study, the Study Board believes that the potential for interconnecting water quantity and quality modeling should be explored. The additional data and knowledge gained from the efforts related to water quality trend analysis and continuous water quality monitoring will offer new insights into the possible interactions between hydrology, climate-driven flow conditions, aquatic ecosystem health and landscape changes.

Manitoba-based concerns raised by Public Advisory Group

Throughout the Study's engagement process, PAG members from Manitoba raised region-specific concerns related to the Souris River in Manitoba in the river's reach from Westhope (at the North Dakota border) to its discharge into the Assiniboine River near Wawanesa. They suggested that more analysis is needed to address the following priority items:

1. a better understanding of the reconstructed hydrology for the Souris River including the reach from Westhope to Wawanesa, for more complete knowledge of how the river in the Manitoba reach may have been influenced by upstream control structures;
2. a better understanding of the United States to Canada apportionment and minimum flow rules established in the current transboundary operating agreement; and,
3. a more comprehensive assessment of how the river's water quality in the Manitoba reach may be impacted or benefited by the operations of the Souris River, including structures not in the Study scope such as the J. Clark Salyer National Wildlife Refuge.

Dam Safety

Dam safety analysis was not originally included in the recommended scope as a task in the work plan for the study. The Study did, however, consider an alternative that used regulation of flows and reservoir pool levels that in extreme events would reduce overtopping dam risk. In a December 21, 2020, letter from governments, the IJC was advised that issues with respect to dam safety were outside of the scope of the Study. In addition, both governments stated that they had separately provided direction to the 'designated entities' under the 1989 Agreement to begin technical discussions on understanding the hydrology of the basin that would support further work related to dam safety.

Several considerations surrounding the implications of various dam safety operating scenarios were investigated within the Study. These concepts and potential options were not brought to a Study conclusion due to the complexity of the tasks, lack of study resources, and the revised direction by the governments. Some dam safety elements oriented towards extreme hydrologic events were initially formulated (pool restrictions, target flow changes, as examples) but the complexity could not be appropriately addressed within the Study.

The Study has produced most, if not all, of the tools that will be required to assess the implications of modifying operational rules to accommodate dam safety criteria. Once the issue of dam safety is satisfactorily resolved, these tools are available to assess and identify a plan that is consistent with the 1989 Agreement and the 1909 Boundary Waters Treaty.

Adaptive management

Adaptive management is a structured, iterative approach for improving decisions through long-term monitoring, modeling and evaluation. It is increasingly recognized as having an important role to play in water management, particularly at the scale of large basins such as the Souris River basin. It can assess the effectiveness of water management efforts in light of changing environmental and socioeconomic conditions. It also may help decision-makers deal with the uncertainty of water supplies associated with climate variability and change in the basin.

Regardless of the alternative Operating Plan measures that may be adopted under the 1989 Agreement, there will continue to be a need in the basin for ongoing efforts in communication, monitoring, modeling and research to assess risk, address uncertainties and changing conditions and identify appropriate adaptive actions.

There are several important challenges for strengthening adaptive management approaches in the Souris River basin. These include:

- the fact that the 1989 Agreement covering the Souris River basin is not an instrument of the IJC, but rather an international agreement between the United States and Canada and therefore not easily modified;
- the need for a long-term funding commitment; and,
- the need to engage multiple agencies in different jurisdictions.

There appears to be opportunities for building on several of the Study's initiatives and findings, and incorporating and strengthening adaptive management approaches for managing water levels and flows in the Souris River basin within the context of the 1989 Agreement.

These opportunities include:

- modifying the 1989 Agreement by clarifying in the Agreement the organization or organizations responsible for conducting the tasks associated with successful adaptive management and extending the period of review from five to 15 years;
- strengthening the role of performance indicators and Indigenous science; and,
- establishing an adaptive management committee for the Souris River basin.

Study Board Findings and Recommendations

Based on the results of the analyses described in this report, the Study Board presents its summary of findings and recommendations. The Study Board acknowledges that the governance mechanism of the 1989 Agreement differs in both countries. Canada has designated the Province of Saskatchewan as the Canadian entity for the construction, operation, and maintenance of the improvements mentioned in the Agreement, whereas in the United States, these responsibilities have been designated to federal agencies – the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service. It is important to acknowledge that the ISRB has an oversight responsibility and function, under the purview of the IJC which includes providing the IJC and the designated entities, under the 1989 Agreement, recommendations on how flood operations and coordination activities could be improved. Keeping this in mind, under the ISRSB's analysis, the Study team has grouped its analyses under a series of five themes, outlining its findings and recommendations. **It is important to understand that some of these findings and recommendations may result in changes to the 1989 Agreement. The Parties to the Agreement (i.e., the governments) will need to determine a resolution framework for these recommendations.**

Theme 1. Reviewing the 1989 Agreement

a. Finding: 1989 Agreement Language review for Annex A

The Study Board completed its review of the language of the 1989 Agreement. The Study Board agreed on an updated 2020 plain language document to strengthen the language for clarity and improved understanding. Six items were unresolved in the review. Improved plain language of the Agreement is useful to guide the IJC and its jurisdictions which operate the water structures in the river system.

Therefore, the Study Board recommends that:

> The IJC support the plain language revisions and clarifications to the 1989 Annex A recommended by the Study Board (revised language will need legal review and an implementation plan).
>
> The IJC consider advising the governments on the six issues that need guidance, direction, and legal analysis by the Parties to the Agreement.

b. Finding: Performance of the 1989 Operating Plan

The Study Board concluded that, overall, the 1989 Operating Plan has performed well in providing water supply and flood control benefits.

The addition of Grant Devine Lake, Rafferty Reservoir, Boundary Reservoir, and Lake Darling to the Souris River System provided flood protection for the spring snowmelt in 2011, but does not provide enough flood storage for protection from runoff similar in magnitude to the summer 2011 basin-wide rainfall runoff events. However, the reservoirs do provide significant to modest flood protection from the Estevan, Saskatchewan, reach to as far downstream as Westhope, North Dakota, and into Manitoba for floods similar in magnitude to the major floods experienced in 1969 and 1976.

In addition to the direct benefits to flood control and water supply, the presence of the Souris River Project reservoirs, as modeled under the baseline simulation, also resulted in benefits and impacts to secondary effects on environmental resources, socio-economic components, historic and cultural sites, water quality and recreation.

The existing plan under the 1989 Agreement works well in relation to water supply and flood control. There are no major operational changes that will result in significant improvements in both water supply and flood control benefits across the basin.

The Study Board recommends that:

> The modeling systems developed by the Study, and used to evaluate flow scenarios (including the effects and performance of the 1989 Agreement), continue to be used and updated to evaluate operational performance.

Theme 2. Strengthening water supply and flood control benefits

Finding: Alternative measures for consideration of improvements to the 1989 Agreement

The hydrological research by the Study supports the conclusion that the 1989 Agreement is effective in achieving its intended objectives of flood protection and water supply benefits. Based on the modeling that was completed, only marginal benefits to water supply and flood protection could be identified. This is due to the constraints of the basin's natural characteristics and the river system's existing water infrastructure.

The Study team has documented, through extensive analyses, the merits and effectiveness of the 1989 Agreement, in providing flood protection and water supply, within the constraints of the natural systems and human-built water infrastructure systems of the Souris River. While the 1989 Agreement is functioning well, options for improvements exist, but will result in a need to balance performance trade-offs.

Therefore, the Study Board recommends that:

> The following suite of alternative measures be considered for incremental or marginal improvements to the 1989 Agreement:
>
> 1. Modify the Winter Drawdown Elevation Targets ***to build greater flexibility into reservoir operations by varying reservoir elevation targets according to antecedent moisture conditions in the basin.***
> 2. Extend the Winter Drawdown Date ***from February 1 to March 1 to provide additional river flow for improved environmental benefits during February.***
> 3. Lower the Spring Maximum Flow Limits ***to reduce flood peaks and agricultural flood risk during small to moderate floods in riverine reaches in North Dakota (i.e., floods under 57-85 m^3/s or 2,000 to 3,000 ft^3/s).***
> 4. Establish a Summer Operating Plan ***to provide more guidance to reservoir operators to better manage summer reservoir operations under all conditions.***
> 5. Shift the Apportionment rule calculations to a Water Year (November to October) ***from the current Calendar Year (January to December) to ensure flood protection releases in November and December are credited towards apportionment.***
>
> Selecting the best options will need to consider the full suite of alternative measures, options within the measures, and seasonal sequencing,

culminating in choices to replace or remain within established 1989 rules. Careful analysis of trade-offs is required by the Governments of Canada and the United States to find the best and most balanced options for Canada, the United States, Saskatchewan, North Dakota, Manitoba, and the citizens in the basin, including Indigenous Nations, and diverse stakeholders who have vested interests in the Souris River.

Theme 3. Improving data collection and management

Finding: Precipitation gauges

The Study Board identified that gaps in precipitation gauging exist, affecting the meteorological data and risk analysis, which could impair data analysis and decision-making for flow management.

Therefore, the Study Board recommends that:

The IJC, through the International Souris River Board, engage with all the appropriate agencies, to report regularly on any efforts to reduce identified gaps in precipitation gauging stations within the Souris River watershed.

The IJC work with the International Souris River Board to determine an appropriate reporting interval.

Finding: Streamflow metering gauges

The Study Board identified gaps in flow gauging (also found in previous studies). These gaps impair analysis of river flow data and risk analysis, which could impair flow management decisions.

Therefore, the Study Board recommends that:

The IJC, through the International Souris River Board, engage with all the appropriate agencies, to report regularly on any efforts to reduce identified gaps in streamflow gauging stations within the Souris River watershed.

The IJC work with the International Souris River Board to determine an appropriate reporting interval.

Finding: Collection of additional hydrologic data

The Study Board identified gaps in key hydrological data and data collection in the Souris River basin. These include gaps in:

- monitoring snow survey data for flood forecasting and water supply management;
- soil moisture data that affect knowledge of antecedent conditions affecting hydrology; and,

- low-flow and drought monitoring tools for water supply decision support, including methods and datasets to better estimate evapotranspiration data for reservoirs and throughout the basin.

In addition, there is a need for improved hydrologic models targeted to the Souris River prairie topography, frozen ground conditions and artificial drainage conditions within the basin.

Each of these gaps and needs influence effective decision making for flood protection and water supply management.

Therefore, the Study Board recommends that:

> The IJC, through the International Souris River Board, engage with the appropriate agencies, to prioritize and report regularly on any efforts to reduce identified gaps in other hydrologic data within the Souris River watershed.
>
> The IJC work with the International Souris River Board to determine an appropriate reporting interval.

Finding: Better dissemination of hydrologic data

Better dissemination of hydrologic data is necessary to incorporate real-time meteorological and hydrological data for the Souris River basin. Reinvigorating the IJC website would allow for improved awareness of actual basin conditions by the public and other users of the IJC website and promote better flood protection and water supply awareness to serve as an advance warning system to guide mitigation measures, as well as to improve public awareness of flow operations management.

Therefore, the Study Board recommends that:

> The IJC, through the International Souris River Board, develop better methods to disseminate all hydrologic data (including flood forecasting, water flows, and flow operations) in the Souris River watershed, and that these efforts be reported on regularly.

Finding: LiDAR and bathymetry for reservoirs

Area-capacity curves are used to understand the volume of water stored in reservoirs. Data gaps need to be filled to develop more accurate area-capacity curves for Rafferty and Grant Devine reservoirs. Gathering these data will improve flood forecasting, water supply and operational flow management of these reservoirs.

Therefore, the Study Board recommends that:

> The IJC work with the Saskatchewan Water Security Agency (through the International Souris River Board) to provide updates on identifying and filling in data gaps in the Rafferty and Grant Devine area-capacity curves (for example, using LiDAR or bathymetry) for developing improved hydraulic models.

Theme 4. Addressing other water management challenges in the basin

Finding: Artificial drainage impacts review

Artificial drainage is practiced throughout the basin. Insufficient scientific data exist to fully understand its potential impacts on water supply, water quality and apportionment for flow management. The public and many stakeholders have expressed concerns about artificial drainage risks and impacts. Regulations and legal requirements are continually being reviewed as scientific understanding of artificial drainage increases. The IJC and the Souris River basin resource agencies and the public need to be aware of the current knowledge and legal requirements of artificial drainage and its potential impacts on operations management of the Souris River.

It is recognized that artificial drainage may have linkages to the IJC's mandate through apportionment. Furthermore, there are also public concerns on drainage impacts to water quality, water quantity and wetlands.

Therefore, the Study Board recommends that:

> The International Souris River Board share scientific understanding of Souris River artificial drainage every two years, to advance evolving expert and public knowledge of the impacts, as well as the associated legal and regulatory requirements.

Finding: Adaptive management

Adaptive management approaches have been established in the 1989 Agreement (e.g., adjusting flows and reservoir levels to address climate and hydrologic variability). Building on several of the Study's initiatives and findings, there are opportunities to strengthen adaptive management approaches for managing water levels and flows in the Souris River basin within the context of the Agreement. Furthermore, adaptive management approaches would seek to continually adapt to new knowledge, new science, and changing basin conditions for improved operations and decision making.

Therefore, the Study Board recommends that:

> The IJC (and, where necessary, the Parties to the Agreement) consider strengthening adaptive management approaches in managing water levels and flows of the Souris River, with the understanding that any changes to the 1989 Agreement will require government to government consensus. Strengthening adaptive management may include, among other things:
>
> - clarifying roles and responsibilities for conducting adaptive management tasks (e.g., determine if the ISRB, a new adaptive management committee, or a different governance structure is best suited to assume adaptive management roles; support roles of operating and designated agencies participating in adaptive management, etc.);

- extending but formalizing the period of review of the Operating Plan from five years to potentially up to 15 years (a better period for adapting to new knowledge); and,
- clarifying the roles and responsibilities of the IJC and the International Souris River Board in adaptive management studies and periodic reviews.

Adaptive management should consider the ongoing role of performance indicators and how they may be a useful tool in guiding new knowledge, studies and decisions. Adaptive management should consider the role of Indigenous Nations and Indigenous Science, and how this knowledge can be incorporated and strengthened under the leadership of the ISRB. The ISRB should be responsible for reviewing and updating the PIs developed in the Study and collaborating with Indigenous Nations to develop performance indicators that reflect their interests.

Adaptive management will require dedicated resources from many agencies. The IJC and governments will need to work with the ISRB to consider options for establishing adaptive management governance processes and activities.

Moving forward, if adaptive management is to be formally enhanced for the Souris River basin – with its commitment to continuous monitoring and periodic review of the performance of the operations -- then it will need to have some foundation in an updated Agreement between the two countries.

Theme 5. Building on the Study's engagement and outreach

Finding: Continued engagement with the Public Advisory Group and the Resource and Agency Advisory Group

The Study Board has undertaken extensive public and resource agency engagement over the course of the Study. There are now increased interests and expectations for future engagement beyond the Study, and for an ongoing dialogue between these groups and the IJC into the future.

Therefore, the Study Board recommends that:

The IJC and International Souris River Board consider continued engagement with the Study's Public Advisory Group and Resource and Agency Advisory Group.

Finding: Engagement with Indigenous Nations

The Study Board sought input from Indigenous Nations with current and ancestral interests in the Souris River basin. The increased awareness from Indigenous Nations has led to an interest in continued engagement beyond the Study, through an Indigenous Advisory Group and Indigenous representation on the International Souris River Board.

Therefore, the Study Board recommends that:

> The IJC continue to engage with Indigenous Nations. Indigenous Nations expressed interest in forming an Indigenous Advisory Group and participating as Board Members on the International Souris River Board

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Measurement Units

Throughout this report, measurements are reported first in metric units, with the corresponding United States Customary System Units included in parentheses. A list of conversion factors for common measurements is included at the end of the report.

Vertical Datum

All elevations listed in this report referring to an elevation in Canada use the CGVD28 vertical datum. All elevations referring to an elevation in the United States use the NGVD29 vertical datum.

List of Acronyms

The following is a list of acronyms used in the report:

ARBI	Assiniboine River Basin Initiative
ARD	Manitoba Agriculture and Resources Development (formerly MB Sustainable Development)
CAG	Climate Advisory Group
CWI	Canadian Wetland Inventory
DO	Dissolved oxygen
ECCC	Environment and Climate Change Canada
ESM	Earth System Modeling
GCM	Atmospheric General Circulation Model
HEC-ResPRM	Hydrologic Engineering Center's Reservoir System Prescriptive Reservoir Model
HEC-ResSim	Hydrologic Engineering Center's Reservoir System Simulation Model
HEC-RAS	Hydrologic Engineering Center's Reservoir Flow Release Model
IJC	International Joint Commission
IRG	Independent Review Group
IWI	International Watersheds Initiative
ISRB	International Souris River Board
ISRREB	International Souris-Red Rivers Engineering Board
ISRSB	International Souris River Study Board
MAFL	Maximum Allowable Flood Level
MESH	Modélisation Environnementale, Surface et Hydrologie
NDSWC	North Dakota State Water Commission (as of Aug1/21: ND Dept. of Water Resources)
NWI	National Wetland Inventory
NWR	National wildlife refuge
PAG	Public Advisory Group

PI	Performance indicator
POS	Plan of Study
RAAG	Resource and Agency Advisory Group
RCM	Regional Climate Model
SPEI	Standardized Precipitation and Evapotranspiration Index
SRJB	North Dakota's Souris River Joint Board (the SRJB is distinct from the ISRB)
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
USNWS	United States National Weather Service
WQOs	Water quality objectives
WSA	Saskatchewan Water Security Agency
WSC	Water Survey of Canada

1 The Souris River Basin

Image 1 Souris River in summer

1.1 Introduction

With a river that crosses the international boundary not once, but twice, and a watershed that drains parts of two provinces and one state in the middle of the North American continent, the Souris River basin has long been a model of cooperative water management between Canada and the United States.

The Souris River valley, formed by glacial melt water, has a riparian and flood plain zone that is much more extensive than the small river channel that meanders along the flat prairie topography. The basin's semi-arid prairie landscape has been extensively cultivated and supports a highly productive agricultural economy of farming and ranching. The gently rolling prairie landscape of the basin is also a land of extremes, with risks of drought or flooding from one year to the next. As a result, understanding and managing water supplies and floods in the basin have long been critical to meeting the needs of the many interests that depend on that water – including farming and ranching interests, communities, industries, and the natural environment.

Since 1940, Canada and the United States have worked together through the International Joint Commission (IJC) to establish rules for managing the transboundary waters of the Souris River. These rules, in the form of water-sharing arrangements and Operating Plans, address ongoing critical questions of water supply apportionment and flood control measures. The current Operating Plan has been in place since 1989, part of the *1989 International Agreement between the Government of Canada and the Government of the United States of America for Water Supply and Flood Control in the Souris River Basin* (the 1989 Agreement) (see Appendix 1). That Agreement requires a periodic review of the plan to improve the provision of flood control and water supply benefits.

The International Joint Commission

Under the *Boundary Waters Treaty of 1909* (the Treaty), the governments of the United States and Canada established the basic principles for managing many water-related issues along their shared international boundary. The Treaty established the IJC as a permanent international organization to advise and assist the governments on a range of water management issues. The IJC has two main responsibilities: regulating shared water uses; and investigating boundary water issues and recommending solutions.

In 2011, the Souris River basin experienced an unprecedented flood. It far exceeded any other flood event in the more than 100 years for which records are available (United States Army Corps of Engineers, 2012). Extremely wet conditions in the preceding years, combined with an above average snowmelt and above normal spring and substantial summer rainfall resulted in a series of flood events that significantly affected homeowners, businesses, properties, industry and ecosystems throughout the basin, causing the evacuation of an estimated 12,000 residents and $600 million of property and infrastructure damages throughout rural and urban communities. Industries and agriculture suffered significant impacts as did the ecology of the basin (e.g., loss of trees, ecosystem changes, etc.). Water management and control structures were severely tested as never before.

The 2011 flood focused attention on the existing Operating Plan under the 1989 Agreement. Members of the public, as well as government flood protection and water-management agencies, requested that options for additional flood protection measures, beyond what is currently provided for in the Agreement, be evaluated. In response, the IJC supported the International Souris River Board (ISRB) (a permanent board established by the IJC responsible for oversight of transboundary water issues in the basin, including flood operations and apportionment of river flows), in the establishment of a binational task force in 2012 to develop a scope for a study to review operations in the basin to mitigate flooding while providing secure water supplies.

Following extensive review and engagement with interests in the region, the ISRB prepared a Plan of Study (POS) in 2013. That plan outlined an approach to investigating water management operations in the context of changing hydrological and climatological conditions in the basin. In 2017, the Governments of Canada and the United States issued a Reference to the IJC to undertake the POS (Appendix 2). Later the same year, the IJC established the International Souris River Study Board (Study Board) and issued a Directive providing direction and guidance on the Study's operations (Appendix 3).

Managing Water Supply and Flood Control in the Souris River Basin is the final report of the Study Board to the IJC on its evaluation of water management operations under the 1989 Agreement. The report presents the Study Board's analysis, findings, and recommendations regarding the Operating Plan under the 1989 Agreement and opportunities to strengthen the provision of flood control and water supply benefits to interests in the international basin.

The report is organized into the following nine sections:

Section 1 presents an overview of the Souris River basin.

Section 2 presents an overview of the objectives, organization, and approach of the Study.

Section 3 outlines the comprehensive engagement and outreach component of the Study.

Section 4 summarizes the approach, analysis, and key findings of the Study Board with respect to its:

- review of the language of the existing Operating Plan governing management of the Souris River, as set out in Annex A of the 1989 Agreement; and,
- evaluation of the performance of the 1989 Operating Plan.

Section 5 describes the methodology used by the Study Board to formulate and evaluate alternative Operating Plan measures with potential for improving flood control and water supply benefits in the Souris River basin.

Section 6 summarizes the Study Board's detailed evaluation of a small number of selected alternative Operating Plan measures that could provide improved flood control and water supply benefits in the Souris River basin.

Section 7 presents the Study Board's analysis with respect to climate variability and change in the Souris River basin.

Section 8 presents an overview of several important evolving water management issues in the basin.

Section 9 summarizes the Study Board's major findings and recommendations.

More detailed information on the Study, including technical reports and background documentation, is available on the Study's website: www.ijc.org/en/srsb.

The report has been prepared for the direct consideration of the IJC and the Governments of Canada and the United States. However, it will be of interest to all parties concerned about the future of water levels and flows in the Souris River basin, including federal, provincial, and state resource management agencies, residents of the region, Indigenous Nations, farmers, ranchers, tourism operators, and industries operating in the basin.

1.2 Study setting

The Souris River basin covers about 61,900 km^2 (23,900 mi^2) in the provinces of Saskatchewan and Manitoba in Canada and the state of North Dakota in the United States. The 700 km (435 mi) river originates in its headwaters in Saskatchewan, just southeast of Regina and continues southward, crossing into North Dakota west of Sherwood. The river continues southeasterly past Minot, North Dakota, before turning northward again and crossing into Manitoba just northeast of Westhope, North Dakota. It eventually terminates in western Manitoba, where it discharges into the Assiniboine River near Wawanesa (Figure 1) For the most part, the Souris River (also known as the Mouse River in North Dakota) is a slow-moving stream with a mild slope and complex meander pattern.

Image 2 Souris, Manitoba

Image 3 Weyburn, Saskatchewan

Image 4 Velva, North Dakota

Major tributaries include Long Creek and Moose Mountain Creek in Saskatchewan, and the Des Lacs River, which joins the Souris River near Minot, North Dakota; there are also numerous tributaries in the Manitoba reach.

As indicated in Figure 1, the waters of the Souris River are extensively managed for flood control and water supply by dams, diversion canals and other water resource infrastructure. Major reservoirs include the Boundary, Rafferty, and Grant Devine (formerly Alameda) reservoirs in Saskatchewan, and Lake Darling in North Dakota (see Section 1.4.2). The basin also includes several wildlife refuges and small impoundments along the North Dakota portion of the river.

The Souris River supplies water for a variety of interests, including communities, agriculture, industry, recreation, and ecosystems.

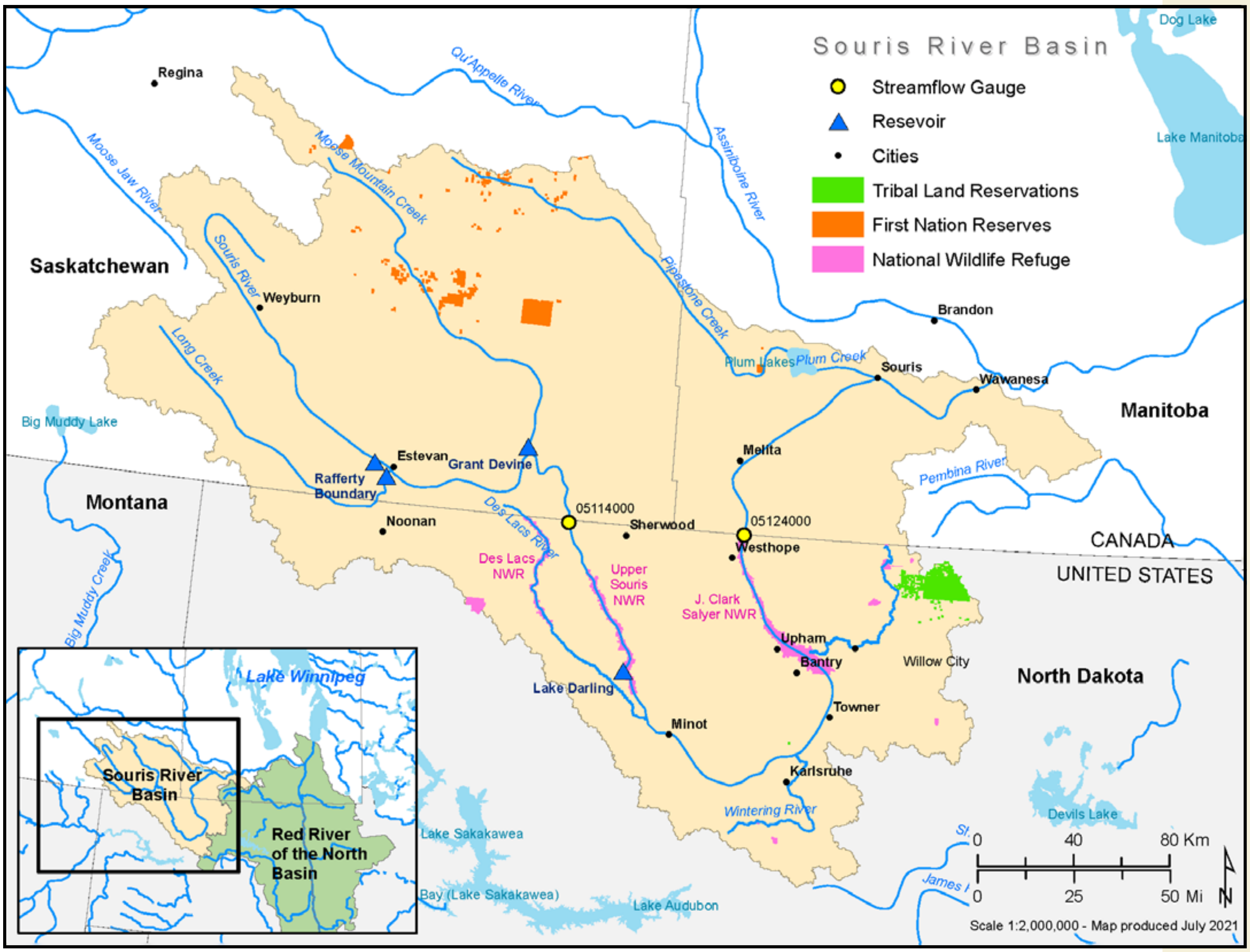

Figure 1 Souris River basin

Natural environment

Until widespread cultivation began in the region about a century ago, the major ecosystem in the Souris River basin was northern mixed grass prairie (United States Fish and Wildlife Service, 2007). Today, the landscape ranges from rolling prairie hills and grasslands with a wide variety of flora and fauna to the scenic Souris River valley and grain fields. The region includes 10 major land cover classifications (Figure 2). The most prominent land cover type is cropland, accounting for more than 72 percent of the region's total area. Other important types of land cover include grasslands (about 12 percent), forests (about four percent) and wetlands (nearly three percent). Water bodies also account for more than five percent of the region's surface cover, largely as shallow ponds and wetlands throughout the relatively flat prairie pothole topography.

In the Souris River basin, an important landscape change in recent decades is related to artificial drainage to increase agricultural production (see section 8.2 for more information on artificial drainage).

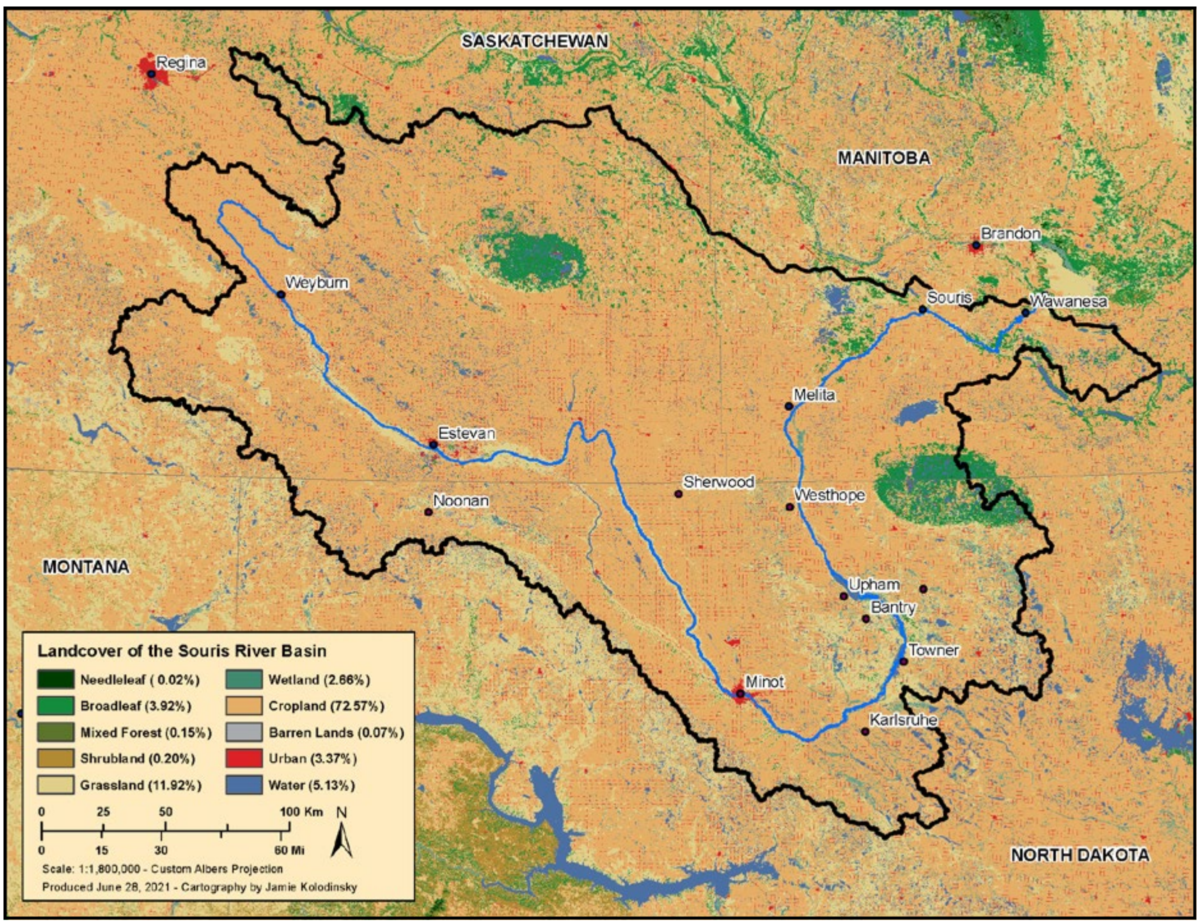

Figure 2 Land cover of the Souris River basin

The wetlands and grasslands of the basin are recognized as globally important breeding and migration habitat for more than 200 species of migratory birds. For example, the prairie pothole region, which covers the entire basin, is the most important waterfowl-producing region on the continent, generating more than 50 percent of North America's ducks (United States Fish and Wildlife Service, 2007). Other birds common to the region include hawks, owls, robins, several species of sparrows, meadowlark, pelicans, crows, starlings, gulls, partridge, swallows, Canada geese, grouse, and pheasant (http://www.sseer.ca/).

Mammals common to the basin include white-tailed deer and mule deer, moose, antelope, coyote, red fox, badger, raccoon, skunks, and rabbits.

In North Dakota, the United States Fish and Wildlife Service (USFWS) manages three National Wildlife Refuges (NWRs) in the Souris River basin: Des Lacs; J. Clark Salyer; and Upper Souris (Figure 1). The refuges were established to serve as a refuge and breeding ground for migratory birds and other wildlife. Two of these refuges include small impoundments to retain water for wetland management, protecting and providing riverine and prairie marshes and other important fish and bird habitat.

Socio-economic setting

The total population in the Souris River basin in both countries is estimated to be 157,000, (IJC, 2020). Major population centers in the basin (as of 2016) include: Estevan (11,250) and Weyburn (10,800) in Saskatchewan; Minot (48,300), Bottineau (2,211 as of 2010) and Belcourt (2,078 as of 2010) in North Dakota; and Souris (1,900) and Melita (1,040) in Manitoba.

The region's economy is relatively diversified, with a mix of agriculture, energy production (including coal mining and coal-fired electricity generation, oil and natural gas production and solar and wind energy development; this region provides 20 percent of the power production for Saskatchewan), service industries and tourism.

Indigenous peoples

Tribes, First Nations, and the Métis Nation have current and/or ancestral interests in the Souris River basin (Figure 3). Their interests can be affected by the changes in water levels and flows in the basin.

Image 5 International Peace Garden

In the Canadian portion of the basin, these include eight First Nations: Swan Lake First Nation; Canupawakpa Dakota Nation; White Bear First Nation; Ochapowace Nation; Cowessess First Nation; Ocean Man First Nation; Pheasant Rump Nakota Nation; and Carry the Kettle Nakoda Nation. As well, the Métis Nation is represented by the Manitoba Metis Federation and the Métis Nation of Saskatchewan (Eastern Region IIa and III).

In the United States portion of the basin, there is one Tribe with reservation land, the Turtle Mountain Band of Chippewa Indians. However, other Tribes with ancestral interests in the Souris River were also contacted as part of the Study: Fort Belknap Assiniboine (Nakoda) and Gros Ventre (A'aninin); Fort Peck Assiniboine and Sioux; Lower Brule Sioux; Rosebud Sioux; Cheyenne River Sioux; Santee Sioux; Crow Creek Sioux; Spirit Lake- Sisseton, Wahpeton and Cut-Head Bands of Yanktonais; Northern Cheyenne; Standing Rock Sioux; Oglala Sioux; MHA- Three Affiliated Tribes – Mandan, Hidatsa, Arikara; Turtle Mountain Chippewa; and Sisseton Wahpeton Oyate of the Lake Traverse.

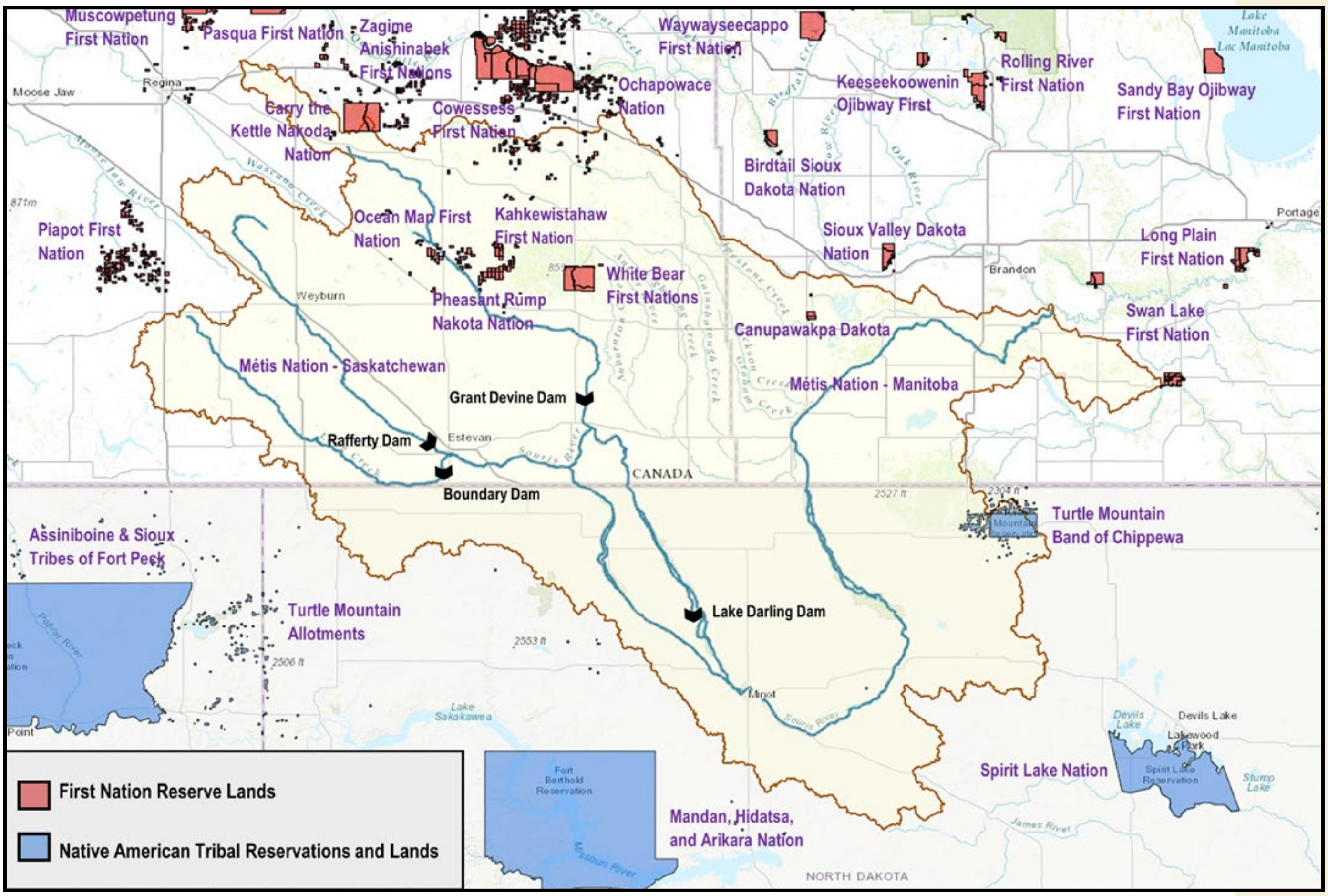

Figure 3 Indigenous Nations in the Study area. (There are Indigenous Nations with ancestral interests in the basin, some of which are indicated in the report text and not on the map).

1.3 Climate and hydrology

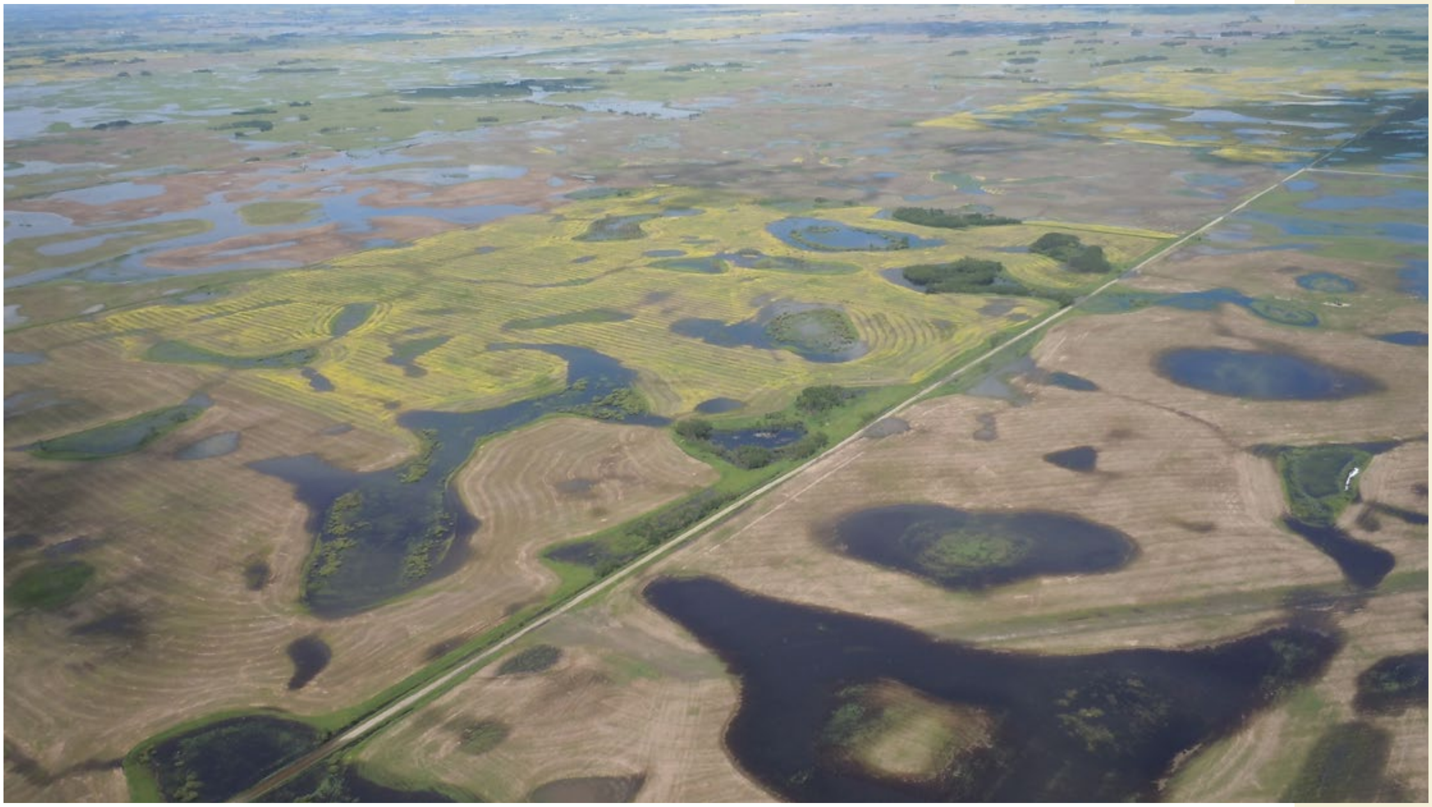

Image 6 An aerial view of the Prairie Pothole landscape and topography

Climate

The Souris River flows through the Great Plains of North America and experiences a continental climate. Average annual precipitation in the basin is relatively low, ranging from about 325-500 mm (about 13-20 in). Long, cold winters tend to retain snowfall until the spring melt, which typically provides most of the stream flow (International Souris River Board, 2009). However, precipitation in the basin can be highly variable, as indicated in Figure 4. Monthly precipitation for 2011 at Estevan, Saskatchewan, is compared to monthly precipitation for 1945 through 2014. The shaded box represents the range in monthly precipitation from the 25th to the 75th percentile. Monthly precipitation in this range is often referred to as normal. The horizontal line within the boxes indicates the median monthly precipitation. The red dots indicate the monthly precipitation in 2011. Blue dots show 2010 precipitation, a much wetter than normal period from May to December. The 2011 extreme flooding followed the extremely wet antecedent conditions of 2010. As illustrated in Figure 4, maximum monthly precipitation for the period of record during both May and June occurred in 2011.

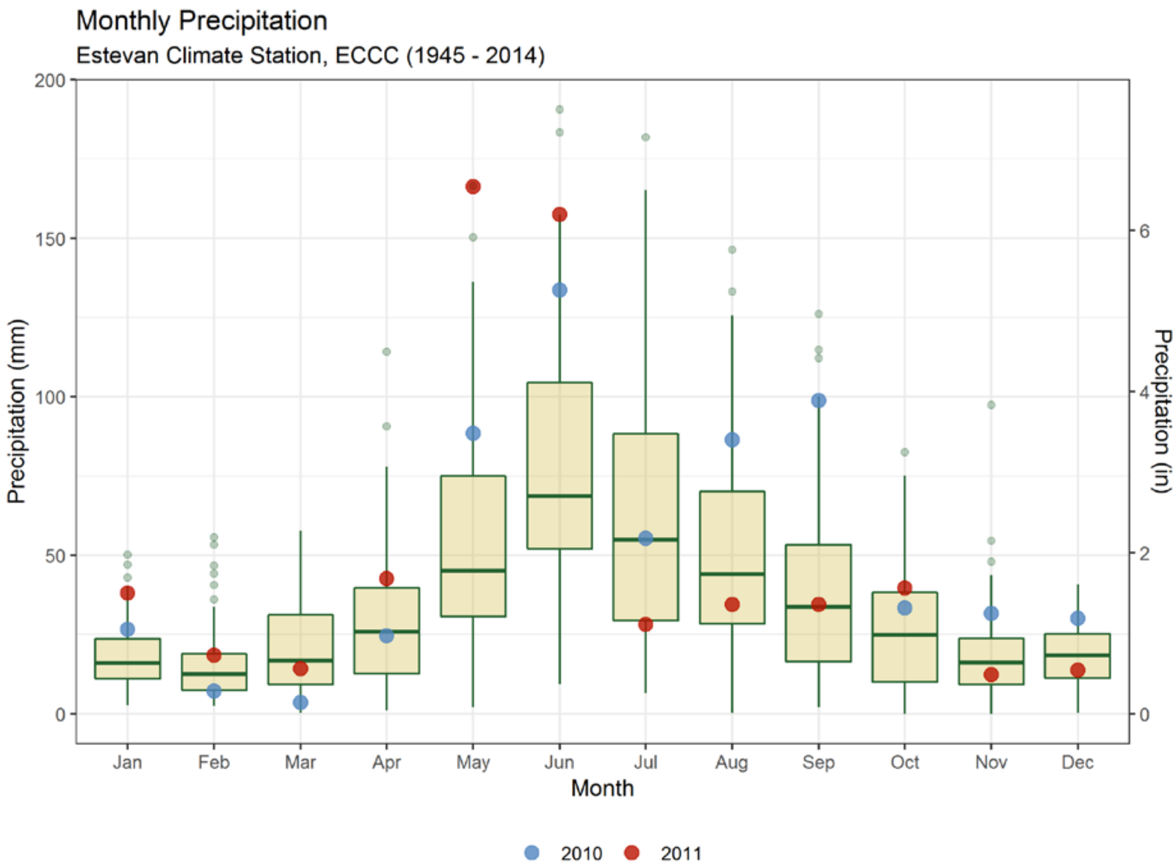

Figure 4 Example of variability of precipitation in the Souris River basin

Hydrology

Figure 5 shows the existing network of gauging stations in the Souris River basin. Discharge and water levels are observed by 70 active gauging stations, of which 49 stations record water levels for the purposes of calculating river discharge, and 21 stations record water levels at lakes and reservoirs. Of the active gauging stations, 57 are in Canada and 13 are in the United States. The Water Survey of Canada (WSC) and the United States Geological Survey (USGS) systematically exchange data for five of the active gauges (two in Canada and three in the United States). The 10 remaining gauges in the United States are operated by the USGS, while in Canada, 42 are operated by the WSC, six by the Saskatchewan Water Security Agency (WSA), and nine by Manitoba Infrastructure.

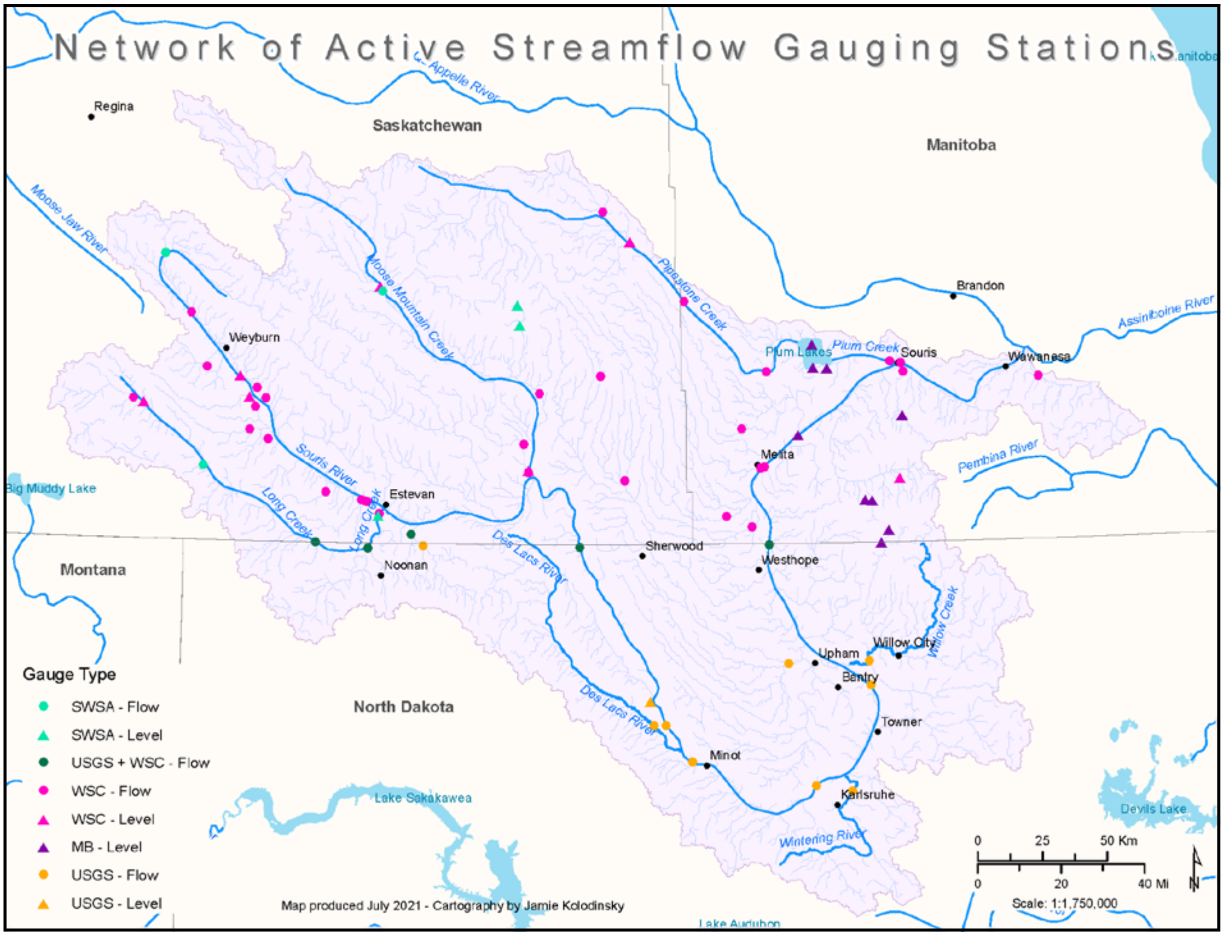

Figure 5 Network of active streamflow gauging stations

The effects of snowmelt and rainfall on river flows and reservoir levels are part of the unique hydrology that characterizes the Souris River basin. Much of the basin is part of the prairie pothole region, which stretches across Alberta, Saskatchewan, Fand Manitoba and extends into North Dakota, South Dakota, Iowa, Minnesota, and Montana. The topography of this region is characterized by the presence of shallow wetlands, called potholes or kettles, which are remnants of the last period of continental glaciation in North America (International Souris River Study Board Fact Sheet, 2012). Elevations in the Souris basin range from 768 m.a.s.l. (2,520 ft. above sea level) at the headwaters of Gibson Creek near Radville, Saskatchewan, to about 349 meters above sea level (m.a.s.l; 1,145 ft. above sea level) at the Souris River's outlet into the Assiniboine River near Wawanesa, Manitoba (a vertical change of only about 419 m or 1,375 ft. over the river's roughly 700 km or 435 mi length).

During the spring snowmelt, the shallow potholes can fill with water, though they typically are isolated from streams and rivers. Under non-flood conditions, much of the watershed does not contribute to the Souris River flows directly because the potholes store water and keep it from flowing into the river. The region's hot, dry summers typically result in rapid evaporation loss from these water bodies, as well from reservoirs and the soil. As a result, the basin normally has an extremely low runoff ratio (that is, the percentage of precipitation received in the basin that ultimately flows out of the basin), compared to other river basins of similar size. Runoff is often less than one percent of the precipitation it receives, and is rarely above five percent of precipitation (Figure 6).

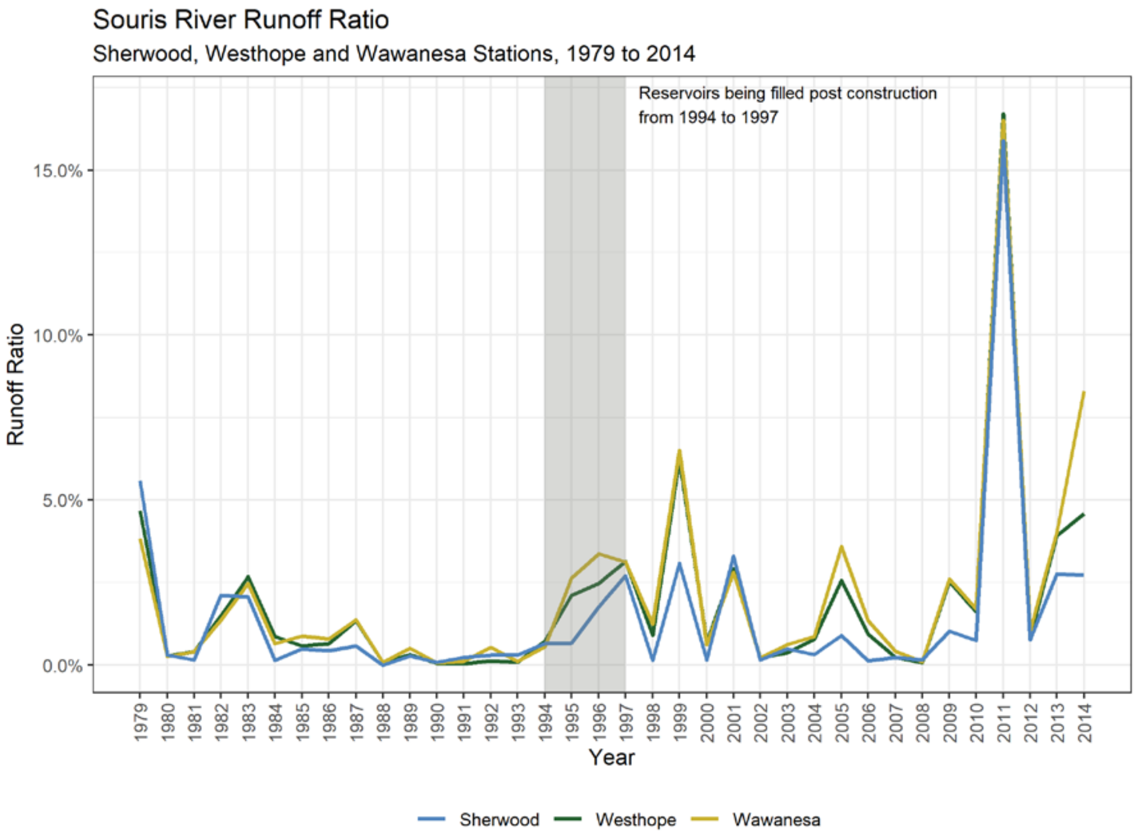

Figure 6 Runoff Ratio of the annual streamflow versus precipitation for the Souris River at Sherwood, North Dakota, Westhope, North Dakota, and Wawanesa, Manitoba, 1979 through 2014

During the winter, blowing snow is extremely common and results in increased sublimation[1] and wind redistribution from wind-swept areas to wind-sheltered areas. Exposed areas can lose 30 to 75 percent of their annual snowfall due to this sublimation and redistribution, resulting in a profound impact on the surface hydrology and energy cycle (Pomeroy and Li, 2000). Most hydrological models do not account for this process in any way.

Frozen soils also have a strong influence on snowmelt runoff, contributing to streamflow and prairie pothole storage. Meltwater infiltration into frozen soils is complex and can be grouped into three general classes for frozen agricultural soils that are predominant in the Souris River basin. One type of frozen soil infiltration results from large cracks in the soil, allowing for unlimited infiltration of snowmelt and little-to-no contribution of snowmelt to streams or prairie potholes. At the other end of the spectrum, another type of frozen soil infiltration results from an ice-lens that completely restricts the infiltration of snowmelt, which allows all the meltwater to runoff to the streams and potholes. Between these two extremes, snowmelt has limited infiltration that depends primarily on the amount of snow in the snowpack and the water/ice content of the first 30 cm (12 in) of the frozen soils. As with blowing snow, frozen soil infiltration is rarely represented properly in hydrological models.

[1] Sublimation is the conversion between the solid and the gaseous phases of matter, with no intermediate liquid stage. In terms of the water cycle, sublimation is the process of snow and ice changing into water vapor in the air without first melting into water.

Lastly, and likely most importantly, the contributing drainage area of the basin is dynamic, making the tracking of how much of the watershed is actually contributing during any given melt or rainfall event difficult. This phenomenon is unique to the prairie pothole environment, making the simulation of streamflow in modeling exceedingly difficult. As was noted in Figure 6 above, the runoff ratios typical in the basin are rarely above five percent.

As a result, only a small fraction of the snowfall or rainfall that falls within the basin ever makes it to the stream. Instead, much of the snowfall or rainfall typically gets caught up in the soil and evaporates, or collects in prairie pothole features (ponds, wetlands) that will fill and evaporate or infiltrate, never or rarely contributing to the rivers. Gross drainage area is essentially static and contributing drainage area changes with the wetness of the basin and the corresponding connectivity of the landscape with the streamflow network. Humans also alter the effective drainage of watersheds to increase agricultural production. These artificial drainage efforts change the relationship between the wetness of the basin and the connectivity of the landscape to the streamflow network.

Image 7 Souris River near Minot, North Dakota, in winter

This drainage system changes how water moves across the landscape and is difficult to characterize in a hydrological model without the appropriate data. A foundational dataset that attempts to characterize gross and effective drainage in the prairie pothole region is from Agriculture and Agri-Food Canada's (AAFC's) now dismantled Prairie Farm Rehabilitation Administration (PFRA). The PFRA began characterizing gross and effective drainage areas in 1970 (Canada, 2013[2]). Figure 7 shows the results of this effort for the Souris River basin. The average contributing areas are considered to contribute flow to the rivers in one out of every two years. In typical runoff years, it is assumed that the effective drainage area contributes water but in wetter years, the contributing area will be greater. It is generally assumed that the flooding of 2011 (see Section 1.5) resulted in nearly 100 percent of the gross drainage area contributing to the streamflow, largely due to the extremely wet antecedent conditions from the previous year, the high snowpack and spring snowmelt, followed by numerous late spring and summer rain events in 2011.

[2] Agriculture and Agri-Food Canada's Prairie Farm Rehabilitation Administration existed from 1935-2013. the reference cited is "PFRA sub-basins of the AAFC Watershed Project - 2013" posted at: https://open.canada.ca/data/en/dataset/4f3c7d6d-e018-4a69-a6cf-a4c327572b24

The relative flatness of the basin also affects the duration of runoff periods. Typically, when flood waters rise above the riverbanks, large areas can be inundated, and it can take many weeks for flood waters to drain.

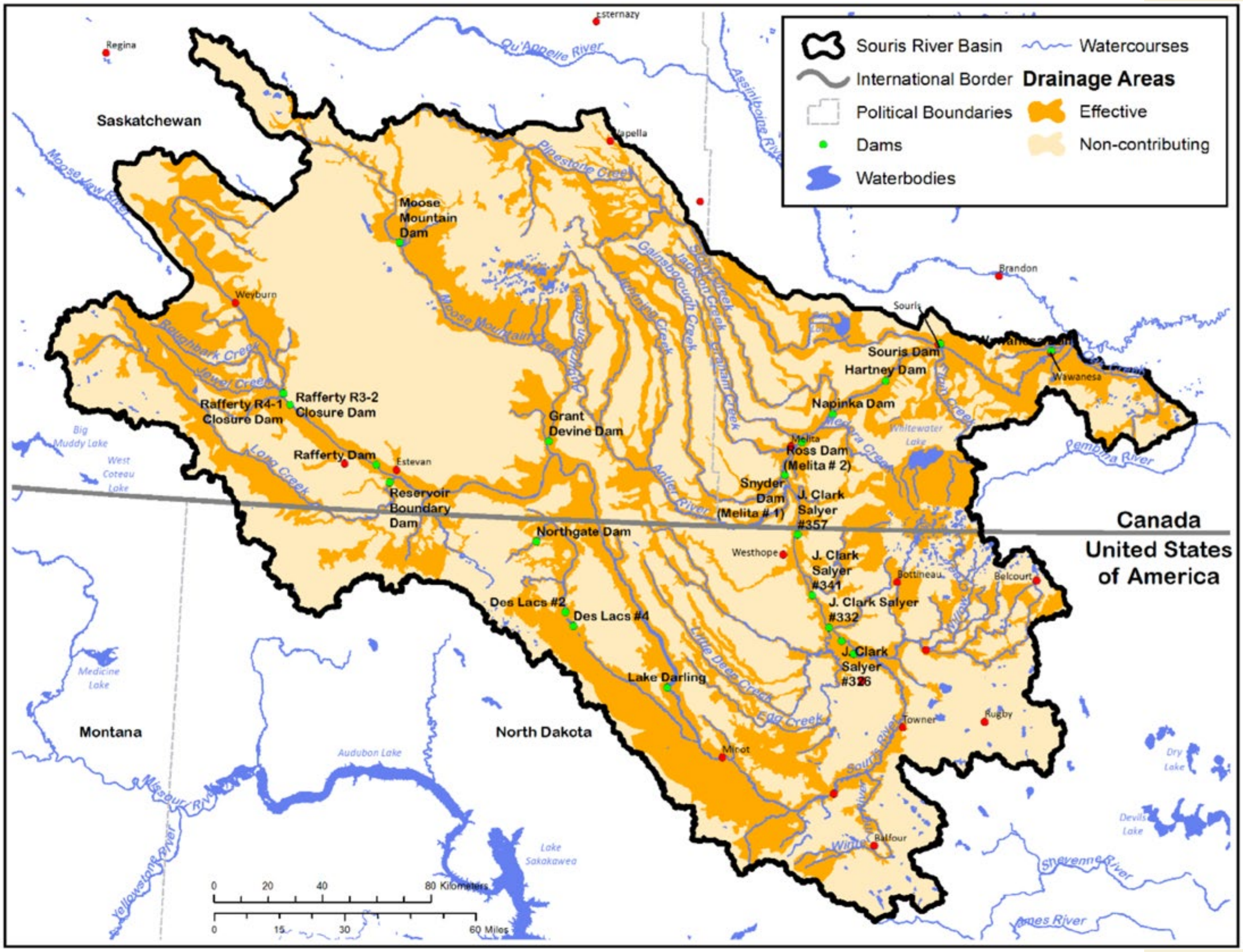

Figure 7 Prairie Farm Rehabilitation Administration (PFRA) average effective and non-contributing drainage areas

The combination of climate and terrain also contributes to highly variable flows in the basin, from day to day and from year to year. When the potholes are empty and the basin is generally dry, precipitation does not have a significant effect on river flows. However, when the potholes and wetlands are full and the basin is already wet, precipitation has a much greater impact. Figure 8 illustrates the high variability in Long Creek, upstream from the Boundary Reservoir in Saskatchewan near the international border. Under certain conditions, the flow can change from a trickle to a torrent in a few days. As indicated in the figure, the annual peak flow in 2011 of 306 m^3/s (10,806 ft^3/s) was more than 16 times the median peak flow of 18.4 m^3/s (650 ft^3/s), while in 1988, the annual peak flow in Long Creek across the international boundary was a negligible 0.008 m^3/s (0.30 ft^3/s).

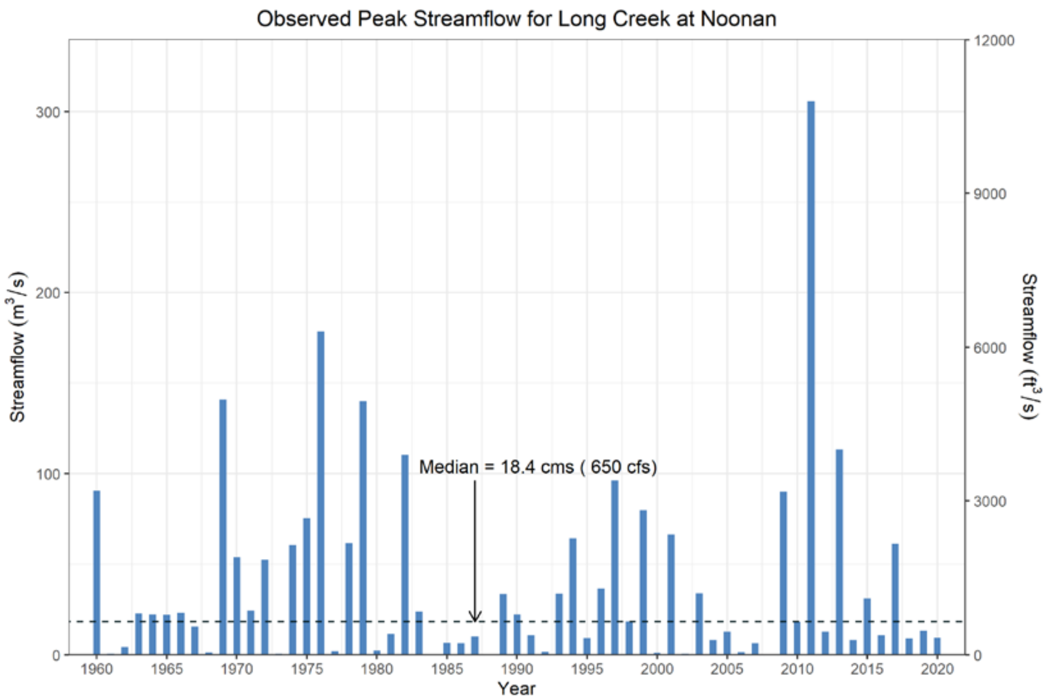

Figure 8 Annual peak streamflow for Long Creek at Noonan, North Dakota, 1960-2020

1.4 An international river basin

The Souris River basin is a transboundary basin under the *Boundary Waters Treaty of 1909*. The involvement of the IJC in the Souris River basin began in 1940, and its role has evolved since that time.

1.4.1 THE ROLE OF THE INTERNATIONAL JOINT COMMISSION

The 1941 Interim Measures

In 1940, the Governments of Canada and the United States asked the IJC to investigate regulation, water use, and the apportionment of the Souris River waters between the two countries. In response to that Reference, the IJC submitted a report to the governments later that same year recommending measures for the cross-border sharing of waters (IJC, 1940). The recommendations were adopted in 1941. They were known as the Interim Measures, as the 1940 IJC study had concluded that the available flow data were insufficient to support a definitive recommendation regarding apportionment between the two countries.

The Interim Measures stipulated that Saskatchewan and North Dakota could continue their current uses of the Souris River waters, and that each could construct a reservoir (at Weyburn, Saskatchewan and on Long Creek near Crosby, North Dakota, respectively). In addition, the measures stipulated that a minimum flow of 0.28 m^3/s (10 ft^3/s) be released from North Dakota to Manitoba from June through October of every year. In 1942, the IJC issued an order doubling that flow level into Manitoba.

From 1941 to 1956, several applications were made to the IJC regarding the management of waters in the basin. In 1949, the IJC approved the construction of a dam on the Souris River near Minot, North Dakota, though the dam was never built.

International Souris-Red Rivers Engineering Board

In 1948, at the request of the Canadian and United States governments, the IJC formed the International Souris-Red Rivers Engineering Board (ISRREB) to report on the use and apportionment of water in the Souris and Red River basins and to develop plans that would benefit both countries. The ISRREB undertook studies on issues of concern and reported to the IJC annually on development activities that had potential transboundary impacts. The geographic jurisdiction of the ISRREB extended along the transboundary region in the prairies from the Poplar River in the west to the Red River in the east, including the Assiniboine River in Manitoba.

International Souris River Board

In 1957, Saskatchewan informed the IJC that it wished to increase water use beyond the levels set out in the Interim Measures. It suggested the provision of 50 percent of the Souris River's natural flow to North Dakota replace the 1941 measures.

In response to this request, the IJC undertook further analysis and in 1958 recommended to the Governments of Canada and the United States that the 1941 Interim Measures be changed to provide both North Dakota and Saskatchewan additional rights to store and divert Souris River basin waters originating within their own jurisdictions. Under these new provisions, Saskatchewan was required to provide a minimum of 50 percent of the river's natural flow to North Dakota.

In 1958, the governments approved the IJC recommendations, including the establishment of a new body, the International Souris River Board of Control (ISRBC) to oversee the water apportionment. The ISRREB and the ISRBC both operated until 2002, at which time they were transformed into two new boards – the International Red River Board (IRRB) and the ISRB. The two new boards combined both engineering responsibilities and water quality and ecosystem health responsibilities for their respective basins. (The ISRB assumed responsibility for water quality in 2007).

Towards a new agreement

Several factors spurred the improvement of water management structures and the construction of new control structures within the Souris River basin -- the ongoing concerns in Saskatchewan of drought conditions and the need to secure a more reliable water supply, severe flooding in 1969, 1975 and 1976, and growing energy development in Saskatchewan.

During this period, the United States was interested in additional flood protection for Minot, North Dakota, and surrounding areas and Saskatchewan was interested in additional water supply for its growing energy industry near Estevan. The United States purchased additional flood control storage in Rafferty Reservoir and Grant Devine Lake (called Alameda Reservoir at the time) from Canada by funding the additional cost associated with constructing larger, dual-purpose structures instead of smaller reservoirs intended solely for water supply.

To respond to these emerging interests, the Governments of Canada and the United States signed an agreement in 1989 providing a new and comprehensive framework for jointly managing the waters of the Souris River basin. The *1989 International Agreement between the Government of Canada and the Government of the United States of America for Water Supply and Flood Control in the Souris River Basin* (the 1989 Agreement) provided a set of objectives, operating guidelines and responsibilities, and review mechanisms regarding management of the major water control structures and apportionment of flows in the basin.

Since 1989, the waters of the Souris River basin have been governed by the 1989 Agreement.

1.4.2 EXISTING CONTROL STRUCTURES

The four main reservoirs covered under the agreement – Rafferty Reservoir, Grant Devine Dam (formerly Alameda Dam), Boundary Dam Reservoir and Lake Darling Dam – are collectively known as the Souris River Project. The Rafferty and Grant Devine reservoirs are operated by the Saskatchewan Water Security Agency (WSA), formerly the Saskatchewan Watershed Authority, and Boundary Dam is operated by the Saskatchewan Power Corporation (SaskPower). WSA assumes responsibility for the Boundary Dam operations during declared flood events. The Lake Darling Dam is operated by the United States Fish and Wildlife Service (USFWS) during non-flood periods and by the United States Army Corps of Engineers (USACE) during periods of flood threats and flooding events.

Figure 9 illustrates the capacity for flood storage in the four main reservoirs of the Souris River Project. Rafferty is the most important reservoir for flood storage. Grant Devine and Lake Darling Reservoirs provide some storage capacity, while the Boundary Reservoir is used primarily for water supply and has limited flood storage capacity. More detailed information on each of the reservoirs is presented below.

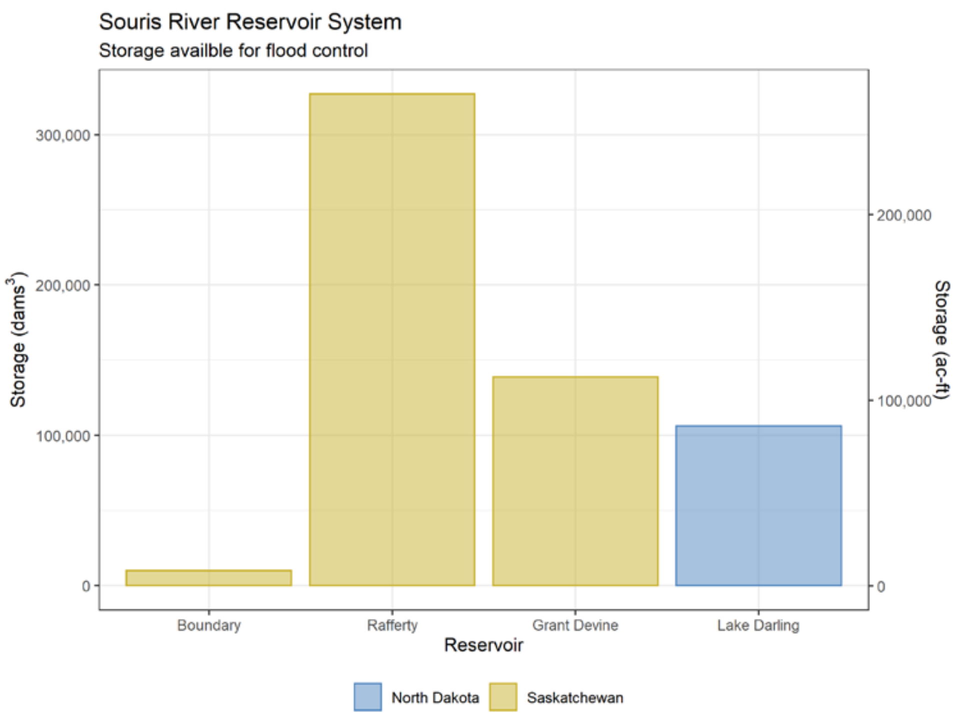

Figure 9 Flood storage in the Souris River Project

Rafferty Dam and Reservoir

Completed in 1992, the Rafferty Dam is located about 6 km (4 mi) from the City of Estevan, Saskatchewan. It was designed to provide both flood control and water supply benefits. The dam is controlled by a 20 m (66 ft) high earth-fill dam and has one low level, modified horseshoe outlet controlled by a single slide gate and a controlled spillway with five gates. When full, the reservoir is the largest of the four main reservoirs in the basin, stretching about 57 km (35 mi) upstream from the dam. About 9 km (5.6 mi) of the natural, meandering river channel downstream of the Rafferty reservoir and dam have been channelized to alleviate local flooding problems.

Note: Since the construction of Rafferty Dam, flood operations for the Souris River System were officially declared and put into effect during the 2001, 2009, 2011, 2013 and 2017 flood events.

Image 8 Rafferty Dam and Spillway

Grant Devine Dam and Reservoir

Grant Devine Dam, completed in 1994 (originally named Alameda Dam), is a 38 m (about 125 ft) high earth-filled embankment located north of the Town of Oxbow, Saskatchewan, on Moose Mountain Creek, near the international border.

Grant Devine Lake is operated by the WSA to meet flood control and water supply objectives. The reservoir is typically used to fulfil Saskatchewan's apportionment obligation outlined in Annex B of the 1989 Agreement (see Section 5).

Image 9 Grant Devine Dam and Reservoir

Boundary Dam and Reservoir

Boundary Dam, completed in 1958, is an earth-filled dam located about 5 km (3 mi) south of Estevan, Saskatchewan. It is an important water supply reservoir and has limited flood control storage.

The dam is located beside the Boundary Dam power plant, a 672-megawatt (MW) coal-fired power plant owned by the provincial utility, SaskPower, which uses water from the reservoir for cooling. The power plant opened in 1959, and today consists of four production units.

In 1993, the Boundary Reservoir was modified so that Rafferty Reservoir can receive water from Boundary Reservoir via an open channel diversion, the Boundary Diversion Channel, and send water to Boundary Reservoir by pumping it through the Rafferty Pipeline. In 1998, the dam was widened by extending the downstream side of the dam to accommodate a wider coal haul road on the top of the main embankment.

In 2010, modifications to the dam were completed. Prior to this rehabilitation effort, the full capacity of the main spillway gates could not be used and operations relied heavily on use of the diversion channel. As a result of the rehabilitation work, Saskatchewan Power now relies primarily on the main spillway when making flood control releases.

Image 10 *Boundary Dam and Spillway Structure*

Lake Darling Dam and Reservoir

The Lake Darling Dam, the oldest of the four major control structures in the Souris River basin, was completed in 1936. It is located about 43 km (27 mi) northwest of Minot, North Dakota. Originally, its primary purpose was to provide water to support fish and waterfowl habitat at the J. Clark Salyer National Wildlife Refuge (NWR), constructed in 1935 and located about 177 km (110 mi) downstream.

Between 1994 and 1998, Lake Darling Dam underwent a major rehabilitation that altered its flood control capacity. The dam was raised about 0.15 m (0.5 ft) and a gated spillway was installed to replace the uncontrolled spillway and emergency spillway as part of the Souris River Project.

Image 11 *Lake Darling Dam and Reservoir*

1.5 The 2011 flooding

This section presents an overview of the causes and impacts of the 2011 flooding in the Souris River basin and is based largely on a study undertaken by the United States Army Corp of Engineers in 2012 (USACE, 2012).

1.5.1 CAUSES OF THE FLOODING

Prior to the 2011 flood, one of the largest floods ever observed in Minot, North Dakota, had occurred in 1969, before the construction of the major flood control structures now in place. The 1969 flood was driven by snowmelt, more typical of major flooding in the basin. Flooding began in April of that year. Local runoff in the areas just upstream of Minot, including the Des Lacs River, led to the initial flooding, but it was a substantial melting snowpack originating in the Souris headwaters in Saskatchewan that resulted in the exceptional flooding observed in Minot. Following the 1969 flood, several flood protection measures were initiated, including the raising of Lake Darling Dam and a proposal to build a dam at Burlington, North Dakota (which was not undertaken). Ultimately, the severe flooding in 1969 and again in the mid-1970s, was one of the driving forces in the construction of new dams and control structures completed in the 1990s within the Souris River basin in Saskatchewan.

The 2011 flood was the largest flood ever recorded in the basin, with records going back about 100 years. For reference, the 1989 Agreement was based on providing one-percent (1:100-year) flood protection at Minot, North Dakota (about 141.6 m^3/s or 5,000 ft^3/s based on 1989 data; the 2011 peak flow was estimated to be over 5 times higher). Records were set for peak flows and flow volumes along the entire length of the river. Adding to the regional impact of the Souris River flood, serious flooding also occurred on the Assiniboine River in Manitoba, of which the Souris River is a tributary.

The flood was the result of a combination of several exceptional meteorological forces and events. First, in the fall of 2010, prior to the flood, the basin experienced near record rainfalls. In the Souris River basin within Saskatchewan, for example, the 90-day precipitation for August through October was up to 200 percent above average. At the same time, North Dakota experienced its ninth wettest fall since 1895. As a result, soils in the basin were saturated going into the 2010-2011 winter.

Secondly, the development of a La Niña weather system[3] during the summer of 2010 had set the stage for a potentially active winter storm season in North America. The resulting storm track brought record snowfall across parts of the Rockies and northern plains of the continent. Precipitation in the basin over the winter (November to April) ranged from 100 to 150 percent of the long-term seasonal average in North Dakota, 50 to 150 percent in Saskatchewan, and 130 to 150 percent in Manitoba. Minot, North Dakota, for example, one of the hardest hit communities in the 2011 flood, recorded its fourth highest snowfall since 1905.

[3] La Niña is part of the El Niño Southern Oscillation (ENSO) phenomena of irregular changes in air and sea temperatures over the eastern equatorial Pacific Ocean. These deviations from normal surface temperatures, which can last for several months, can have large-scale impacts not only on ocean processes, but also on global weather and climate, influencing the jet stream and weather patterns over North America. La Niña is sometimes referred to as the cold phase of ENSO and El Niño as the warm phase of ENSO. During this timeframe, the Pacific Decadal Oscillation (PDO) was also in a negative phase which tends to result in wetter conditions in the prairies (the PDO is another indicator that captures trends in ocean-climate variability; it is centered over the mid-latitude Pacific basin).

Finally, compounding these forces, the basin received considerable rainfall in the spring and early summer months of 2011, including a series of moderate rainstorms in May and early June and major rainfall events in mid-June. In a large part of the Saskatchewan portion of the basin, mid-April to mid-June rainfall was more than 200 percent above average.

In North Dakota, rainfall in May ranged from 150 to 300 percent of the long-term average, with some locations receiving 400 percent above average. Similarly, rainfall in May over the Manitoba part of the basin was 200 to 300 percent above average. These rainfall events occurred at a time when all the flood control reservoir impoundments in the basin were already full to capacity from the spring snowmelt runoff, leaving no further water storage capacity to protect from flooding.

Figure 10 and Figure 11 illustrate the extreme impact of these weather events on the Souris River basin. Figure 10 compares the levels of the three major storage reservoirs in the basin in 2011 to the median levels and the previous maximum ranges. Figure 11 compares the flows at the international crossing at Sherwood, North Dakota, with average flows and previous maximum range of flows at that location. Both figures illustrate how the 2011 conditions in the summer months far exceeded any that had been previously recorded in the basin.

As a result of these weather forces and events, there were three distinct major runoff periods in the basin:

- the spring snowmelt in April and early May;
- in May following the numerous moderate rainfalls; and,
- in mid-June following major rainstorms.

The flooding was an unprecedented event in the basin. For example, on a volume basis, the 2011 spring flood event was two and a half times greater than the previous record flood in 1976. In fact, the volume of flow in 2011 was greater than the combined volume of flows from the three greatest floods previously recorded in 1975, 1976 and 1979.

According to frequency analysis that was performed prior to the 2011 flood, runoff volumes for the spring snowmelt event at both the Rafferty and Boundary Dams were approximately equal to the 1:100-year event. At the Grant Devine Dam, the spring snowmelt volume was estimated to range from a 1:20 to 1:50-year event. When combined with significant, additional rainfall in May and June, flows in the river and its tributaries exceeded the 1:100-year design capacity of the basin's flood control system, leading to major flooding along the entire reach of the Souris River. Figure 12 shows a timeline of reservoir operations during 2011 from the onset of spring runoff to the flood peak in late June.

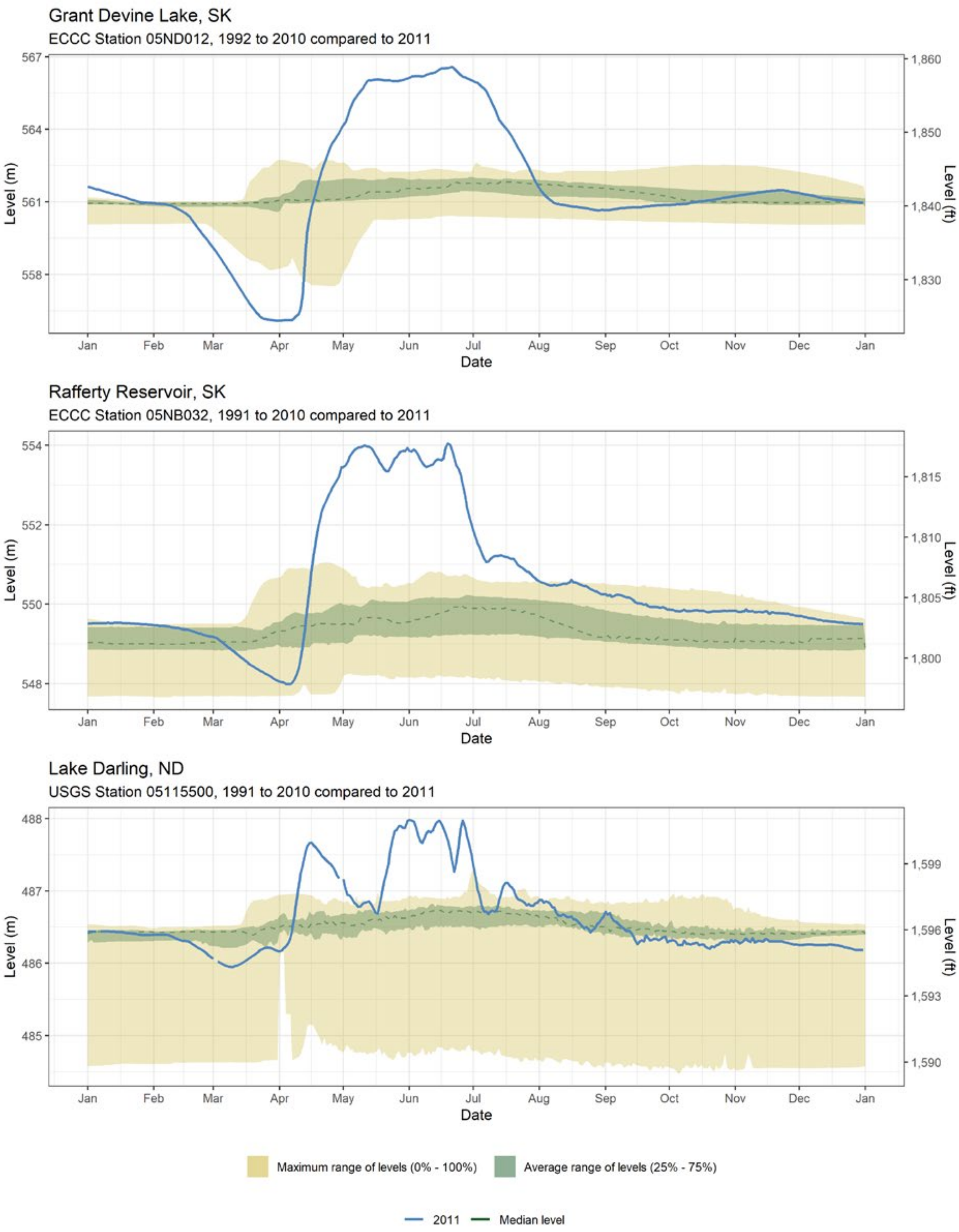

Figure 10 Souris River basin reservoir levels, 2011, compared to all other years for each reservoir

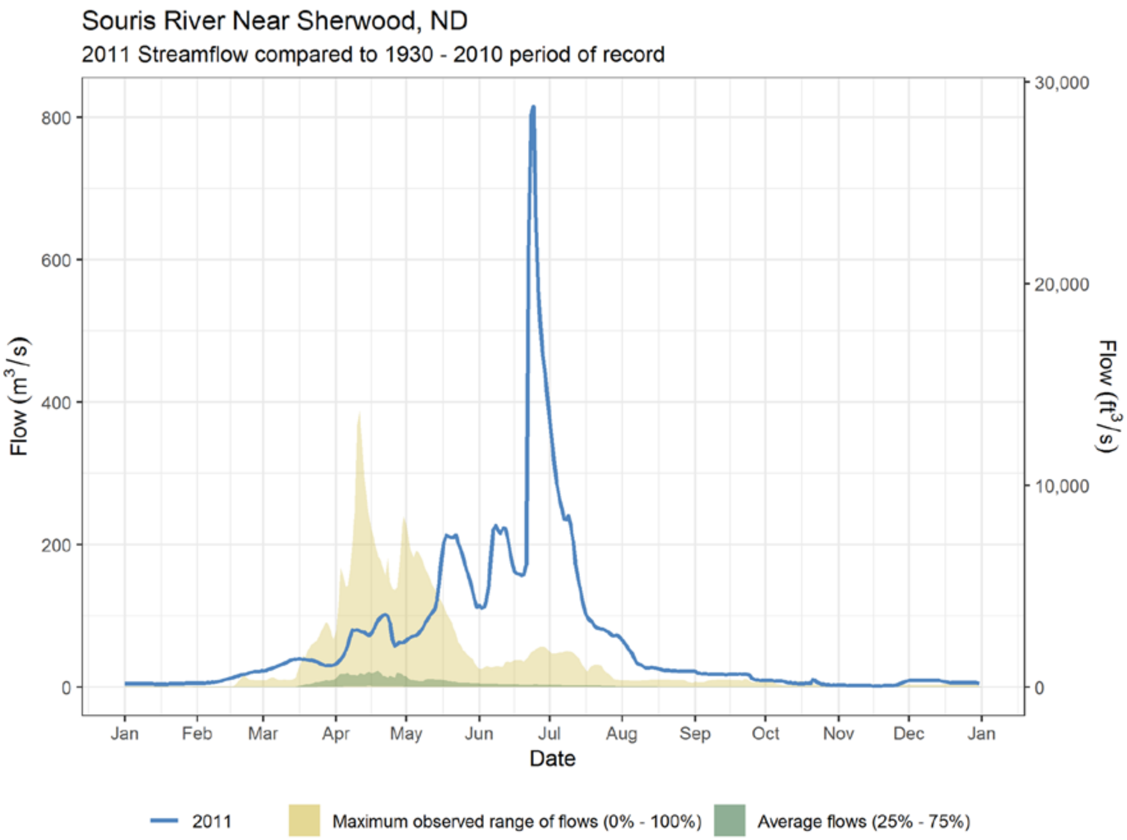

Figure 11 Souris River flows, 2011

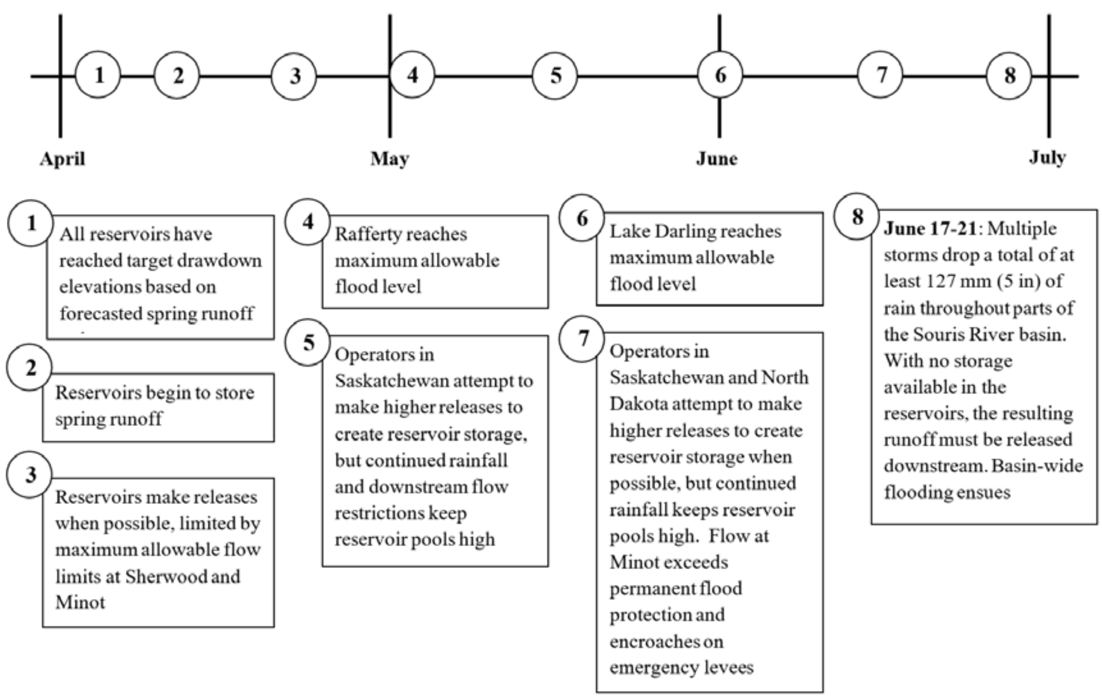

Figure 12 Timeline of reservoir operations during the 2011 flood

Finally, it must also be emphasized that the 2011 flooding overwhelmed the existing water storage capacity of the reservoirs, with the significant spring snowmelt runoff followed by much above normal rains causing runoff during May to July. The Canadian reservoirs provide the bulk of the flood storage for the Souris River basin. Figure 13 depicts the annual inflow volume into the Canadian reservoirs for the five largest flood events that occurred from 1930 to 2017. In fact, the 2011 annual inflow volume to the reservoirs dwarfs previous flood events by roughly a factor of three. The January to May 2011 inflow volume represents about half of the 2011 inflow (such large rainfall inflows are very rare events). Finally, the full reservoir storage volume, including all four reservoirs was also severely exceeded by the 2011 events.

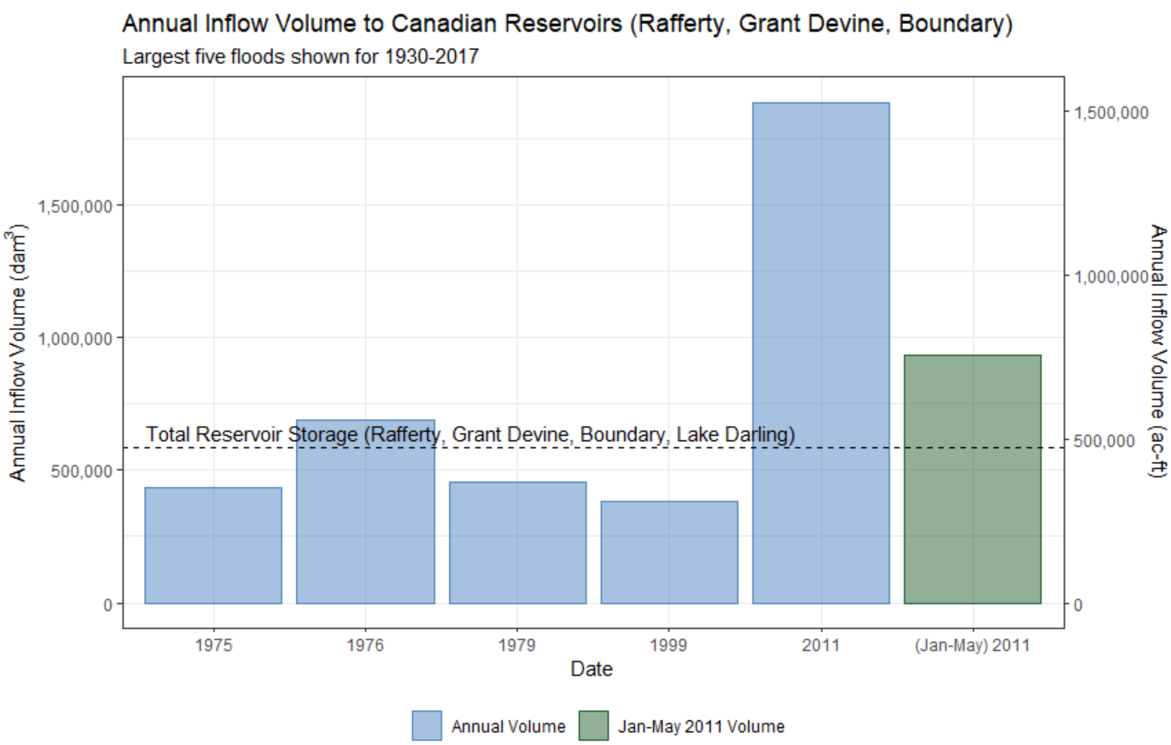

Figure 13 Annual inflow volume into the Canadian reservoirs for the five largest floods (1930 – 2017)

1.5.2 IMPACTS OF THE FLOODING

Saskatchewan

Image 12 Highway washout south of Estevan, Saskatchewan

In Saskatchewan, heavy rainfall in mid-June caused extensive flooding along the Souris River and impacted several major roads, causing road closures. States of emergency were declared in the cities of Estevan and Weyburn. More than 4,000 people along the river were forced from their homes (International Institute of Sustainable Development, 2016). In Weyburn, the city's wastewater lift station was overwhelmed and risked contamination of drinking water sources, leading to a boil water order for the city's drinking water. Several local parks were severely damaged by flood waters. In Estevan, about 400 residents of a trailer park were evacuated, along with the residents of more than 40 homes in the surrounding rural municipality.

The Village of Roche Percée, on the Souris River about 20 km (12 mi) east of Estevan, was among the hardest hit areas. Nearly every home in the village of 153 (2011 census) was inundated, community water and sewer infrastructure were damaged, and several roads were destroyed.

Farmers were also affected by the flooding, with an estimated two million ha (five million acres) of crop land left unplanted in the spring (USACE, 2012).

The flooding also affected the energy sector. Flooded roads, bridges and culverts limited access to oil production sites and monitoring wells. Flooding also led to the shutdown and abandonment of some oil wells because of access difficulties and environmental risks, including spills and contamination (International Institute of Sustainable Development, 2016).

Transportation of coal to the Boundary Dam Power Station was also impacted as the coal haul road was inundated and passage was temporarily halted.

North Dakota

Image 13 Flood in residential area in Minot, North Dakota

North Dakota experienced extensive impacts from the 2011 flood. Damage to property and infrastructure was estimated at $691 million ($US 2011). More than 4,700 residential, commercial, and public structures were impacted. Much of this damage was concentrated in the city of Minot, on the Souris River, where more than 12,000 residents were evacuated from 4,000 homes. About 200 businesses in the city were damaged, all of the city's wastewater lift stations were destroyed, and its water system was compromised.

The city of Burlington, near Minot, at the confluence of the Souris and Des Lacs Rivers, was also impacted. Two deaths were reported as a result of the flooding, and the city's lift station and sports complex were destroyed.

Wet field conditions affected agriculture throughout the basin. Ranchers faced difficulties reaching pastureland to feed and care for livestock. Many farmers had to delay seeding for weeks, and some were unable get their crops in at all as wet conditions persisted after the flooding ended. It was estimated that only about 30 percent of typically planted acreage in the basin was seeded in 2011.

Impacts on transportation included closures of and damages to roads, bridges, railway lines, and electrical power lines. The state's energy sector experienced similar impacts as those in Saskatchewan, including loss of access to water supply wells and risks of spills and contamination as a result of flooding.

Environmental impacts were also significant. Flood waters covered dikes, roads, and trails for several months, leading to long-term damage to sensitive waterfowl nesting habitat, wetland and meadow plant communities and riparian woodlands in the three National Wildlife Refuges (NWR) in the basin. The extensive long-term duration of floodwater inundation over the landscape destroyed many trees and caused significant ecological impacts that persist to this day. The USFWS noted the frequent back-to-back flooding that occurred in 2011, 2013 and 2014 resulted in over 70 percent tree mortality in the riparian corridor from Towner to J. Clark Salyer NWR; after these floods, there was also a significant loss of native sedges and rushes and a roughly 400 percent increase of invasive Reed Canary grass in the NWR meadows.

Image 14 Tree mortality caused by long duration flooding

Manitoba

Image 15 Road washout caused by 2011 flood

In Manitoba, agriculture was particularly impacted by the 2011 flooding. The high snowmelt runoff combined with heavy spring rains led to a prolonged period of extensive flooding followed by saturated field conditions. Agricultural production declined, as farmers were unable to plant crops in the wet fields. Within the 12 rural municipalities in the province's portion of the Souris River basin, the estimated share of unseeded annual cropland ranged from 50 to more than 90 percent.

About 140 Manitoba residents were evacuated as a result of the flood, either by mandatory order or on a voluntary basis. In the towns of Melita and Souris, existing municipal dikes needed to be repaired and reinforced. In Souris, 5 km (3 mi) of new earth dikes were constructed in a short period of time. In both towns, residents of threatened neighborhoods were evacuated.

Infrastructure was also damaged in Manitoba during the flood. Several provincial roads were washed out and closed for weeks or more. As a result of scouring of the riverbank adjacent to the structure, emergency repairs were needed on a small dam in Wawanesa during the flood. In addition, a temporary natural gas supply line across a bridge over the Souris River was constructed to replace a pipeline threatened (and subsequently destroyed) by riverbank erosion.

1.5.3 POST 2011 FLOOD ACTIVITIES AND RESPONSES IN NORTH DAKOTA[4]

The state of North Dakota suffered the most serious impacts from the 2011 flood. Currently (as of 2021), North Dakota and the city of Minot are pursuing substantial improvements to the flood protection within the city of Minot and surrounding communities. The Mouse River Enhanced Flood Protection Project (MREFPP) aims to provide flood relief to Mouse (Souris) River valley residents in North Dakota – both urban and rural. The MREFPP was originally initiated by the North Dakota State Water Commission in response to a request for assistance from North Dakota's Souris River Joint Board (SRJB) following the record-breaking 2011 flood.

The first phase of the MREFPP included the development of a plan to reduce flood risk in the river valley from Burlington to Velva, North Dakota, and Mouse River Park, which is documented in a Preliminary Engineering Report (PER). During later stages of the development of the PER, the focus shifted to the rural areas of the river valley. Evaluations of erosion, sedimentation, hydraulics, and hydrology were completed to assess the basin-wide implications of proposed improvements.

The MREFPP is now being implemented. The total estimated cost of this program, in 2020 dollars, is approximately $1 billion. The MREFPP in Minot consists of several phases involving earthen levees, floodwalls, diversions, and pump stations. Work at Minot is being implemented in stages with much in Phase 1 nearing completion. In Burlington, levee construction and bridge improvements are ongoing. Bridge improvements in the rural areas at Mouse River Park, Sawyer, and Velva are also planned. These bridge improvements are crucial for rural communities as only two bridges were passable during the 2011 flood, leaving long commutes for many rural residents.

For rural property owners, the SRJB also developed the Structural Acquisition Relocation and Ring Diking (StARR) Program. The StARR program contained options for rural landowners to receive funding assistance from the North Dakota State Water Commission, city of Minot Sales Tax collections directed at flood protection, and a local share of five percent, for the purpose of structure acquisition and demolition, structure relocation, or the ring diking of property. There were a total of 166 structures acquired with 135 of those demolished and 17 of those were resold.

While flood protection projects in North Dakota are ongoing for Minot and other communities and rural areas, many are still being planned and none are fully completed (as of 2021). Therefore, the Study determined it was not possible to consider post-2011 projects when evaluating alternative reservoir Operating Plans. In the future, as new flood control infrastructure becomes established and operational, reevaluation of the Operating Plan may be necessary to capture the decrease in flood risk from the implementation of these projects.

[4] See "Securing the future of the Mouse River Basin" posted at: https://www.mouseriverplan.com

2 The International Souris River Study

Section 2 presents an overview of the objectives and approach of the International Souris River Study (the Study) in addressing the challenge of managing water levels and flows in the basin. More detailed information on the Study's approach and activities can be found in the extensive background documentation available on the Study's website: www.ijc.org/en/srsb.

2.1 Responding to the 2011 flood

Image 16 Meeting of the Study Board in Bottineau, North Dakota, 2019

The unprecedented flooding in the Souris River basin in 2011 focused immediate attention in both Canada and the United States on the the *1989 International Agreement between the Government of Canada and the Government of the United States of America for Water Supply and Flood Control in the Souris River Basin* (the 1989 Agreement) (see Appendix 1).

Following the 2011 flooding, interests across the basin, particularly in North Dakota, asked that additional flood protection measures be considered, above and beyond what is provided under the 1989 Agreement. Responding to these concerns, the International Souris River Board (ISRB) established the Souris River Basin Task Force (SRBTF) in early 2012. The task force was directed by the IJC and the ISRB to develop a Plan of Study (POS) for the consideration of the Governments of Canada and the United States that described the detailed studies needed to:

- review the existing Annex A Operating Plan of the 1989 Agreement; and,
- evaluate alternatives to maximize flood control and water supply benefits.

The POS presented three options in terms of the scope of the proposed work. The ISRB submitted its POS to the IJC in April 2013 and recommended that the full scope option be conducted.

The IJC provided opportunities for review and comment on the POS to ensure that it responded to concerns of the public and other interests in the basin. The engagement and outreach included public meetings and webinars, and a webinar for stakeholders and federal, provincial, state, and local resource management agencies in both Canada and the United States.

These outreach activities found general support for the proposed POS among members of the public, government agencies and other stakeholders. No important gaps in the proposed scope of work or requirements for additional analysis were identified.

In June 2013, following the period of review and comment, the IJC submitted to the two federal governments its *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* (International Joint Commission, 2013). In making the submission, the IJC recommended that the full scope option be conducted, and that funding be provided for that option.

On July 5, 2017, after four years of discussion among governments and collaborating agencies, the Governments of Canada and the United States issued a Reference for the IJC to undertake the POS (see Appendix 2). In accordance with Article IX of the *Boundary Waters Treaty of 1909*, the governments requested 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 POS.

On September 5, 2017, the IJC established the International Souris River Study Board (ISRSB, or Study Board) and issued a Directive providing direction and guidance on the Study's approach and operations (see Appendix 3). The Study Board was directed to examine and report to the IJC on matters raised by the Governments of Canada and the United States in the 2017 Reference. Under the Directive, the Study Board developed a detailed work plan and submitted it to the IJC on November 5, 2017. This work plan was updated and re-submitted to the IJC on October 10, 2018. (International Joint Commission, 2018)

2.2 Scope and objectives of the Study

The 2017 Reference from the Governments of Canada and the United States to the IJC established the scope and objectives of the Study. It directed the IJC to undertake a study to evaluate and make recommendations regarding:

- **the Operating Plan contained in Annex A to the 1989 Agreement for Water Supply and Flood Control in the Souris River Basin; and,**
- **how the provision of flood control and water supply benefits in the basin might be maximized.**

To address these objectives, the Reference directed the Study to include:

1. the collection and harmonization of data necessary to support hydraulic and hydrologic modeling and associated studies;
2. the development of hydrological watershed runoff and inflow sequences to allow for the simulation of various water supply conditions including historical conditions, extreme conditions, and conditions influenced by the effects of climate change;
3. the development of hydraulic, hydrologic and optimization modeling tools that will allow for the accurate simulation of flows within the Souris River so that operational scenarios may be evaluated;
4. studies evaluating the physical processes occurring in the Souris Basin which are thought to have contributed to recent flooding events;
5. a detailed review of the Operating Plan contained in Annex A of the 1989 Agreement;
6. identifying and, as appropriate, making recommendations regarding improvements to the Operating Plan contained in Annex A of the 1989 Agreement to reduce the flooding and water supply risks in the Souris River basin with consideration to low flow, apportionment, water quality and aquatic ecosystem health;
7. the evaluation, on a qualitative and quantitative basis, of the costs and benefits of a range of possible infrastructure and operational plans regarding flooding and water supply in the Souris River basin;
8. the evaluation of additional flood protection measures, beyond what is currently provided under the 1989 Agreement, which may include feasibility evaluations of increasing storage at existing dams, more efficient channel alignment and capacity, and the provision of flood control measures in and around communities within the basin;
9. assessing possible adaptation strategies to address the potential future variability in water supplies associated with climate change;
10. facilitating collaboration among various federal, state, provincial and local agencies, the public, as well as Native American Tribes, First Nations, and Métis located within the basin to share their views and provide input during the study process; and,
11. considering any other matters that the IJC, in consultation with governments, deems relevant to the purpose of this study.

Revised scope of work

Several issues originally envisioned to be addressed in the Study, particularly those related to Reference items 2, 7, 8 and 9 in the IJC Reference, were not included in the eventual work:

Item 2 - Hydrological watershed runoff and inflow sequences including historical conditions, extreme conditions, and conditions influenced by the effects of climate change:

The availability of the resources required to produce credible projections of climate-changed hydrology is extremely limited for transboundary watersheds. The Study produced a workflow that can be used to generate climate-changed hydrology specific to the Study area in the future. Proof-of-concept runs were carried out to ensure that the defined workflow was robust. However, future work to produce credible climate-changed streamflow scenarios will require more downscaled and bias-corrected, projected meteorological datasets that straddle the Canada-United States border. Additionally, post-processing of projected hydrology will have to be considered to facilitate comparison to historically observed streamflows. Future efforts will also need to quantitatively account for other sources of uncertainty that are relevant to representation and interpretation of climate-changed hydrology.

Item 7 - Infrastructure, such as enlarged dams, channels, installation of flood control measures in and around communities:

Early in the Study, the IJC and Study Board agreed that assessing the feasibility and costs of such infrastructure improvements was, for any single infrastructure project, both costly and time consuming. It was determined that the Study would not focus on this issue, but rather on measures or modifications that could be introduced into the existing 1989 Operating Plan. Should options be considered for infrastructure improvements, such as dams, channel modifications, etc., specific and targeted investigations are suggested for future analysis.

Item 8 - Dam safety:

The July 5, 2017 Reference did not include potential dam safety issues. A December 21, 2020 letter from the governments advised that dam safety was outside the scope of the study. The study did incorporate a performance indicator to consider aspects based on reservoir pool elevations. The study has produced most, if not all, of the tools that will be required to assess the implications of modifying operational rules to accommodate dam safety criteria. Once the issue of dam safety is satisfactorily resolved in the future (by others tasked with this mandate), these Study tools remain available to assess and identify a plan that is consistent with the 1989 Agreement and the 1909 Boundary Waters Treaty.

Item 9 - Adaptation strategies to address future climate change variability:

The potential effects of climate change are documented under Section 7 of this report. The information provides high-level insights of possible climate change impacts. The Study team was not able to assess specific climate change adaptation strategies as this type of research requires much more in-depth and targeted investigations as new science becomes available over time. The Study team does, however, provide commentary on the need for strengthened adaptive management processes in the Souris River basin (see Section 8.5).

2.3 Study governance and organization

The Directive from the IJC sets out the roles, responsibilities, reporting relationships and guiding principles of the Study.

Under the Directive, the organization of the Study consisted of a Study Board, technical teams, and an independent public advisory group (PAG), (Figure 14). Table 1 lists the members of the Study Board. Lists of all Study contributors are provided in Appendix 4.

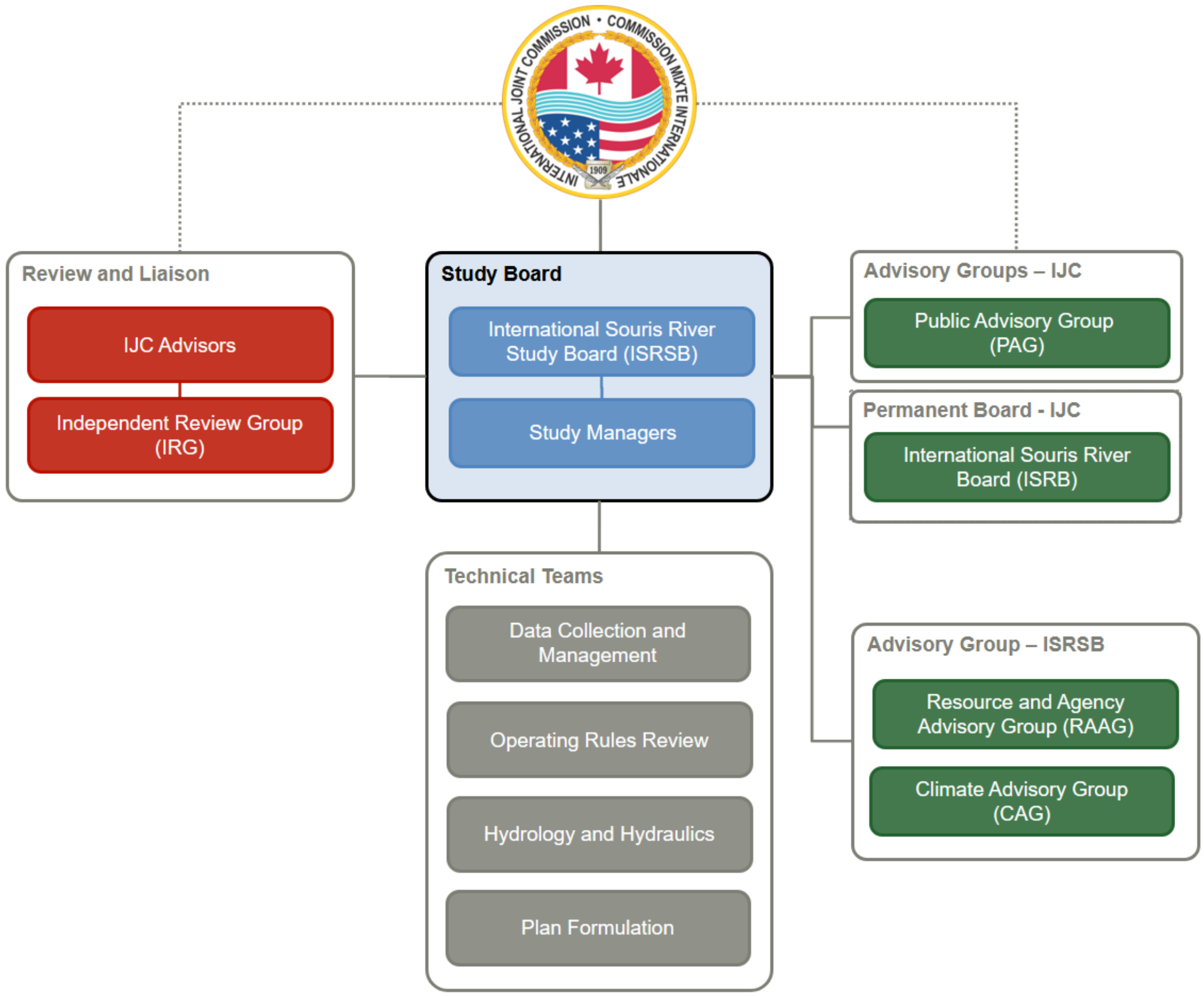

Figure 14 International Souris River Study organizational structure

Table 1 International Souris River Study Board members

	Canada	United States
Study Co-Chairs	Dr. Alain Pietroniro, P. Eng. Professor and Chair in Sustainable Water Systems in a Changing Climate Schulich School of Engineering Department of Civil Engineering University of Calgary Calgary, Alberta Former Director of the National Hydrologic Service Meteorological Service of Canada Environment and Climate Change Canada Saskatoon, Saskatchewan	Michael Bart U.S. Army Corps of Engineers (Retired July 2021) St. Paul, Minnesota
Members	Jeff Woodward *Canadian Alternate Co-Chair* Saskatchewan Water Security Agency Regina, Saskatchewan (formerly ECCC) John Fahlman Water Security Agency Moose Jaw, Saskatchewan Mark Lee Manitoba Agriculture and Resource Development (formerly Sustainable Development) Winnipeg, Manitoba Debbie McMechan *PAG Co-Chair* Reeve, Municipality of Two Borders Pierson, Manitoba	Rebecca Seal-Soileau *U.S. Alternate Co-Chair (appointed co-chair in July, 2021)* U.S. Army Corps of Engineers - St. Paul District St. Paul, Minnesota Brian Caruso U.S. Fish & Wildlife Service Lakewood, Colorado James T. Fay North Dakota State Water Commission (Retired) Bismarck, North Dakota Tammy Hanson *PAG Co-Chair* Sherwood, North Dakota (Former US Co-Chair: David O'Connell)
Study Co-Managers	Bruce Davison Hydrologist Environment and Climate Change Canada Saskatoon, Saskatchewan	Gregg Wiche United States Geological Survey (Retired) Bismarck, North Dakota

Study Board

The Study Board, comprised of five members each from Canada and the United States, was responsible for providing overall direction and management of the Study, including reporting formally to the IJC on a regular basis. Study Board members included experts from federal, provincial, and state government agencies. The two co-chairs of the PAG were also members. All participants served in their personal and professional capacities, and not as representatives of their agencies, organizations, or other affiliations.

Two study co-managers, one each from Canada and the United States, were responsible for the Study's day-to-day operations, including coordination and liaison with the technical teams and advisory groups.

Technical teams

Technical teams were established for each of the 19 technical tasks undertaken as part of the Study. Teams included scientists and engineers from federal, provincial, and state agencies, as well as external expert consultants.

Public advisory group

The PAG, established by the IJC, helped plan and implement the Study's engagement and outreach plan. (See **Section 3** for more information)

Expert advisory groups

The Study benefitted from the input of two key advisory groups of experts:

- A **Resource and Agency Advisory Group** (RAAG) was established by the Study Board to ensure that any recommendations made by the Study Board with respect to the existing Operating Plan or alternative measures would be compatible with the mandates and resources of the agencies. (See **Section 3** for more information)
- A **Climate Advisory Group** (CAG), also established by the Study Board, helped ensure the validity of the climate change analysis performed within the Study. Members were drawn from both Canada and the United States, with expertise in water resources, hydrology, climatology, and atmospheric science.
- **Indigenous Advisors** representing First Nations, the Métis Nation, and Tribes provided input on Indigenous Knowledge and their Nations' interests in the Souris River basin (see Section 3.3)

International Souris River Board

Over the course of the Study, the Study Board maintained a close working relationship with the ISRB, the permanent board established by the IJC in 2002 and responsible for oversight of transboundary water issues in the basin, including flood operations and apportionment of river flows. The Study Board kept the ISRB informed of progress at all stages and engaged with ISRB members to solicit feedback and discuss the transfer of various products and tools to the ISRB following the Study.

Independent review group

The IJC established the independent review group (IRG), separate from the Study Board, to provide independent scrutiny and guidance throughout the Study. The IRG provided input at key stages, including evaluating the appropriateness and sufficiency of the studies and models used to inform the Study Board's findings and recommendations.

2.4 Overview of Study methodology

In undertaking the Study, the Study Board established 19 technical task teams. The teams worked together on four core interrelated activities.

More detailed explanations of the Study's methodology are presented in Sections 4 and 5. Brief summaries of the reports of the technical task teams are presented in Appendix 4. The full reports of the technical teams are available on the Study's website: www.ijc.org/en/srsb.

The Study team organized and undertook its analysis of the Souris River basin study in accordance with key tasks and groups identified in their work plan (Table 2).

Table 2 Study core activities and technical task teams

Core Activity	Technical Task Teams
Operating rules review	OR 1: 1989 Agreement Language Review
Data collection and management	DW 1: Projects and Report Progress since 2011 DW 2: Bathymetry and LiDAR Data DW 3: Hydro meteorological Network Review DW 4: Data Collection for Performance Indicators
Hydrology and hydraulics	HH 1: Regional and Reconstructed Hydrology HH 2: Stochastic Hydrology HH 3: Artificial Drainage Impacts Review HH 4: Flow Simulation Tools Development HH 5: Climate Change Analysis HH 6: Reservoir Flow Release Modeling (HEC-ResSim) HH 7: Reservoir Flow Release Modeling (HEC-RAS) HH 8: PRM Model Development (HEC-ResPRM) HH 9: Model System Integration HH 10: Flow Forecasting Assessment
Plan formulation	PF 1: Workshops and Engagement PF 2: Run and Evaluate Alternatives PF 3: Dam Safety PF 4: Apportionment, Water Quality and Ecosystem Health

1. Operating rules review

The operating rules review (OR1) was responsible for identifying areas where the language and text in Annex A of the 1989 Agreement can be improved for ease of understanding and clarity of interpretation. This Study activity directly addresses the Governments' Reference item 5.

2. Data collection and management

Image 17 ISRSB site visit to Grant Devine low-level building, June 2018

Data collection and management teams (DW1-DW4) were responsible for collecting and harmonizing the data necessary to support hydraulic and hydrologic modeling and associated studies. This Study activity directly addresses the Governments' Reference Item 1.

The first step was to review existing hydrological and meteorological studies and collect, update, and analyze key data on the basin's hydrology and meteorology needed to support the modeling of alternatives. This included physical data on the Souris River basin, data on each reservoir's elevation, storage, volume and outflow, and climate and bathymetric information.

Technical teams also developed a set of runoff sequences as input to the modeling and testing of alternatives. These included scenarios of historical water supply conditions in the basin, going back to 1930. In addition, the Study reviewed progress on flood control and water supply security made in the basin since the Study's original POS was completed in 2013. It summarized available studies, datasets and modeling setups related to various work components of the Study to ensure that any new information could be integrated into the Study's analysis.

3. Hydrology and hydraulics

The hydrology and hydraulics teams (HH1-HH10) established the stochastic, hydrologic, hydraulic, and reservoir modeling platforms to be used for testing and evaluating alternative Operating Plan measures. These activities directly address the Governments' Reference Items 2, 3, and 4.

4. Plan formulation

The plan formulation teams (PF1-PF4) formulated and evaluated alternatives regarding improvements in the Operating Plan outlined in Annex A of the 1989 Agreement. These activities directly address the Governments' Reference items 6 through 10.

The evaluation of alternatives involved the development and testing of performance indicators (PIs). PIs consist of a relationship between a specific streamflow or reservoir elevation and a corresponding impact on specific basin interests, infrastructure, and ecosystem elements. In this way, PIs allow for a comparison of the likely outcomes and impacts of alternative Operating Plans and other measures. Examples of PIs developed in the Study included inundation of agricultural lands, bridges and cultural sites, fish and bird habitat at certain locations and boat and fishing access at certain locations. This step included workshops with the public, resource agencies, and other interests in the basin to evaluate and refine the various PIs.

The Study integrated runoff sequences, basin data and PI data into models to allow for the evaluation of alternative Operating Plan measures. This was a highly iterative process. Feedback from the PAG, RAAG, IRG, Indigenous advisors and other interests was critical at this stage to allow the Study to focus in on a manageable number of potentially suitable alternatives.

One important tool to facilitate this feedback was the development and incorporation of a hydrologic visualization tool that allows users to compare alternative simulation results at specific locations in the Souris River basin. The tool helped the technical teams, advisory groups and the Study Board better understand the impacts on various areas of the basin from different Operating Plan measures.

5. Other water management issues

Over the course of the Study, the Study Board addressed several important emerging water management issues in the basin, including addressing climate variability and change; artificial drainage; aquatic and ecosystem health and adaptive management.

6. Findings and recommendations

Finally, because of extensive analyses and consultations, the Study Board developed its draft findings and recommendations. The draft findings and recommendations were then reviewed by the Study's RAAG and PAG, the ISRB, and by the IRG. The final report was then prepared, incorporating input received from these reviews.

3 Engagement and Outreach in the Study

Section 3 outlines the comprehensive engagement and outreach plan designed and implemented as a core component of the International Souris River Basin Study (the Study). It includes how the Study addressed engagement and outreach with:

- the public;
- representatives of government resource and regulatory agencies and industry; and,
- Indigenous Nations, including First Nations, Métis Nation, and Tribes

The reports of the PAG, RAAG, and Indigenous Nations events are available through the Study's website: www.ijc.org/en/srsb.

- "Public Perceptions in the Souris River Basin: a report of the Public Advisory Group, 2018" https://ijc.org/en/srsb/public-perceptions-souris-river-basin-report-public-advisory-group
- "ISRSB PAG Mid-Term Report September 2019" https://ijc.org/en/srsb/pag-midterm-report
- "Synthesis Report of Indigenous Nations Peace Garden Workshop November 6-7, 2019" https://ijc.org/en/srsb/indigenous-nations-workshop-report-nov-2019
- "IJC-Indigenous Nations Virtual Workshop September 17-18, 2020" https://ijc.org/en/srsb/indigenous-nations-workshop-report-sept-2020
- "ISRSB-Indigenous Nations Virtual Workshop March 2021" https://ijc.org/en/srsb/indigenous-nations-workshop-report-march-2021

3.1 Public engagement and outreach

In all of its work related to transboundary water issues, the IJC is committed to providing interested parties with convenient opportunities to contribute their insights and knowledge to the Study. The Directive from the International Joint Commission (IJC) establishing the Study stated that the IJC "expects the Study Board to involve the public in its work to the fullest extent possible." (see Appendix 3)

Under the Study's work plan, the objectives of public engagement and outreach in the Study were to:

- ensure that the Study process is open, inclusive, and fair;
- make the public aware of the Study, its purpose and process, including how decisions will be made;
- provide opportunities to the public and stakeholders to participate;
- enhance public understanding of factors that contribute to flooding in the basin;
- identify and build on local expertise and information;

- invite and consider public and stakeholder views of the principal issues;
- identify and consider the public's priorities and preferences;
- broadly disseminate study findings as they become available; and,
- encourage the public and stakeholders to share the Study's findings.

The work plan defined "the public" broadly to include any person, association, organization, or group that is affected by, likely to be affected by, or has an interest in the Study and any decisions that may ultimately be taken by the governments in response to the findings and recommendations of the Study. This included individuals and organizations representing a range of interests in the basin: environment; recreational boating; local industry; agriculture; water supply and water treatment facilities; riparian interests; and municipalities.

In the Study, the term "stakeholders" referred primarily to elected officials and others with a decision-making responsibility in the basin.

Image 18 ISRSB public meeting in Minot, North Dakota, February 2020

3.1.1 PUBLIC ADVISORY GROUP

The IJC, with advice from the Study Board, established a binational Public Advisory Group (PAG) responsible for helping develop and implement the Study's engagement and outreach plan. PAG members represented key interests and different geographic areas within the basin (Table 3). The co-chairs of the PAG were also members of the Study Board.

Table 3 Public Advisory Group members

Canada	United States
Debbie McMechan, Co-Chair Pierson, Manitoba	Tammy Hanson, Co-Chair Sherwood, North Dakota David O'Connell, Former Co-Chair
Joe Goodwill, Alternate Co-Chair Souris, Manitoba	Paul Smetana, Alternate Co-Chair Lansford, North Dakota
Dan Cugnet Weyburn, Saskatchewan	Lori Berentson Bottineau, North Dakota
Yasemin Keeler Deloraine, Manitoba	Leland Goodman Towner, North Dakota
Kelly Lafrentz Estevan, Saskatchewan	Jeanine Kabanuk Burlington, North Dakota
Wanda McFadyen Winnipeg, Manitoba	Lynn Kongslie Towner, North Dakota
David Pattyson Estevan, Saskatchewan	

Note: PAG members as of the Study's completion in 2021. For a complete list of members who served over the course of the Study, see Appendix 4.

PAG members were responsible for:

- advising the Study Board on public consultation, involvement, and information exchange;
- helping involve the public by bringing information from the Study Board to their various networks throughout the community, as well as bringing back views from the community for consideration by the Study Board;
- reviewing and providing feedback on the Study's approaches, reports, products, findings, and conclusions; and,
- advising the Study Board on the responsiveness of the Study process to public concerns.

PAG members were asked to draw upon their knowledge, contacts, and experiences to provide informed input to the Study, including:

- developing effective techniques to engage the public and stakeholders on a wide range of issues;
- facilitating outreach to First Nations, the Métis Nation and Tribes to encourage participation in the Study; and,
- assisting in the Study's development of a participatory mapping framework that captures stories, observations, and other geospatial data across the basin.

Image 19 Meeting of the Public Advisory Group in Estevan, Saskatchewan. June 2019

3.1.2 ENGAGEMENT AND OUTREACH PLAN

Working with the PAG, the Study Board prepared a communications plan to guide the engagement and outreach plan over the course of the work. The plan identified:

- key interests in the basin;
- audiences for the Study, including municipalities, elected officials, Indigenous Nations, local media, and interest groups;
- communication opportunities and challenges; and,
- major communication products and events to support the Study.

The Study implemented the communications plan through the activities of the PAG, public meetings and workshops, and the Study's website.

1. Public meetings and workshops

Over the course of the Study, the Study Board convened public meetings throughout the Souris River basin (Table 4). The meetings and workshops were structured to present information on the objectives and approach of the Study, respond to questions, receive comments, present and discuss preliminary findings, explore options through practice decisions, and discuss recommendations. Members of the PAG assisted with the organization, publicity and facilitation of several of these meetings.

Table 4 Public meetings during the Study

Date	Location
February 20, 2018	Minot, North Dakota
June 25, 2018	Estevan, Saskatchewan
February 19, 2019	Brandon, Manitoba
June 25, 2019	Lake Metigoshe, North Dakota
February 20, 2020	Minot, North Dakota
August 16, 2021	Virtual

2. Study website

Over the course of the Study, the Study's website (www.ijc.org/en/srsb) served as the primary means of providing information to members of the public. The website included extensive background documentation on the Study, notices of public meetings, progress reports, brochures, and other information resources.

3. Networking with other organizations

The Study Board took advantage of existing networking opportunities in the basin for reaching out to various interests. For example, Study Board members participated in the 2019 and 2020 annual conferences of the Assiniboine River Basin Initiative (ARBI) to inform the organization of the Study and to explore opportunities for cooperation. The ARBI is an organization of governments, business, industry, conservation groups and other interests from Saskatchewan, Manitoba and North Dakota that works to help shape the future of the Assiniboine River basin, of which the Souris River basin is a part of.

In addition, the Study's United States manager met with the North Dakota State Legislative Water Topics Oversight Committee to inform legislators about the Study and its linkages to the ISRB.

3.1.3 PUBLIC CONCERNS IN THE BASIN

The Study Board sought to understand and respond to public concerns about water levels and flows and water quality in the study area. Through the efforts of the PAG, community workshops and other engagement activities, the Study identified the key public concerns about water management in the basin. Table 5 Study meetings with the Public Advisory Group lists the Study meetings with the PAG.

Table 5 Study meetings with the Public Advisory Group

Date	Location
June 25, 2018	Estevan, Saskatchewan
December 18, 2018	Webinar
January 28, 2019	Webinar
February 19, 2019	Brandon, Manitoba
March 4, 2019	Webinar
March 18-19, 2019	Minot, North Dakota
April 29, 2019	Estevan, Saskatchewan
June 25, 2019	Lake Metigoshe/Bottineau, North Dakota
July 30-31, 2019	Estevan, Saskatchewan
November 19-20, 2019	Minot, North Dakota
March 15, 2021	Webinar
July 16, 2021	Webinar
July 21, 2021	Webinar
July 29, 2021	Webinar

The following is a summary of these major public concerns. For more information, see the 2018 and 2019 reports of the PAG, available through the Study's website: www.ijc.org/en/srsb.

1. Impacts on agricultural lands

Across the basin, members of the public are concerned that potential impacts on agricultural lands, particularly flooding and erosion, have, to date, not received sufficient consideration or investment to mitigate. In their view, this lack of attention is particularly critical, given the importance of farming and ranching to the society and economy of the basin.

For example, flooding can result in productive arable lands being inundated for long periods of time. These lands can become saline or alkaline, and eventually populated with invasive species such as cattails. In some cases, flooding has forced farmers and ranchers to undertake costly and lengthy land rehabilitation projects. Severe flooding, especially for extended durations of time, such as what occurred in 2011, can cause significant damages to agricultural land (e.g., soil compaction), as well as serious impacts to riparian ecology and ecosystems.

Sedimentation and silting from flood events are other common problems experienced by rural residents throughout the basin. Silting can build up in reservoirs and against roads, bridges, and other infrastructure. After flooding events, sedimentation can impact the productivity of hay meadows and other agricultural lands.

2. Control of levels and flows

The timing, location and volumes of water released from the major reservoirs are major concerns among basin residents. Some call for a need to address levels and flows on a basin-wide basis.

Some residents suggest that there is a need to reconsider the timing of releases from the reservoirs, in the hopes of reducing impacts to rural communities. They note that riverbanks, roads and bridges can be damaged by high volumes of releases. As a result, they suggest that the release of waters earlier in the season be considered under certain conditions.

Other residents express concern about decisions on apportionment flows. They note that improved monitoring of moisture conditions across the basin could, in turn, improve forecasting and allow for earlier releases of water. They suggest that such an approach could reduce mid-summer flooding of meadows that impacts ranchers, while still providing protection to urban centers through the peak-flow season.

In addition, there is considerable concern regarding the extent to which reservoir operations in the basin can lead to low-to-zero flow of the river downstream from the reservoirs. Such low flows can severely affect the many ranches along the Souris River that draw from the river to water livestock.

3. Community vulnerability

There is concern among many residents about the continued vulnerability of basin communities, large and small, to the volatility of the flow of the Souris River and its tributaries. They note such impacts as the loss of local infrastructure and impacts on the safety of drinking water, and believe that mitigative actions are sometimes taken only after major flooding events. These residents call for improved communication between basin communities and reservoir operators, such as sharing contingency plans to lessen the impacts of drought and flooding. Rural residents expressed a need for better communications and to be kept more informed in advance of reservoir releases or flow adjustments throughout the Souris River System, to help rural residents prepare for possible local changes in flow.

Image 20 Souris River near Westhope: 2021 Drought Conditions have caused widespread agricultural and ecological losses

On a related issue, some basin residents have suggested that more dams be built on various tributaries of the Souris River. The dams would help mitigate flooding by providing more water storage along these tributaries during peak flows. The dams would also promote economic development through increased opportunities for irrigation and livestock watering, and greater environmental protection through enhanced wildlife habitat.

4. Impacts on ecosystems

Basin residents have a strong connection to the land and waters of the region, and highly value a healthy river and environment. There are concerns about the environmental impacts of the successive fluctuations between floods and droughts, and of the management of the reservoirs. Concerns focus on the impacts on water quality, such as algal blooms, and on habitat for fish, birds, and other wildlife.

5. Impacts on industry

Basin residents are concerned about the vulnerability of oil and gas industry infrastructure to flooding. They note that floods in 2011 and 2014 flooded exploration and production sites, resulting in high costs to operators and even the abandonment of some sites, leading to health and safety hazards.

6. Impacts of artificial drainage

There are public concerns in the basin about the possible impacts of artificial drainage. Artificial drainage has the potential to impact both the quality and quantity of water flows in the basin.

3.2 Engagement with key government agencies and industry

A key component of the Study's engagement and outreach initiative was to ensure that water management agencies and users in the basin had the opportunity to review and comment on the Study's plans, analysis, findings, and recommendations. A binational Resource and Agency Advisory Group (RAAG) was established early in the Study to act as a conduit for input from federal, provincial, state, and municipal agencies, and from the electric power industry over the course of the Study. The group worked to ensure that any recommendations made by the Study Board with respect to the existing Operating Plan or alternative measures would be compatible with the mandates and resources of the agencies.

RAAG membership consisted of about 20 core members from federal agencies and agencies in Saskatchewan, Manitoba, and North Dakota (Table 6). Two co-chairs, one from each country, provided ongoing liaison with the Study managers.

Participating agencies included those that:

- have authority to alter Souris River flows or that of its tributaries;
- own infrastructure that control flows;
- have regulatory responsibilities for flows;
- administer water use permits;
- oversee floodplain development policies; or,
- have a public service interest in how water is managed.

The Study Board and Study teams met regularly with the RAAG over the course of the Study, both in-person and by webinar (Table 7). RAAG activities in the Study included:

- reviewing information provided by the Study Board for compliance with members' policies and interests;
- reviewing and providing feedback on performance indicators (PIs) and alternative measures;
- proposing additional alternatives for the Study to consider;
- ensuring all business needs and risks are accounted for in the Study's findings and recommendations; and
- disseminating outcomes of the Study to participating agencies.

Table 6 Resource and Agency Advisory Group members

Canada	United States
Russell Boals, Co-Chair Regina, Saskatchewan	Laura Ackerman, Co-Chair North Dakota State Water Commission Bismarck, North Dakota
Dr. John-Mark Davies Water Security Agency Saskatoon, Saskatchewan	Ryan Ackerman Souris River Joint Board Minot, North Dakota
Helen Fornwald City of Estevan Estevan, Saskatchewan	David Ashley Souris River Joint Board Voltaire, North Dakota
Jeff Hovdebo Water Security Agency Moose Jaw, Saskatchewan	Tom Bodine North Dakota Department of Agriculture Bismarck, North Dakota
Richard Janusz Fisheries and Oceans Canada Winnipeg, Manitoba	Frank Durbian U.S. Fish & Wildlife Service Upham, North Dakota
Ralph Leibel Government of Saskatchewan Regina, Saskatchewan	John Paczkowski North Dakota State Water Commission Bismarck, North Dakota
David Pattyson Upper Souris Watershed Association Estevan, Saskatchewan	Heather Husband North Dakota Department of Health Towner, North Dakota
Kevan Sumner Manitoba Municipal Relations Brandon, Manitoba	Dan Jonasson City of Minot Minot, North Dakota
Erin Zoski Agriculture and Agri-food Canada Regina, Saskatchewan	Jason Lee North Dakota Department of Game & Fish Riverdale, North Dakota
Chris Propp Manitoba Infrastructure Winnipeg, Manitoba	Elizabeth Nelsen U.S. Army Corps of Engineers St. Paul, Minnesota
	Jim Redding North Dakota Department of Transportation Minot, North Dakota
	Jason Thorenson North Dakota Department of Transportation Bismarck, North Dakota

Canada	United States
	Mitchell Weier U.S. Army Corps of Engineers St. Paul, Minnesota
	Chris Korkowski North Dakota State Water Commission Bismarck, North Dakota

Note: RAAG members as of the Study's completion in 2021. For a complete list of members who served over the course of the Study, see Appendix 4.

Table 7 Study meetings with the Resource and Agency and Advisory Group

Date	Location
Monday, June 25, 2018	Estevan, Saskatchewan
December 18, 2018	Webinar
January 29, 2019	Webinar
March 4, 2019	Webinar
March 19-20, 2019	Minot, North Dakota
April 29, 2019	Estevan, Saskatchewan
July 22, 2019	Webinar
August 15, 2019	Webinar
November 20-21, 2019	Minot, North Dakota
January 8, 2020	Webinar
July 22, 2020	Webinar
September 2, 2020	Webinar
March 15, 2021	Webinar
July 16, 2021	Webinar
July 21, 2021	Webinar
July 29, 2021	Webinar

Image 21 Research and Agency Advisory Group workshop in Minot, North Dakota, March 2019.

3.3 Engagement with Indigenous Nations

The Tribes, First Nations and the Métis Nation in the Study area and adjacent regions hold special knowledge of the Souris River basin's waters and ecosystems. Their interests can be affected by the changes in water levels and flows in the basin. (see Section 1.2 Study setting, Indigenous Nations which identifies approximately 25 Indigenous Nations with current and ancestral interest in the Souris River basin).

From the outset of the Study, the Study Board sought to establish lines of communication and build relationships with the Indigenous Nations in and around the basin so that their interests could be properly addressed and that all participants could share their knowledge and perspectives. Meetings were held with Tribes, First Nations, and the Métis Nation throughout the basin (Table 8) to:

- introduce the Study;
- discuss whether the Nation or Tribe and its traditional land use have been or could be affected by water management measures in the basin; and,
- explore the potential for longer term relationships regarding water management and, in particular, with the ISRB.

Image 22 Study meeting with Métis Nation citizens from Saskatchewan, Weyburn, Saskatchewan

Table 8 Study meetings with Indigenous peoples

Date	Location	Participants
October 29, 2018	Cowessess, SK	Cowessess First Nation
October 30, 2018	Headingly, MB	Swan Lake First Nation
December 6, 2018	Carry the Kettle First Nations	Carry the Kettle Nakoda Nations
January 4, 2019	Bismarck, ND	United Tribes of North Dakota
February 27, 2019	Bismarck, ND	Tribal Historic Preservation Officers (from Mandan, Hidatsa and Arikara Nation, Spirit Lake Nation, Standing Rock Sioux Tribe, Turtle Mountain Band of Chippewa)
September 16, 2019	Ochapowace, SK	Ochapowace Nation
September 20, 2019	Canupawakpa, MB	Canupawakpa Dakota Nation
September 21, 2019	Weyburn, SK	Métis Nation – Saskatchewan Eastern Region III
October 30, 2019	Winnipeg, MB	Manitoba Metis Federation

Date	Location	Participants
November 6-7, 2019	International Peace Garden (ND and MB)	First Nations, the Métis Nation and Tribes
September 17-18, 2020	Virtual Workshop	First Nations, the Métis Nation and Tribes
July 16, 2021	Webinar	Final report preview

In November 2019, the Study Board hosted a meeting at the International Peace Garden, with about 16 participants from 10 Tribes, First Nations and the Métis Nation to discuss the Study and explore areas of interest and concern. Several common themes emerged, including the vital role water has played and continues to play in the lives and well-being of all peoples in the Souris River basin. There was strong interest expressed in protecting the quantity and quality of water resources for future generations, while identifying and preserving areas of special significance to Indigenous peoples.

A follow-up workshop was held online in September 2020, with up to 15 participants, to continue the dialogue on advancing collaboration. The Study provided an update on the main components of work, including the review of operating rules and the evaluation of various Operating Plan scenarios to see if the operating rules can be improved for flood protection and water supply benefits.

Much of the September 2020 workshop was dedicated to gathering the ideas of Indigenous participants on how Indigenous Nations could collaborate and provide input on matters relating to the Souris River, the IJC and the ISRB. Participants stated that there is interest in creating an ongoing Indigenous advisory group for the Souris River watershed. The group would continue the relationships established under the study, and, in the future, advise both the ISRB and IJC; an Indigenous advisory group would continue to include interested Indigenous Nations with current and/or ancestral interests in the watershed.

In addition to establishing relationships between Indigenous Nations and the Study team, the ISRSB, the IJC and Indigenous contacts, the engagement events held under the study provided a unique opportunity for Indigenous people from Canada and the United State to interact, share common connections amongst each other, and grow new relationships around a common interest.

Image 23 Workshop with Indigenous Nations, International Peace Garden, November 2019

4 Review of the 1989 Operating Plan

Section 4 summarizes the key findings of the Study Board with respect to its:

- review of the language of the existing Operating Plan governing management of the Souris River, as set out in Annex A of the 1989 Agreement; and,
- evaluation of the performance of the 1989 Operating Plan.

This Study objective directly addresses the Governments' Reference item 5: *a detailed review of the Operating Plan contained in Annex A of the 1989 Agreement*.

Image 24 Release from Lake Darling Dam

4.1 Key provisions of the 1989 Agreement[5]

This section provides only selected highlights of key provisions of the 1989 Agreement; these key provisions were selected to aid the reader gain a better understanding of some of the operational requirements established in the Agreement. For a complete understanding, it is necessary to read the full 1989 Agreement, its annexes, the Interim Measures and the amendments in their entirety (See: https://ijc.org/sites/default/files/1989-10-26SourisRiverFloodControlAgreement.pdf and https://ijc.org/en/srb/who/mandate).

[5] The 1989 Agreement was established for 100 years (1990 to 2090) or until the useful lives of the Rafferty and Grant Devine Reservoirs end.

The objectives of the 1989 Agreement Operating Plan are specifically stated as:

> ***"To provide 1-percent (100-year) flood protection to Minot, North Dakota***
>
> ***To provide flood protection to urban and rural areas downstream from Rafferty Dam, Alameda Dam, and Lake Darling Dam***
>
> ***To ensure, to the extent possible, that the existing benefits from the supply of water in the Souris River Basin and the supply of water to the Souris River Basin Project are not compromised."*** [1989 Agreement Annex A Page A-1]

For flood operations, the 1989 Operating Plan further recognizes that floods greater than the 1 percent flood which the system was designed for can occur:

> ***"In those cases where the flood event is greater than a 1-percent (100-year) event, the Project will be operated as set forth in the Reservoir Regulation Manuals[6] to attempt to reduce downstream damages without endangering the structures themselves. This may require flows greater than 5,000 cfs[7] at Minot for the period before June 1, and may also require flows greater than 500 cfs (which could also exceed 5,000 cfs) after June 1."*** [1989 Agreement Annex A Page A-26]

The following is a summary of the 1989 Agreement's key provisions.

Article II

Under Article II, Canada agrees to provide the United States with a minimum volume of flood storage at both Rafferty Reservoir (327,100 dam^3; 265,200 acre-feet) and Grant Devine Reservoir (138,900 dam^3; 112,600 acre-feet).

Article III

Under Article III, Canadian works are to be operated and maintained by Canada at no cost to the United States. As well, Canada must notify the United States of any maintenance curtailment, providing a one-year notice when possible, and minimize the effects of the curtailment.

Article V

Under Article V, Canada and the United States agree to prepare Reservoir Regulation Manuals for the operation of the reservoirs in consultation with interested states and provinces. The Parties also agree to review the Operating Plan at five-year intervals or as otherwise mutually agreed upon, to optimize the flood control and water supply benefits.

Article X

Under Article X, the province of Saskatchewan is responsible for the construction, operation, and maintenance of the control structures in Canada.

[6] The Canadian reservoirs do not have established Reservoir Regulation Manuals as depicted in the 1989 Agreement.

[7] The 1-percent flood is the 1:100-year flood; hydrological data in 1989 established the 1-percent flood to be 5,000 cfs or 5,000 ft^3/s (141.6 m^3/s) for the Souris River at Minot.

Article XIII

Under Article XIII, Canada and United States agree that the agreement will be in effect for 100 years (1990 to 2090) or until the useful lives of the Rafferty and Grant Devine Reservoirs end, whichever comes first.

Annex A

Annex A of the agreement provides the Operating Plan for the operations of the four main reservoirs for flood control and water supply. It includes data on the physical characteristics of the reservoirs, prescribes rules for flood and non-flood operations, and sets out procedures for communications and the exchange of information among the responsible agencies.

Under the Operating Plan set out in Annex A, the operators of the reservoirs seek to:

- achieve drawdown targets prior to the start of spring runoff;
- store reservoir inflows up to full supply;
- release surplus volumes of water without exceeding the target flow at the Sherwood Crossing, the international gauging station located where the Souris River flows from Saskatchewan into North Dakota;
- return the reservoirs to full supply in a timely manner;
- release flows in a similar pattern to what would have occurred in a state of nature (except during flood years), as much as possible; and,
- ensure that apportionment obligations under the 1989 Agreement are being met.

Under these operating principles, the reservoirs provide flood protection to urban and rural areas downstream of the four major control structures.

Annex B

Annex B outlines the water apportionment agreement between the two countries. It contains rules for low flow and apportionment, as calculated currently annually by Environment and Climate Change Canada (ECCC). The annex was amended in 2000 to provide greater clarification of the conditions that must prevail for making the apportionment determinations.

Under Annex B, the Parties agree that:

- The annual flow of the Souris River from Saskatchewan into North Dakota shall be at least 50 percent of the flow that would have occurred naturally. In wet years, it may be only 40 percent to account for evaporation from the reservoirs in Saskatchewan and for the flood control benefits to North Dakota;
- The timing of the flows of the Souris River from Saskatchewan to North Dakota should be close to natural conditions or for the most beneficial use of North Dakota. This could include holding back flows to reduce flooding or until they would be more useful to the interests in North Dakota;

- From June through October of each year, at least 0.566 m^3/s (20 ft^3/s) shall flow in the Souris River from North Dakota to Manitoba (note: The minimum flows were established in the 1959 Interim Measures and included in the Agreement as modified in 2000; see https://ijc.org/en/srb/who/mandate). During drought conditions, the International Souris River Board (ISRB) can establish a lower flow level; and,
- The annual flow of Long Creek from North Dakota into Saskatchewan shall not be less than its flow from Saskatchewan into North Dakota.

Operational responsibilities

The ISRB is responsible for overseeing Souris River flow, its apportionment, and flood control in the Souris River basin, in accordance with non-flood and flood operations specifically established in the 1989 Agreement and subsequent amendments and directives. The ISRB monitors the flows and levels in the basin's rivers, as well as the elevations in the main reservoirs. When the ongoing monitoring indicates that flows or levels will exceed or fall below the values set out in the Operation Plan, the ISRB, in its oversight role, ensures the process is in place for coordination and communications between the operating agencies, IJC, parties to the agreement, and stakeholders.

1. Regular (non-flood) operations

Most years are non-flood years in the basin. During this time, the focus of operators of the main reservoirs is on water supply and conservation. The apportionment balance is estimated by the ISRB. If additional releases are needed to meet the apportionment balance, then North Dakota assesses its needs and may call for a release any time prior to Oct. 1.

When spring runoff begins, drawdowns from the reservoirs are ended. The reservoir operators will balance the inflows and outflows at the three reservoirs in Saskatchewan. Discharges from these reservoirs are limited by the maximum target flow at Sherwood Crossing, 113 m^3/s (4,000 ft^3/s) when flows exceed the 1:50-year event (the threshold is 90 m^3/s or 3,200 ft^3/s for flows less than the 1:50-year event).

Lake Darling Dam also balances inflow and outflow during the spring runoff. Releases from the dam are limited to the maximum target flow in Minot, North Dakota, 142 m^3/s (5,000 ft^3/s).

Under some conditions, a delayed release[8] of water from one or more of the three Saskatchewan reservoirs may be required. In these cases, the delivery of water at Sherwood, North Dakota, should not be less than the release minus the losses that would have occurred under natural conditions between the point of release and Sherwood. If the release is not needed in North Dakota, the water may be retained for use in Canada.

A final apportionment balance is determined by the ISRB on Oct. 1. Any portion of the North Dakota apportionment remaining in Saskatchewan on that date is released from Rafferty or Grant Devine Reservoirs to the Souris River for delivery to the United States.

[8] The delayed release is measured at the points of release.

2. Flood forecasting and flood operations coordination

The current Operating Plan for managing flows in the Souris River basin, contained in Annex A of the 1989 Agreement, relies heavily on flood forecasting. The ISRB's Flow Forecasting Liaison Committee is responsible for coordinating and ensuring the sharing of all forecasting activities for flows and flood operations in the basin. The group includes representatives of:

- the designated operating agencies for the dams in Canada and the United States (WSA and USACE are responsible for flood operations, while WSA and USFWS are responsible for non-flood operations; one exception is Boundary Dam which is operated by SaskPower during non-flood events);
- other agencies responsible for forecasting or streamflow, including ECCC in Canada, and the United States National Weather Service (USNWS) and the United States Geological Survey (USGS) in the United States; and,
- other agencies with a direct responsibility for water management in the region, including the USFWS, North Dakota State Water Commission, Manitoba Infrastructure, and Manitoba Agriculture and Resource Development.

The first forecast for the system is issued on Feb. 1, typically two months in advance of the start of the runoff and just past the mid-point of the snow accumulation season. This timing allows for the completion of any drawdown requirements prior to the start of the spring melt, as it takes time for the stored water to leave the reservoirs. Subsequent forecasts are issued on or near the 15th and last day of each month up to the start of the runoff.

Under the 1989 Agreement, flood operations come into effect when the spring runoff estimate on Feb. 1 or later shows a 50 percent or greater chance that:

- the estimated 30-day unregulated volume of the river at Sherwood, North Dakota, is equal to or greater than 216,110 dam^3 (about 175,200 acre-feet) (this is about a 1:10-year event[9] based on the data available in 1989); and/or,
- the local 30-day volume at Sherwood is expected to equal or exceed 37,000 dam^3 (about 30,000 acre-feet).

When flood operations are in effect, additional drawdown of the reservoirs may be required to provide for flood control storage. Given the importance of the water supply to the power plant at the Boundary Reservoir, an additional drawdown on the Rafferty Reservoir may be used instead.

Downstream maximum flow targets at Sherwood and Minot, North Dakota, are also set based on the snowmelt forecast provided to the ISRB by the WSA and USNWS. Flood operations end when the flood volumes have safely passed through the reservoirs (i.e., the reservoirs are returned to their full supply levels) and the flow at Minot is at or below 14.2 m^3/s (500 ft^3/s).

When significant flooding occurs, the focus is on limiting downstream damages while not endangering the control structures themselves. This provision may require flows greater than 141.6 m^3/s (5,000 ft^3/s) at Minot prior to June 1 (see Section 4.1).

[9] A 1:10-year flood has a 10-percent chance of occurring every year and a 99.5 percent chance of occurring at least once over a period of 50 years.

The reservoirs must be operated as a system to achieve the 1:100-year[10] protection levels at Minot, North Dakota. When runoff events are larger than the system's design capacity, as occurred in 2011, flood protection is limited and the system may be unable to meet all the terms of the 1989 Agreement.

After the spring snowmelt, the reservoirs return to water supply operation. Currently, there is minimal guidance in the 1989 Agreement on flood operations caused by rainfall-driven events. This reflects the fact that when the 1989 Agreement was originally developed, summer rain-driven floods in the region were rare and considered only minor runoff events relative to the spring snowmelt runoff.

4.2 Review of the language of Annex A

This section summarizes the approach and key findings of the Study regarding the review of the language of Annex A of the 1989 Agreement. For more detailed information on this issue, see the technical task team's

- "Annex A - Addendum to the Souris River Flood Control Agreement dated October 26th Side-by-Side Version Comparison (2020 vs 1989)" drafted Sept. 21, 2020, summarizing proposed language updates to the Operating Plan, on the Study's website: https://ijc.org/en/srsb/side-side-version-comparison-2020-vs-1989-annex-addendum-1989-souris-river-flood-control. The proposed language updates are for clarification (e.g., removing ambiguities) and to ensure a clear understanding of the language; the proposed language updates are not meant to change the intent of the 1989 Agreement.

4.2.1 BACKGROUND

The unprecedented flooding in the Souris River basin in 2011 challenged operations as never before. For the operators of the dams, the flooding highlighted long-standing language ambiguities and shortfalls in some provisions of the Agreement.

During the 2011 flood event, the operators of the reservoirs on the Souris River system in Canada and the United States (the WSA in Saskatchewan, and the USFWS and USACE in North Dakota) were in regular and frequent contact to coordinate reservoir operations and releases as well as to share information on the current and forecasted conditions. These operational conversations daylighted existing ambiguities in the wording of the agreement concerning operations that had been recognized before, but the experience of the 2011 event highlighted the importance of clarifying it. As well, they noted, that the "…Operating Plan does not cover all possible flood circumstances…", such as experienced in June 2011, "…and it may be necessary to jointly agree on changes to the Operating Plan." Revising the language based on a common understanding of the conditions and requirements of the Operating Plan is important for operators to work with the agreement in special circumstances and into the future.

The agencies responsible for reservoir operations presented their observations to the ISRB with respect to the uncertainties related to operations and terminology used in Annex A of

[10] A 1:100-year flood has a 1-percent chance of occurring every year and a 63.4 percent chance of occurring at least once over a period of 100 years.

the Agreement. The ISRB requested that a committee of the designated agencies work to identify specific areas where the language and text in Annex A of the 1989 Agreement could be improved for ease of understanding and interpretation.

Beginning in 2014, the ISRB facilitated ongoing discussions among the agencies. The committee identified numerous items in Annexes A and B of the 1989 Agreement dealing with both flood and non-flood items that required clarification. These items included updating and re-plotting a number of tables and graphics pertaining to reservoir properties. The ISRB committee also noted that the Agreement was written assuming that any flood event would be the result of spring snowmelt and that late spring/summer/fall rain events would only cause minor flooding.

In July 2017, the IJC established the Study, and the work of the agencies' language review committee was assumed by the Study Board. A Study Task Team was formed to complete the review.

4.2.2 STUDY APPROACH

Building on the earlier work of the operating agencies' committee, the Study's Task Team identified a range of issues that needed to be addressed to update and improve the clarity of the language of the 1989 Agreement. None of the proposed plain language revisions are meant to change the original intent of the 1989 Agreement, and it is clearly understood that any proposed language changes would require a comprehensive legal review of the items in the side-by-side 2020 vs. 1989 suggested language updates. These language changes or issues can be organized into several interrelated categories:

- specific wording that could be revised or added to clarify the meaning or intent of a provision in the Operating Plan and/or to ensure consistency in implementation;
- specific wording that could be added or revised to clarify responsibility for a process or action;
- specific wording or data that should be updated or revised to consider existing conditions or reservoir operations; and,
- specific concerns or questions that have evolved over time on which the 1989 Agreement is silent.

Note that the scope of the Study's language review was the existing 1989 Agreement and Operating Plan. The review did not include considerations beyond the Operating Plan, such as dam operations in response to adaptive management or climate change considerations.

Image 25 Grant Devine Dam during 2011 Drawdown

4.2.3 KEY FINDINGS

The key findings presented here include:

- specific proposed changes in language and data in the 1989 Agreement that will help improve the clarity and ongoing relevance of the Operating Plan and ensure consistency in its implementation; and,
- a set of six outstanding issues for which no consensus was reached among the operating agencies nor the Study Board; resolution of these issues may involve policy considerations and require the attention of the IJC and the Governments of Canada and United States.
- The plain language review was designed to clarify understanding and ambiguity; as noted, legal review of the language would be required prior to the Parties adopting any changes to the official agreement.

Updating language and data

The Study team worked with reviewers from the dam operating agencies and the ISRB to address the issues that had been identified by the operating agencies. The team developed a detailed side-by-side comparison of the original 1989 Agreement wording and proposed language updates to specific provisions and tables in the Operating Plan. In most cases, a consensus recommendation was readily developed by the team and reviewers from the operating agencies.

For example, there was agreement that data for a meteorological station network for the Souris River basin in Saskatchewan required updating and that the source of the Souris River channel capacity data contained in Annex A need to be noted for reference purposes.

As well, the Study team developed proposed new wording to provide greater clarity in meaning or intent for a number of Operating Plan provisions. For example, the team concluded that the elevation and datums section of Annex A can be revised to address the uncertainty with the vertical datum used for elevations. New language was also proposed to explain that the elevations and datums are appropriate for each reservoir with respect to the relationships between stage, discharge, and volume and are not necessarily appropriate for comparison between reservoirs.

It is worth noting that in its review of one of the issues – the designation of the apportionment year – the Study team's suggestion that water management and sharing under the Operating Plan could be improved by using a different apportionment year became the basis of one of the Study's final alternative operating plan measures. Section 6 has more information on this option incorporating a change in the apportionment year.

Outstanding issues

Over the course of its review, the Study team identified a small number of substantive issues that may require direction from the IJC or the governments to resolve. In these cases, either the operating agencies were not able to reach consensus on a proposed change, or the Study Board recognized that the proposed change likely would require broader policy consideration by the IJC or Governments.

Table 9 summarizes these outstanding issues and the Study Board's conclusions regarding the next steps.

1. Section 4.3.1 Flood Operating Plan

The existing language in the Operating Plan states that the flood Operating Plan under the Agreement is divided into four separate phases in accordance with the annual hydrograph. These phases relate to operations:

a. to lower reservoirs prior to spring freshets

b. during spring freshets

c. after spring freshets to restore reservoirs to full supply level

d. during the summer, fall, and winter

The concern is that the 1989 Agreement was written with a focus on managing flow operations from spring snowmelt runoff. However, operations also must consider managing runoff during periods outside of spring snowmelt, which could occur during any season.

As a result, there was consideration for revising part (d), above, to read:

d. operations during runoff events not due to spring freshets

However, there was concern expressed by some reviewers that the proposed revision would change the original intent of the 1989 Agreement, and therefore would need a policy review and decision.

The Study Board concluded that:

- this item can be resolved by reverting to the 1989 Agreement language; and,
- the need for any revision could be reconsidered if or when there are substantive updates to the 1989 Agreement.

2. Section 4.3.3 Drawdown during spring freshet

The Study team concluded that there was a gap in the 1989 Agreement regarding drawdowns during the spring freshet. The concern is that events such, as significant late snow falls or substantial early snow melts, could cause one of the operators not to meet drawdown targets prior to the spring freshet. There is nothing in the existing Operating Plan that clarifies procedures in such a case.

New language was proposed to address this gap and help clarify procedures when certain conditions exist during these drawdowns. Specifically, the following new text was considered:

> ***It is possible that conditions outside the control of governments or agencies may impact the ability to meet drawdown levels at a specified date, such as significant late snowfalls or early snowmelts. Agencies of both countries will follow the drawdown schedules as much as possible. In the event that conditions prevent necessary drawdowns on schedule, the affecting agency will inform the other pertinent agencies as well as the ISRB. The ISRB will make the final determination, on a case-by-case basis, on a modified drawdown schedule.***

The Study team was not able to reach a consensus on this issue, with some participants viewing the addition as a basic change to the 1989 Agreement.

The Study Board concluded that

- the proposed language should not be included as part of its recommended revisions to the 1989 Operating Plan; and,
- the need for additional text could be reconsidered if or when there are substantive updates to the 1989 Agreement.

3. Section 4.3.4 Drawdown after spring freshet

The existing 1989 Operating Plan includes the following statement regarding drawdowns after the spring freshet:

> "It should be noted that at no time will releases from the Canadian reservoirs cause the flows at Sherwood Crossing to exceed the target flow from Figure 4-1[11] unless the flow cannot be controlled by the reservoirs."

The concern is that the existing language does not address or define the meaning of the phrase: "flow [that] cannot be controlled by the reservoirs."

The following new language (highlighted in ***bold italicized*** text) was proposed to correct this lack of clarity:

> "It should be noted that at no time will releases from the Canadian reservoirs cause the flows at Sherwood Crossing to exceed the target flow from Figure 4-1[12] unless ***a reservoir is above Maximum Allowable Flood Level (MAFL), a dam safety issue exists or mutually agreed upon between Canada and the U.S.***"

However, no consensus was reached on the proposed additional wording. Some reviewers suggested that, because the additional language assigns reservoir operating rules that are not in the original 1989 Operating Plan, the proposed change could be considered a change in the 1989 Agreement, and therefore requires further policy consideration by the IJC and governments.

The Study Board concluded that:

- the proposed language should not be included as part of its recommended revisions to the 1989 Operating Plan; and,
- the need for additional text could be reconsidered if or when there are substantive updates to the 1989 Agreement.

4. Section 4.3.5 Significant spring and summer rainfall

The existing 1989 Operating Plan includes the following statement regarding significant spring and summer rainfall:

> "If significant rainfall occurs during the spring or summer flood recession, the Reservoir Regulation Manual will provide for discharging the rainfall runoff based on following the unregulated flow recession."

[11] This reference is to a figure within the 1989 Operating Plan
[12] This reference is to a figure within the 1989 Operating Plan

The concern is that the existing language lacks sufficient detail. Revised text was proposed to clarify this section by adding details regarding the operating steps:

> If significant rainfall occurs during or following the spring freshet, the Reservoir Regulation Manual will provide for discharging the rainfall runoff ***released as quickly as possible following the constraints in the subject agreement and taking into consideration downstream impacts***.

No consensus was reached on this issue. Some participants suggested that the phrase "as quickly as possible" could imply maximum target flow. As a result, it was suggested that, while the proposed language adds detail, it also added unintentional ambiguity to this section.

The Study Board concluded that:

- this item may be resolved by reverting to the 1989 Agreement language, given that the proposed new language could be viewed as a change in procedures of the 1989 Agreement.

5. Section 4.3.6 Flood operation steps

The original 1989 Operating Plan included the following statement regarding the operational steps to be followed during a flood:

> "DURING FLOOD (May 16 to May 31)...
>
> B. Sherwood Crossing Target (after peak at Sherwood Crossing)
> After the peak flow has occurred at Sherwood Crossing, estimate the average daily flows expected at Sherwood Crossing from the uncontrolled areas. Using this flow, the current Lake Darling Reservoir elevation, and the local flows at Minot, estimate future Lake Darling Reservoir elevations. Using this data, to include the Sherwood Crossing target flows, make releases to drawdown Rafferty Reservoir and Alameda Reservoir within the target flows in Plate A-5. Plate A-9 contains storage data for Lake Darling Reservoir to aid in the estimates.
>
> Repeat this operation as needed to reduce reservoir levels to FSL."

The issue is that at some period prior to 2020, this section was deleted and replaced with much shorter text to simplify the section:

> ***"Balance releases within target flows from all the reservoirs in order to return all reservoirs to full supply level."***

The change is believed to have been made in an earlier update of the 1989 Agreement prior to the Study being established in 2017.

The Study Board concluded that:

- the changed language should remain in the 1989 Agreement; and,
- the issue could be reviewed again later, if and when substantive changes to the 1989 Agreement are considered.

Image 26 Informational sign at Rafferty Dam and Reservoir.

6. Section 4.3.6 Flood operation steps - reporting

The original 1989 Operating Plan included the following statement regarding reporting requirements following a large flooding event:

a. Following the operating guidelines, release allowable flows to bring the reservoirs to their FSL's,

b. Review actions taken during flood and note problems which occurred,

c. If flood was a large event, prepare a Post Flood Report.

Item (c) listed above was included in the original text of the 1989 Agreement. However, it was subsequently removed by editors, as it was considered redundant, as reporting requirements following a flood are already listed in Section 5 Reports of the Agreement.

The Study Board concluded that:

- this issue can be resolved by reverting to the original language of the 1989 Agreement; that is, by re-inserting "Item (c)" of section 4.3.6.

Table 9 Review of 1989 Operating Plan language: summary of outstanding concerns

1989 Operating Plan Item	Study Team Proposal	Outstanding Concern	Study Board Conclusion
1. Section 4.3.1 Flood Operating Plan	Revised language to address runoff during periods outside of spring snowmelt	Proposed revision could change the original intent of the 1989 Agreement	Retain existing language Reconsider if or when there are substantive updates to the 1989 Agreement
2. Section 4.3.3 Drawdown during spring freshet	New language proposed to address existing gap in Operating Plan procedures regarding drawdowns during the spring freshet	Proposed addition could be seen as a basic change to the 1989 Agreement	Proposed language should not be included as part of its recommended revisions to the 1989 Operating Plan Reconsider if or when there are substantive updates to the 1989 Agreement
3. Section 4.3.4 Drawdown after spring freshet	Revised language to clarify existing language regarding drawdowns after the spring freshet	The additional language assigns reservoir operating rules that are not in the original 1989 Operating Plan, and therefore, could be considered a change in the 1989 Agreement	Proposed language should not be included as part of its recommended revisions to the 1989 Operating Plan Reconsider if or when there are substantive updates to the 1989 Agreement
4. Section 4.3.5 Significant spring and summer rainfall	Revised text to provide more details on operational procedures during significant spring and summer rainfall events	Proposed text may add unintentional ambiguity	Revert to the 1989 Agreement language, given that the proposed new language could be viewed as a change in procedures of the 1989 Agreement
5. Section 4.3.6 Flood operation steps	Reviewed an editorial change to the 1989 Agreement made prior to 2017 that sought to simplify procedures during a flooding event	The 1989 Agreement language had been changed at some period prior to the 2017 Study being established.	Retain the changed language Reconsider if or when there are substantive updates to the 1989 Agreement considered
6. Section 4.3.6 Flood operation steps - reporting	Reviewed an editorial change to the 1989 Agreement made prior to 2017 that sought to remove redundancy	The 1989 Agreement language had been changed at some period prior to the 2017 Study being established.	Revert to the original language of the 1989 Agreement; that is, re-insert “part c” of section 4.3.6

4.3 Evaluation of the performance of the 1989 Operating Plan

The first step when considering the potential for improving flood control and water supply benefits in the basin is to evaluate how well the existing Operating Plan performs. This section provides an overview of the Study’s evaluation of the performance of the 1989 Operating Plan under the Agreement.

4.3.1 STUDY APPROACH

The Souris River Project includes the four reservoirs operated according to the 1989 Agreement, three in Saskatchewan and one in North Dakota. The four reservoirs provide water security for the Souris basin in times of water scarcity and drought, as well as protection from floods during periods of excessive precipitation and basin runoff. The Souris River and its tributaries comprise a highly variable river system, susceptible to both water shortages and excesses. Though the four reservoirs alter river flow from its natural state, their main purpose is to provide better water management by conserving water during dry periods and storing water in reservoirs to regulate outflows to reduce impacts of flood conditions (the basis for the 1989 Agreement).

Three simulations

Using the HEC-ResSim model, a Study team analyzed and compared three simulations to understand how operations based on the 1989 Agreement manage balancing flood control measures and water supply benefits, as well as assessing other key areas affected by water management (e.g., environmental and ecosystem needs). (For more details on the modeling and evaluation tools, see section 5.2.3.) The simulations were run using data from 1930 to 2017. This period coincides with the period of most reliable data for analysis and allowed the Study team to analyze conditions from both severe droughts and extreme flooding events in the basin.

The three simulations were:

- a ***baseline simulation***, based on following the operational rules in the existing 1989 Agreement and its Annex A and Annex B, as if all dams had been in place during the entire period from 1930-2017. The baseline simulation includes Rafferty Dam (1992), Boundary Dam (1958), Grant Devine Dam (1994; formerly Alameda Dam), and Lake Darling Dam (1936, raised 0.15 m or 0.50 ft. in 1998). While the reservoirs were constructed and commissioned at different dates, the baseline scenario simulates operations to compare what their influence would have been if they existed and had been operated in accordance with the 1989 Agreement throughout the entire 88-year period of record.
- a ***pre-Agreement simulation*** was conducted using operational plans used prior to the 1989 agreement for Boundary and Darling Reservoirs from 1930-2017. In this simulation, Rafferty and Grant Devine Reservoirs were removed from the model, allowing the Study team to evaluate the conditions that existed on the river with Boundary and Lake Darling Reservoirs in place from the mid-1950s until the 1989 Agreement went into effect.

- an ***unregulated simulation*** representing a scenario close to the "state-of-nature" for the Souris River basin from 1930-2017, with all four reservoirs removed from the model. This simulation does not represent an exact natural state, as the J. Clark Salyer National Wildlife Refuge[13] was not removed from the model, nor was all built infrastructure within the Souris River basin removed from the model (towns, cities, roads, rail, landscape/land use modifications, etc.). By removing all major dams and reservoirs from the Souris River System, the unregulated simulation allows comparison to Souris River flows without major water infrastructure in place.

By comparing the simulations, the Study team was able to analyze how effective the 1989 Agreement has been at providing water supply and flood control benefits to each jurisdiction in the Souris River basin. For example, comparing the baseline to the pre-Agreement simulations identifies the benefits and impacts that were obtained by the 1989 Agreement going into effect, while comparing the baseline to unregulated simulations identifies the benefits and impacts each of the reservoirs in the system provides.

It should be noted that the analysis is based on the results of simulations using the HEC-ResSim model; the datasets were simulated from reconstructed hydrology. The Study teams considered this approach appropriate for medium and high flows in the river. However, the accuracy of the simulations may be uncertain for low-flow conditions (due to limitations of the model and reconstructed hydrology data).

Key reaches of the river

The 1989 performance evaluation simulation runs for this comparison used 13 key locations to assess changes in flows and/or water levels in distinct river reaches along the Souris River (Figure 15). The locations analyzed were chosen based on their significance in the hydrologic system and the different jurisdictions. For example, Westhope, North Dakota, was included to show the differences between the unregulated and baseline simulations and how they affect flows into Manitoba and the river's final reach, prior to discharging into the Assiniboine River. Reconstructed hydrology downstream of Westhope to Wawanesa was not undertaken by the study due to scope and budget constraints, and a lack of complete data sets for the 1930–2017 hydrology for the Manitoba tributaries. The Study team determined that it was not practical nor necessary for the study's purposes to reconstruct the hydrology of the Manitoba reach from Westhope to Wawanesa. Benefits and impacts to the Manitoba reach were successfully represented and assessed by analyzing flow changes at Westhope and determining how these flows affected performance indicators in Manitoba. Evaluation of flow changes at Westhope also enabled the Study team to assess benefits and impacts of how the 1989 Agreement affected river flow in the Manitoba reach to the Assiniboine River. It should be noted, as earlier stated, that the hydrological analysis of the upstream reaches in North Dakota did not exclude the J. Clark Salyer National Wildlife Refuge and its control structures.

[13] In existence since 1935, the J. Clark Salyer National Wildlife Refuge is comprised of a series of low dikes and water control structures. The system provides shallow-reservoir water-pooling management to enhance Souris River aquatic health, riparian biodiversity, and wildlife habitat over approximately 70 km (45 mi) of the Souris River extending north from its southern limits near Bantry, North Dakota, to its downstream limits near the Manitoba border.

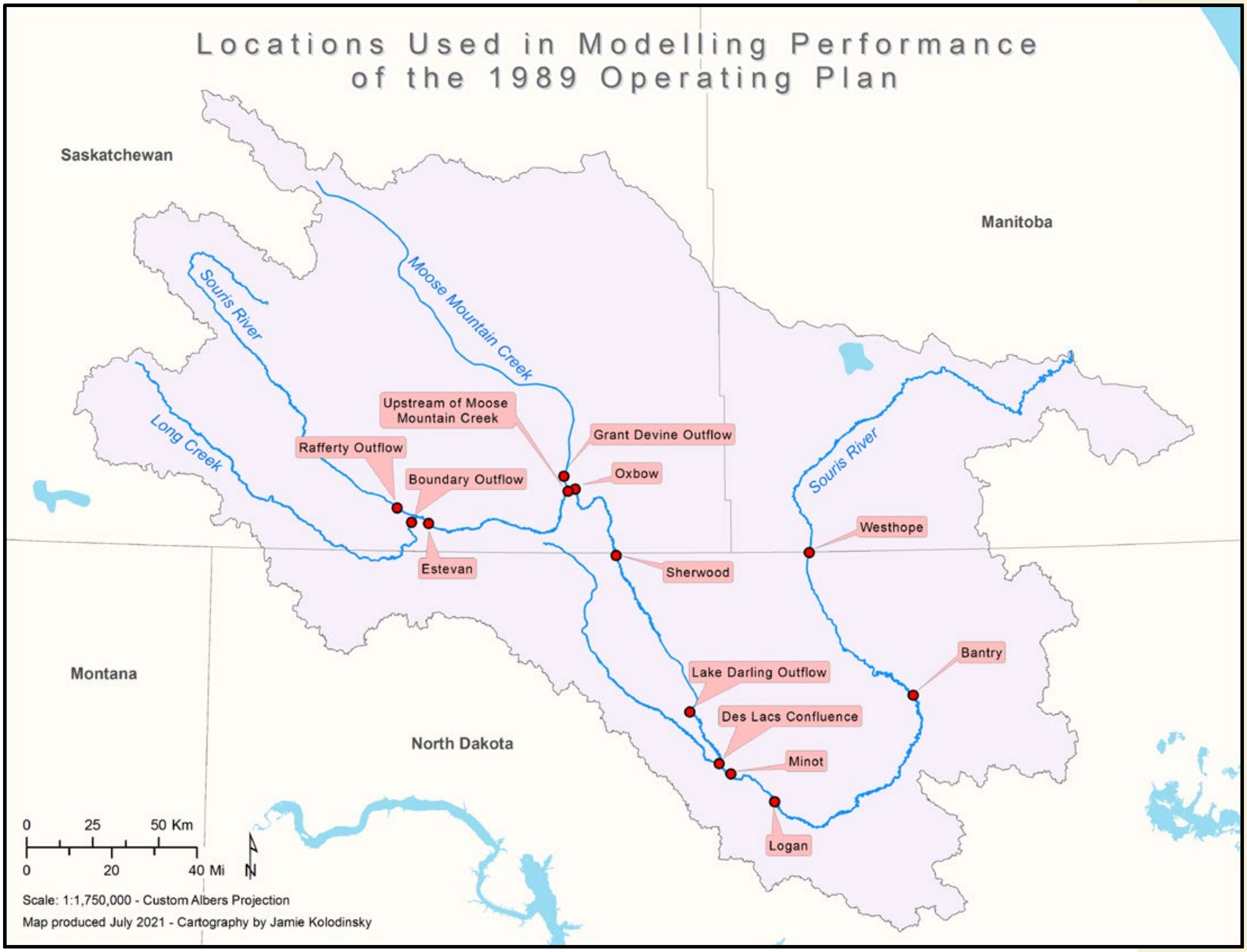

Figure 15 Locations used in modeling performance of the 1989 Operating Plan

The performance of the 1989 Operating Plan was evaluated to assess how river flow management resulted in benefits or impacts to all river reaches, as categorized under three groups of effects:

- flood control, including socio-economic effects;
- water supply; and,
- indirect or secondary effects on environmental resources, socio-economic components, cultural sites, and water quality.

4.3.2 FLOOD CONTROL

Analysis of the three simulation results was undertaken to address four questions about the provision of flood control benefits in the basin:

- How does each simulation affect the frequency of bankfull exceedances (overflows and flooding in the basin)?

- How does each simulation affect the magnitude of annual peak flow?
- How does each simulation affect the mean monthly flow?
- Are there any locations that are too far downstream for reservoir operations to effectively prevent flooding?

Table 10 shows the bankfull flow capacity for 13 selected reaches of the Souris River[14] and summarizes the data for the total number of days that bankfull exceedances occurred for each. Bankfull exceedances depict flows that will flood the river's riparian zone and the flat prairie topography. The analysis found that the existing 1989 Operating Plan (i.e., the baseline simulation) is highly effective at flood prevention, compared to both the pre-Agreement and the unregulated (natural state) simulations. In 12 of the 13 selected locations, the baseline simulation results in fewer days in which the Souris River would have exceeded its banks.

Results at four strategic locations are presented in more detail below to illustrate the analysis and findings. The four locations summarized here are:

- Grant Devine Reservoir, Saskatchewan outlet reach;
- Sherwood, North Dakota reach;
- Bantry, North Dakota reach; and,
- North Dakota/Manitoba reach from Westhope, North Dakota, to Wawanesa, Manitoba.

Table 10 Bankfull exceedances[15] at selected reaches, 1930-2017

Days Flow Exceeds Bankfull Capacity				
Reach	Approximate Bankfull Capacity (cfs)	Baseline (days)	Pre-agreement (days)	Unregulated (days)
Rafferty (SK)	500	886	936	936
Boundary (SK)	900	125	283	325
Estevan (SK)	2,000	138	373	390
Upstream of Moose Mountain (SK)	2,000	203	430	473
Outflow Grant Devine (SK)	1,800	0	62	62

[14] The Souris River is a small meandering shallow river with very limited natural channel capacity for containing runoff events. It is a common and natural condition that the Souris River overflows its banks into the riparian zone and floods the flat prairie topography. Some reaches (e.g., Minot) have been modified with channel widening to enable passage of larger flows without causing flooding.

[15] Each of these tables identifies the number of days of occurrence during 1930-2017, where flow exceeded the riverbanks (i.e., the river's channel capacity in the identified reach). A lower "number of days" is a lower "out-of-bank flooding period" for the reach. The 1930-2017 period represents a total of 32,151 days.

Days Flow Exceeds Bankfull Capacity				
Reach	Approximate Bankfull Capacity (cfs)	Baseline (days)	Pre-agreement (days)	Unregulated (days)
Oxbow (SK)	3,200	121	344	362
Sherwood (ND)	2,000	247	627	664
Outflow Darling (ND)	1,900	372	749	838
Des Lacs Confluence (ND)	1,500	680	1,073	1,203
Minot (ND)	5,000	85	281	247
Logan (ND)	1,400	756	1,149	1,301
Bantry (ND)	300	4,705	4,569	6,017
Westhope (ND/MB)	600	3,580	3,611	4,187

1. Grant Devine Reservoir outflow reach, Saskatchewan

The three simulations analyzed the extent of flow reduction that the reservoir has on Moose Mountain Creek in the spring and summer. The creek is a major tributary of the Souris River, entering the river 7.8 km (4.8 mi) downstream of the reservoir. Moose Mountain Creek has a channel capacity of approximately 51 m^3/s (1,800 ft^3/s) in the reach from Grant Devine Reservoir to the confluence with the Souris River.

Table 11 summarizes the total number of days, by month, that bankfull exceedances occurred for each simulation at the Grant Devine Reservoir outflow reach over the 1930-2017 period.

The analysis suggests that the 1989 Operating Plan (the baseline) provides significant reductions in flows for this reach, compared to the pre-Agreement and unregulated conditions. Under the baseline simulation, there were no days during the 1930-2017 period of analysis in which the river exceeded its banks. By contrast, in 11 different years (12.5 percent of years evaluated) there were 62 days combined, all in April and May, in which exceedances occurred under the other two simulations. The baseline eliminated out-of-bank flows in all 11 of those years over the period, compared to the other two cases. The most notable reductions in flow were in the flood years 1969, 1974, 1976, 1996 and 2011.

Table 11 Bankfull exceedances for Grant Devine Reservoir outflow reach, Saskatchewan, by month, 1930-2017

Grant Devine Outflow Reach, Saskatchewan - Bankfull Exceedances			
Month	**Baseline (days)**	**Pre-agreement (days)**	**Unregulated (days)**
January	0	0	0
February	0	0	0
March	0	1	1
April	0	48	48
May	0	13	13
June	0	0	0
July	0	0	0
August	0	0	0
September	0	0	0
October	0	0	0
November	0	0	0
December	0	0	0
Total	**0**	**62**	**62**

Table 12 summarizes the mean monthly flows under each simulation. The data suggest that along with reducing peak flows, the reservoir also redistributes flow from the spring throughout entire year. In particular, the bulk of the spring freshet is redistributed from October through February.

Table 12 Mean monthly flow for Grant Devine Reservoir outflow reach, Saskatchewan, 1930-2017

Grant Devine Outflow Reach, Saskatchewan – Mean Monthly Flow						
Month	Baseline (m^3/s)	Baseline (cfs)	Pre-agreement (m^3/s)	Pre-agreement (cfs)	Unregulated (m^3/s)	Unregulated (cfs)
January	0.4	16	0.0	0	0.0	0
February	1.7	59	0.0	0	0.0	0
March	0.8	27	1.3	46	1.3	46
April	2.2	79	6.3	222	6.3	222
May	2.9	104	3.2	112	3.2	112
June	1.2	42	1.4	49	1.4	49
July	0.9	32	0.9	31	0.9	31
August	0.4	13	0.3	10	0.3	10
September	0.2	6	0.2	6	0.2	6
October	0.3	10	0.1	4	0.1	4
November	0.5	18	0.1	2	0.1	2
December	0.4	16	0.03	1	0.03	1

2. Sherwood reach, North Dakota

The reach upstream of Lake Darling Dam, from Sherwood to Mouse River Park in North Dakota, (known as the Sherwood Crossing) is affected by Grant Devine, Rafferty, and Boundary Reservoirs in the baseline simulation. In the pre-Agreement simulation, this reach is affected only by the Boundary Reservoir. Channel capacity for the river from Sherwood to the Upper Souris National Wildlife Refuge is approximately 56.6 m^3/s (2,000 ft^3/s).

Bankfull exceedances over the period by month for the Sherwood reach are shown in Table 13. The data suggest that the baseline simulation provides a significant reduction in bankfull exceedances during the peak flow months of March, April, and May. The additional out of bank flows in August were from 2011 and a product of following drawdown of an extreme flood.

Similarly, the analysis of monthly flows under each simulation computed for the Sherwood reach (Table 14) indicates that the inclusion of Grant Devine and Rafferty Reservoirs in the baseline simulation offers a significant reduction in mean monthly flows in spring and early summer. Flows in the winter months from December through February are significantly greater under the baseline simulation, as reservoir releases are made in most years to create the necessary storage for spring snowmelt runoff.

Table 13 Bankfull exceedances for Sherwood reach, North Dakota, by month, 1930-2017

Sherwood Reach, North Dakota - Bankfull Exceedances			
Month	**Baseline (days)**	**Pre-agreement (days)**	**Unregulated (days)**
January	0	0	0
February	0	0	0
March	9	42	63
April	89	335	349
May	65	196	199
June	30	32	31
July	31	22	22
August	23	0	0
September	0	0	0
October	0	0	0
November	0	0	0
December	0	0	0
Total	**247**	**627**	**664**

Table 14 Mean monthly flow for Sherwood reach, North Dakota, 1930-2017

Sherwood Reach, North Dakota - Mean Monthly Flow						
Month	**Baseline (m^3/s)**	**Baseline (cfs)**	**Pre-agreement (m^3/s)**	**Pre-agreement (cfs)**	**Unregulated (m^3/s)**	**Unregulated (cfs)**
January	1.4	49	0.2	6	0.2	6
February	3.3	116	0.3	10	0.3	11
March	5.0	175	4.9	173	5.6	197
April	9.5	335	24.1	853	25.9	915
May	8.1	287	13.8	486	14.1	497

Sherwood Reach, North Dakota - Mean Monthly Flow						
Month	Baseline (m^3/s)	Baseline (cfs)	Pre-agreement (m^3/s)	Pre-agreement (cfs)	Unregulated (m^3/s)	Unregulated (cfs)
June	6.5	229	7.6	270	8.0	281
July	3.3	115	4.1	146	4.4	157
August	1.4	50	1.1	40	1.3	46
September	0.6	22	0.8	27	0.8	29
October	0.6	22	0.6	22	0.6	23
November	1.5	52	0.5	18	0.5	18
December	1.4	51	0.2	9	0.3	9

Note that a comparison of the pre-Agreement and state-of-nature unregulated flows in Table 13 and Table 14 suggests that the Boundary Reservoir has only minimal impact on providing flood protection.

The baseline simulation – which includes Grant Devine and Rafferty Reservoirs with Boundary and Lake Darling Reservoirs – does provide a significant flood reduction at Sherwood and other locations in bankfull exceedances and mean monthly flow during snowmelt runoff in all flood years. For example:

- in the flood year of 1969, the maximum streamflow in the unregulated simulation was 380.9 m^3/s (13,450 ft^3/s), compared to 240.7 m^3/s (8,500 ft^3/s) in the baseline simulation; and,
- in the flood year of 1976, the maximum streamflow in the unregulated simulation was 383.1 m^3/s (13,530 ft^3/s), compared to 181.5 m^3/s (6,410 ft^3/s) in the baseline simulation.

The 2011 flooding event was too large for the reservoirs to provide much flood reduction with the post-snowmelt rains which occurred basin wide. For example, the 2011 summer peak flow for the Souris River at Sherwood is 739.4 m^3/s (26,110 ft^3/s) in the baseline simulation, compared to 753.2 m^3/s (26,600 ft^3/s) in the unregulated simulation – a difference of only 13.8 m^3/s (490 ft^3/s) (Figure 16).

To determine the maximum flood reduction theoretically possible, a "dry dam" scenario was modeled – that is, assuming the reservoirs upstream of Minot, North Dakota, were empty. The findings indicated that even under such an extreme assumption, a flood of similar magnitude to the 2011 flood could not be mitigated. The spring snowmelt peak was stored, and flood impacts were reduced until runoff from additional rainfall in May and June used all remaining flood control storage.

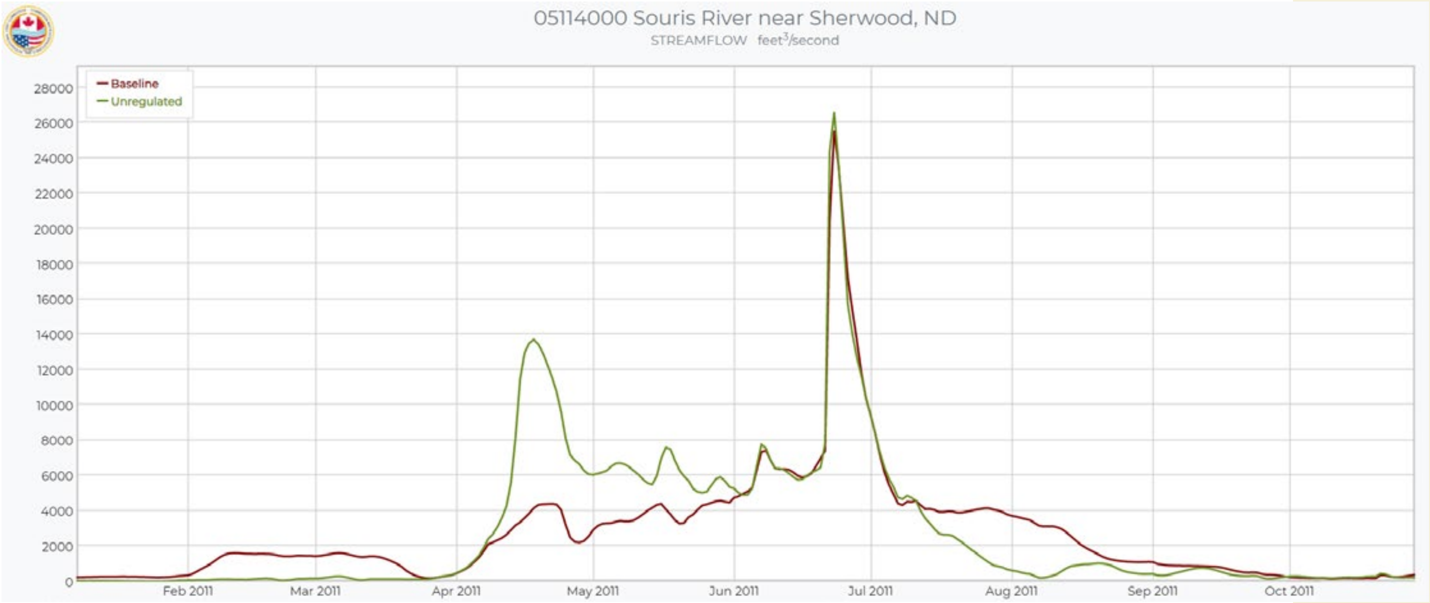

Figure 16 Daily streamflow for the Souris River at Sherwood for baseline and unregulated simulations, 2011

3. Bantry reach, North Dakota

The analysis found that the Bantry reach, North Dakota, was the only reach of the 13 under review in which the baseline simulation had greater bankfull exceedances over the 1930-2017 period than in the pre-Agreement simulation and the unregulated. To investigate this further, the Study team undertook a more detailed review. The bankfull exceedances were broken down into yearly and then monthly occurrences to identify when these larger flows occurred.

Table 15 compares the bankfull exceedances for the three simulations, broken down by month. The findings suggest that while the baseline simulation could result in more bankfull exceedances throughout the year than the pre-Agreement simulation, it would reduce the exceedances in the typical flood months of April, May, June, and July. These months are critical for hay production in this reach. There has been an effort by local interests to have greater flow in the winter months to prevent inundation during the hay production season.

Table 15 Bankfull exceedances for Bantry reach, North Dakota, by month, 1930-2017

Bantry Reach, North Dakota - Bankfull Exceedances			
Month	Baseline (days)	Pre-agreement (days)	Unregulated (days)
January	103	0	0
February	245	21	28
March	633	367	459

Bantry Reach, North Dakota - Bankfull Exceedances			
Month	Baseline (days)	Pre-agreement (days)	Unregulated (days)
April	1,064	1,322	1,637
May	867	1,154	1,390
June	713	827	1,109
July	498	553	774
August	200	162	249
September	65	58	100
October	66	64	137
November	101	36	111
December	150	5	23
Total	**4,705**	**4,569**	**6,017**

4. North Dakota/Manitoba reach[16]

Bankfull exceedances, by month over the period for the Westhope, North Dakota, to Wawanesa, Manitoba reach are shown in Table 16. The data suggest that during April to July, the baseline simulation provides some reductions in bankfull exceedances in the reach compared to the unregulated simulation. Compared to the pre-Agreement simulation, the baseline results in only a slight reduction in exceedances, with the biggest differences occurring in the typical flood months of April and May.

The analysis also found that the baseline simulation provides modest to significant reductions in peak streamflow from Estevan, Saskatchewan, to the Souris River at Westhope, North Dakota, with some reduction in the Manitoba reach. For example, the maximum streamflow at Westhope in 1969 in the unregulated simulation was 307.2 m^3/s (10,850 ft^3/s); the baseline provided a modest reduction with a flow of 271.3 m^3/s (9,580 ft^3/s). In 1976, the maximum streamflow in the unregulated simulation was 438.6 m^3/s (15,490 ft^3/s); the baseline provided a more significant reduction with a flow of 235.6 m^3/s (8,320 ft^3/s). This finding indicates that the baseline simulation reduces peak streamflow, and provides flood protection, for many large flooding events in the period of record.

[16] The North Dakota/Manitoba reach represents the basin from Westhope to Wawanesa (i.e., the reach is located primarily in Manitoba); flows in the reach are compared to simulated flows at Westhope.

Table 16 Bankfull exceedances for North Dakota/Manitoba reach, by month, 1930-2017

Westhope Reach, North Dakota - Bankfull Exceedances			
Month	**Baseline (days)**	**Pre-agreement (days)**	**Unregulated (days)**
January	0	0	0
February	67	0	1
March	391	187	218
April	916	1,051	1,227
May	781	933	1,032
June	707	729	847
July	433	449	540
August	201	189	231
September	58	55	61
October	22	14	18
November	4	4	10
December	0	0	2
Total	**3,580**	**3,611**	**4,187**

4.3.3 WATER SUPPLY – INCLUDING WATER SHARING AND APPORTIONMENT

North Dakota and Manitoba each prescribe to different versions of the prior appropriation doctrine of western water law. Where practiced, prior appropriation doctrine means that these jurisdictions provide initial water users (by date) the greatest legal right to put water to beneficial use; later users have a lesser right to use the resource. Saskatchewan does not follow the prior appropriation doctrine of *"First in time, first in right."* In Saskatchewan, the property in the river/water body and the right to the use of water is vested in the Crown. Those wishing to use water, except for "domestic purposes," must apply for a license from the Crown. The Crown administers allocations and regulates water use and licensing with water apportionment in mind. Saskatchewan no longer maintains a *"First in time, first in right"* doctrine.

Image 27 Moose Mountain Creek, Saskatchewan 2003.

In Saskatchewan, when water availability is limited or scarce, water is allocated to serve the highest priority purposes, ranked by public interest and economic value. Meeting existing basic human needs is an immutable first priority. Once human uses are allocated, water allocations to meet inter-jurisdictional requirements, constitutional commitments, and a desired level of ecosystem health and function are considered. When water is allocated for various purposes during periods of water scarcity or shortages, the licensed water uses would be ranked in priority as follows:

1. Municipal (human needs)
2. Industrial needs
3. Agricultural uses
4. Other purposes

In most cases, water supply on the Souris River between each jurisdiction (Saskatchewan, North Dakota, Manitoba) is based on International Agreements or Interim Measures as established by the Governments of Canada and the United States. Each successive agreement on water use between the governments has been largely due to infrastructure improvements within the system and the growing need to account for water uses between countries.

The first extensive agreement between each jurisdiction on the Souris River system regarding water supply was the 1959 Interim Measures. The 1959 Interim Measures were put in place between the countries following the construction of Boundary Dam in Saskatchewan. The 1959 Interim Measures, which correspond to how the system would have been operated under the pre-Agreement scenario simulations, provided an apportionment agreement between Saskatchewan and North Dakota. The Interim Measures also provided language on providing a minimum flow of 0.566 m^3/s (20 ft^3/s), “except during periods of severe drought,” from North Dakota into Manitoba at Westhope from June 1 through October 31. After the 1959 Interim Measures were adopted, the ISRB defined “severe drought” as “reservoir storage” in Lake Darling Dam and the pools of J. Clark Salyer NWR as being less than 66,610 dam^3 or 54,000 acre-feet (ISRB May 7, 1963).

Image 28 Souris River near Westhope, North Dakota, March 2021

The 1989 Agreement between the Governments of Canada and the United States was reached to develop two new Canadian reservoirs on the system. The baseline simulation included the reservoirs and water supply agreements reached by the 1989 Agreement. It is important to note that slight modifications were made to the 1989 Agreement by the 2000 amendments to Annex A of the 1989 Agreement. This language largely keeps the intent of the 1959 Interim Measures but strengthens some of the language on how apportionment between Saskatchewan and North Dakota should be conducted. It also clarifies language on how the International Souris River Board is involved in the process. (For a more complete understanding of the history and development of the 1989 Agreement, the Annexes, the Interim Measures, and Amendments to the Agreement, see: https://ijc.org/en/srb/who/mandate.

1. Reservoirs in Saskatchewan

The creation of Boundary, Rafferty and Grant Devine Reservoirs has provided secure water supply benefits for Saskatchewan. The reservoirs have allowed Saskatchewan to retain runoff that was produced in the upper portions of the Souris River basin to be put to beneficial uses:

- Boundary Reservoir is used to cool water during power production;
- Rafferty Reservoir is used for municipal water for Estevan, cooling water for power production, irrigation, oil recovery and livestock watering; and,
- Grant Devine Reservoir is used to manage apportionment (shared water flow from Canada into the United States) and supports smaller municipal needs and recreation.

2. Reservoirs in the US

In North Dakota, Lake Darling Reservoir is used for fish and wildlife benefits and flood control. The reservoir is designed to hold a two-year supply of water to safeguard marshes downstream against drought for the purpose of waterfowl production. Operation of Lake Darling Reservoir also provides downstream benefits for flood irrigation and municipal water supply.

3. Sherwood reach, North Dakota

The outputs of the HEC-ResSim model were analyzed for the location upstream of Lake Darling Reservoir at the Sherwood Crossing to evaluate how three modeled scenarios affect water supply. As expected, the model output (Table 14) found that the addition of the Grant Devine and Rafferty Reservoirs in the baseline simulation creates a significant reduction in mean monthly streamflow in March and April and small reductions in streamflow in June and July when compared to the unregulated simulation. In addition, mean monthly streamflow for the baseline simulation compared to the unregulated simulation is significantly larger from November through February, as releases are made from the Grant Devine and Rafferty Reservoirs to create water storage space in the reservoirs for spring snowmelt runoff.

These results demonstrate that the Grant Devine and Rafferty Reservoirs are successful in achieving a significant reduction in mean monthly streamflow in the spring and early summer months and deliver higher streamflows in the winter. Overall, the releases from the reservoirs provide a more uniform distribution of streamflow throughout the year along the reach. The flow in an “average” year for 1987 at Sherwood Crossing is shown in Figure 17.

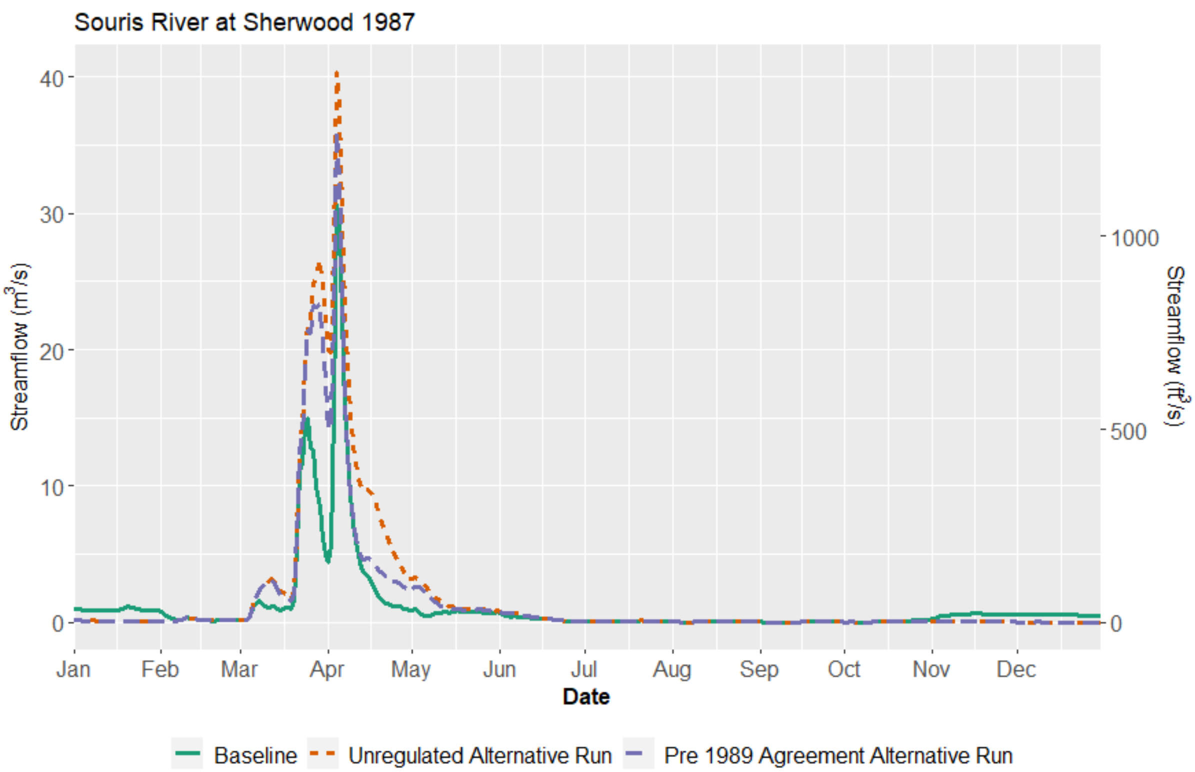

Figure 17 Daily streamflow for the Souris River at Sherwood Crossing comparing the baseline, unregulated, and pre-Agreement alternative simulations for flows in 1987 (an "average" year)

4. North Dakota/Manitoba reach

As noted above, under the 1989 Agreement, North Dakota must provide to Manitoba a regulated flow of not less than 0.566 m^3/s (20 ft^3/s) in the Souris River as measured at Westhope, North Dakota, during the months of June through October to deliver a total volume of not less than 7,486 dam^3 (6,069 acre-feet), "except during periods of severe drought" (1959 Interim Measures; 2000 Amendment to the 1989 Agreement). Under the unregulated (natural state) simulation runs, daily streamflow at the border crossing at Westhope, North Dakota, below this target level occurred on a total of 13 days in three years from 1930 through 2017 (Table 17). By contrast, daily streamflow below this level occurred on a total 119 days in five years under the baseline simulation, and 122 days under the pre-Agreement simulation. Each of these years were drought years; of these 119 days in the baseline simulation, 113 days occurred during four extreme drought years (1930, 1932, 1934, 1935).

When evaluating simulation results at Westhope, North Dakota, it is important to note the role of the J. Clark Salyer National Wildlife Refuge. The Refuge, located between Bantry and Westhope, North Dakota, was established in 1935 and contains five low-head dams that create pools used for enhancing the river ecosystem, and creating habitat for wildlife. In the simulation runs, these pools act as small reservoirs that have limited capacity to store and reduce flows. In the HEC-ResSim model, the pools are operated to reflect how they have been operated historically by the U.S. Fish and Wildlife Service and are used to meet the minimum flow requirement to Manitoba during the months of June through October. Given that water stored in the refuge is used to meet the minimum flow requirement during dry years, the J. Clark Salyer pools can be thought of as small water supply reservoir pools benefiting Manitoba. In the unregulated and pre-Agreement simulations, there are fewer reservoirs in tributaries upstream of J. Clark Salyer. Therefore, more water from these tributaries is delivered to the refuge even in dry years and the number of days that streamflow is less than the 0.566 m^3/s (20 ft^3/s) target at Westhope is less in the unregulated simulation than in the other two simulations.

Table 17 Number of days below streamflow target level for North Dakota/Manitoba reach, selected years

Westhope, North Dakota - Flows less than 20 cfs from June 1st to October 31st			
Year	**Baseline (days)**	**Pre-agreement (days)**	**Unregulated (days)**
1930	33	34	0
1932	4	6	9
1934	73	73	0
1935	3	3	3
1940	0	0	1
2008	6	6	0
Total	**119**	**122**	**13**

Analysis of the recorded streamflow records for the Souris River at Foxholm, North Dakota, (northwest of Minot) and Westhope, North Dakota, (near the Manitoba border) can provide additional insight into the source and delivery of water from the U.S. to Manitoba. An analysis of the stream gauges at Foxholm and Westhope was conducted to determine how often the 7,486 dam^3 (6,069 acre-feet) was available due to the operations of the 1989 Agreement and how often the volume was not delivered to Manitoba from the period of 1959 to 2020. Table 18 provides the annual June through October volumes at Foxholm and Westhope from 1959 to 2020. Flow at Foxholm (downstream of Lake Darling) represents flow available from upstream reservoirs and shows years that these reservoirs did not have 7,486 dam^3 (6,069 acre-feet) passing the gauge during 1959 – 2000 (highlighted in red). By comparing the Foxholm gauge with the Westhope gauge, it is evident that the minimum flow volume was not delivered during years of severe drought, meaning low flow existed throughout the river system. In 1959 and 1961 when the Interim Measures were not met, flow at Foxholm exceeded the minimum flow volume.

For the Foxholm gauge, June through October flow was less than 7,486 dam^3 (6,069 acre-feet) in 22 years of the 62-year period of record. However, June through October flow at Westhope was less than 7,486 dam^3 (6,069 acre-feet) in only four years out of the 62-year period (i.e., minimum flows at Westhope were not delivered in 1959, 1961, 1962, 1977). That is, in many years, flows controlled by the 1989 Agreement (governing the operation of the reservoirs) were insufficient to supply the minimum flow volume due to low runoff and drought conditions in the upstream reaches (i.e., the recorded low flows at the outlet of Lake Darling Reservoir demonstrate that the upstream reservoirs did not have sufficient water to supply the minimum flow requirements at Westhope). However, downstream of Lake Darling (in 20 of 62 years when upstream flows were insufficient to supply minimum flows), the inflows within the lower reaches of the North Dakota portion of the Souris River basin, combined with the storage from the J. Clark Salyer National Wildlife Reserve (NWR), augmented river flow and contributed to providing the specified minimum flow volume at Westhope to meet the 1959 Interim Measures. In summary, the North Dakota watershed contributions, the drainage area feeding from tributaries into J. Clark Salyer, and the J. Clark Salyer NWR reservoir pools were instrumental to ensure delivery of the minimum flow requirement from North Dakota to Manitoba.

Table 18 Annual June through October streamflow volume for Souris River at Foxholm and the Souris River, near Westhope, North Dakota, 1959-2020 (Foxholm is downstream of Lake Darling Reservoir and represents flow available from operating the upstream reservoirs)

Year	Foxholm Volume (dam3)	Foxholm Volume (ac-ft)	Westhope Volume (dam3)	Westhope Volume (ac-ft)
1959	11,164	9,055	7,092	5,752
1960	26,673	21,632	36,344	29,476
1961	9,603	7,789	4,853	3,936
1962	1,900	1,541	3,326	2,697
1963	1,968	1,596	18,087	14,669
1964	4,004	3,248	23,652	19,183
1965	28,166	22,843	100,650	81,630
1966	30,066	24,384	22,227	18,027
1967	16,153	13,100	12,284	9,963
1968	6,583	5,339	25,926	21,027
1969	153,181	124,234	184,401	149,555
1970	114,631	92,969	287,800	233,414
1971	57,010	46,237	75,776	61,457

Year	Foxholm Volume (dam3)	Foxholm Volume (ac-ft)	Westhope Volume (dam3)	Westhope Volume (ac-ft)
1972	95,899	77,777	113,952	92,419
1973	6,244	5,064	27,419	22,238
1974	188,134	152,582	284,508	230,744
1975	231,095	187,425	450,889	365,685
1976	376,539	305,384	255,596	207,296
1977	6,957	5,642	7,126	5,780
1978	28,030	22,733	44,454	36,054
1979	229,670	186,269	281,013	227,910
1980	5,396	4,376	16,289	13,211
1981	3,020	2,449	21,277	17,256
1982	80,018	64,897	85,821	69,603
1983	78,762	63,879	80,730	65,475
1984	7,160	5,807	60,234	48,852
1985	10,486	8,504	32,543	26,394
1986	11,945	9,688	34,410	27,907
1987	15,746	12,770	43,233	35,063
1988	2,986	2,422	7,975	6,468
1989	475	385	9,061	7,348
1990	8,755	7,101	8,314	6,743
1991	3,563	2,890	8,043	6,523
1992	6,753	5,477	8,348	6,770
1993	3,495	2,835	15,203	12,330
1994	1,663	1,349	47,237	38,311
1995	45,201	36,659	95,119	77,144
1996	76,557	62,090	82,529	66,934

Year	Foxholm Volume (dam3)	Foxholm Volume (ac-ft)	Westhope Volume (dam3)	Westhope Volume (ac-ft)
1997	102,143	82,841	90,164	73,126
1998	1,493	1,211	54,228	43,980
1999	179,854	145,867	572,002	463,911
2000	1,527	1,238	108,218	87,768
2001	138,657	112,455	152,197	123,436
2002	2,341	1,899	28,844	23,394
2003	9,671	7,844	24,399	19,788
2004	15,915	12,908	135,297	109,730
2005	43,402	35,201	438,537	355,667
2006	4,513	3,660	13,099	10,623
2007	16,323	13,238	42,859	34,760
2008	8,653	7,018	9,977	8,091
2009	12,929	10,486	96,476	78,245
2010	36,615	29,696	266,590	216,213
2011	966,730	784,047	2,502,848	2,029,885
2012	17,205	13,954	44,013	35,696
2013	156,744	127,124	611,163	495,671
2014	133,363	108,161	546,483	443,214
2015	95,696	77,612	112,629	91,346
2016	6,549	5,312	42,758	34,678
2017	63,729	51,686	19,987	16,210
2018	5,735	4,651	34,070	27,632
2019	12,725	10,321	82,699	67,071
2020	3,088	2,505	72,383	58,704

4.3.4 FLOOD CONTROL AND WATER SUPPLY BENEFITS

The previous sections discussed how simulations demonstrate the results of operations of the 1989 Agreement. The water infrastructure and the Agreement was designed to achieve flood control and water supply management benefits for Canada and the United States. The Study evaluated the direct and secondary benefits of operating for flood control and water supply benefits of the Souris River Project. Direct benefits included the effects of reduced flood risks to property, agriculture, industry, and transportation systems (roads, rail). Secondary benefits included positive effects on environmental resources, other socio-economic benefits, cultural sites, and water quality. Many of these effects were identified as areas of concern by the Study's Public Advisory Group, the Resource Agency Advisory Group, and by Indigenous Nations.

Study approach

The analysis of flood control and water supply benefits focused on comparisons of the unregulated and baseline simulations. The large degree of climate and hydrologic variability of the Souris River system means that any secondary effects tend to arise only under high to extreme flood conditions, or under severe water scarcity to extreme drought conditions. The presence of the reservoirs provides a larger contrast of secondary effects between unregulated (reservoirs not present) compared to baseline (reservoirs present); however, part of the focus of the Study's assessment is how differences of flows affect secondary conditions assuming the dams are present since this water infrastructure is expected to continue well into the future.

The effects were evaluated using performance indicators (PIs) and evaluation of flow/stage hydrographs. As discussed further in section 5.2.3, PIs were used in the Study to help evaluate and compare the effect of alternative operating measures on various socio-economic, environmental, and cultural components in the Study area.

Figure 18 provides a PI plot comparing the baseline and unregulated simulations for the Westhope, North Dakota, to Wawanesa, Manitoba reach for the full period simulated. Benefits to numerous factors occur for the 1989 Agreement operations (crown land preservation, historic site preservation, bird nesting habitat, less bankfull flooding exceedances, less agricultural damages, and less bridge inundation, while the unregulated scenario shows lesser benefits (water quality, boating), and some PIs show similar effects.

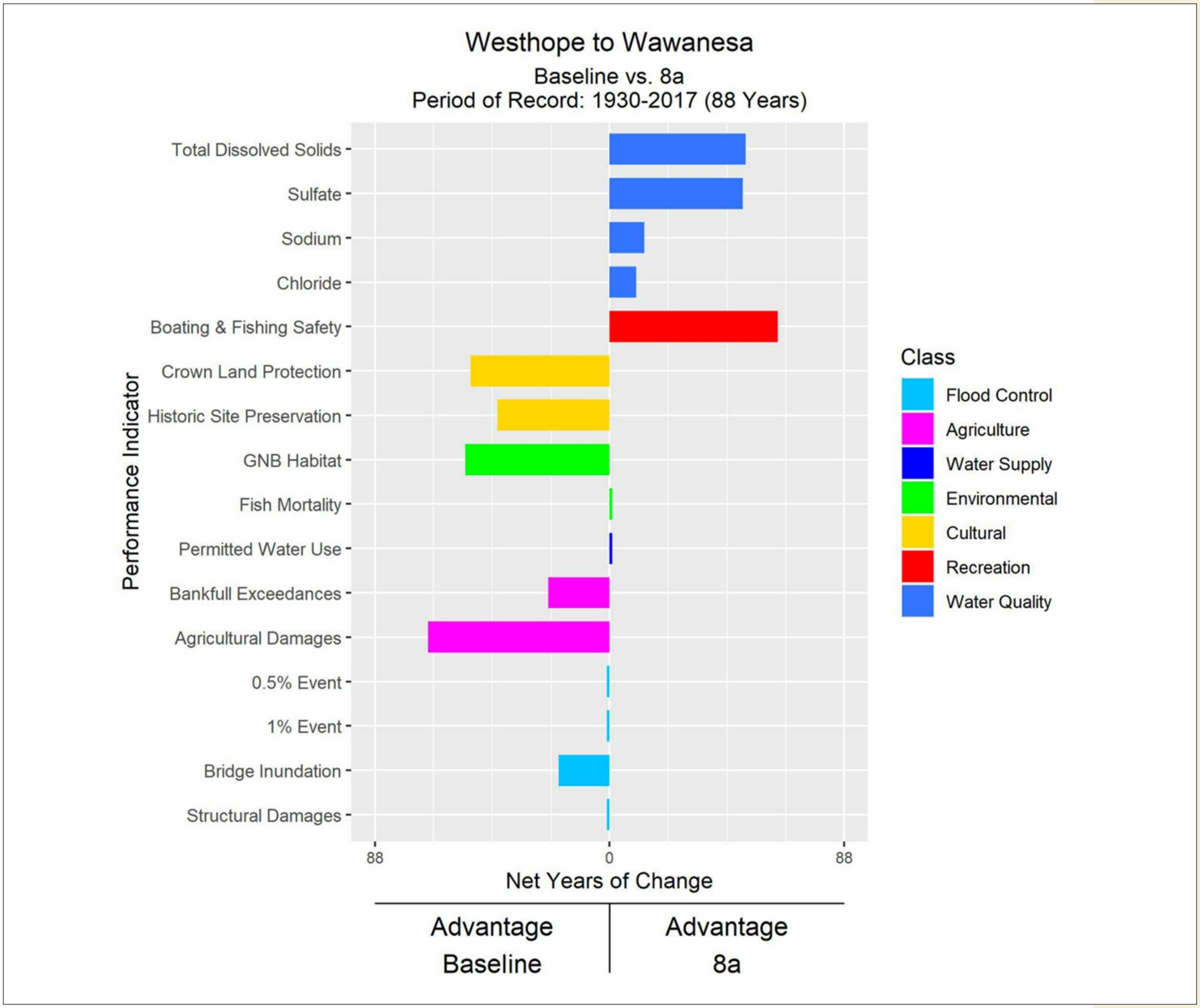

Figure 18 Performance indicator comparing baseline to unregulated simulations for the North Dakota/Manitoba reach (based on flows at Westhope; Scenario 8a depicts the Unregulated simulation (reservoirs not present)

Flood protection benefits

Improved flood protection provided by the dams resulted in reduced damages to rural and urban property at specific reaches throughout the Souris River system. For example, the analysis summarized in Figure 18 indicated that:

- Many reaches throughout the Souris River system experienced decreased bankfull exceedances in the baseline simulation which indicates reduced flooding. Figure 18 illustrates the advantages that the baseline simulation provides for bridge inundation.
- There are significant reductions in agricultural damages from flooding in the reaches at Estevan in Saskatchewan, and in North Dakota at Minot, downstream of Towner and downstream of Westhope.

- The reach around Estevan, Saskatchewan, had improvements (fewer flooding impacts) for the coal crossing roads to the power plant, general bridge inundation, and structural damages.
- Bridges throughout the system were provided considerable reduced flood impacts in the baseline simulation.

Environmental effects

Image 29 Largemouth Bass

New fish habitat in reservoirs

The constructed dams on the Souris River and its tributaries created reservoirs and new fish habitat. Today, these reservoirs have self-sustaining fish populations, and reports of winter fish kills occur very rarely relative to some other reservoirs; this indicates that reservoir management on the Souris River has resulted in creating valuable habitat for fish. Any proposed changes to the management regime should be assessed for potentially negative impacts to reservoirs' fish populations and fish habitat.

The city of Estevan, Saskatchewan, reports that the Boundary Reservoir also creates unique fisheries habitat, as the reservoir has slightly warmer water and is the only place in Saskatchewan that has a self-supporting largemouth bass population.

Fisheries in reaches

In the absence of the reservoirs, the natural variability of the Souris River system would have resulted in very low to no flow in the fall and winter in many years downstream of each reservoir. Instead, the storage provided by the reservoirs allows water to be released to reduce the period the river has little to no flow in the winter. For example, the unregulated average flow at the Sherwood Crossing is 0.25 m^3/s (9 ft^3/s) for December, but with the dams in place, it is 1.44 m^3/s (51 ft^3/s). As noted in the above discussion of flood control at various locations, the reservoirs generally lower the average flows in spring and increase the average flows in the fall and winter.

The reservoirs can also cause lower flows in some circumstances. When there is drought in the entire basin and the reservoirs are holding water, then the modeling shows the presence of reservoirs results in less flow in the river.

Reductions in the magnitude of spring flows, if sufficiently large, can reduce the frequency, extent, and duration of out-of-bank flooding, deepen the channel, and negatively impact riparian habitat and riparian-reliant components of the aquatic community. Fish species reliant on flooded riparian habitat for spawning could be impacted. The baseline operation scenario (Figure 18 above) suggests that some reaches may be negatively impacted by reservoir operations described in the baseline, while some may not.

Reservoir management to maintain low flows throughout the winter benefits the health of the riverine aquatic ecosystems. In Saskatchewan flows in the river are sometimes augmented by winter releases. This change is more dramatic in some reaches than others (Table 12 and Table 14). The increased winter flow may benefit the ecosystem because higher winter flows allow fish to seek refuge in deeper water over the winter and return to an enhanced ecosystem in the spring.

Change from natural system

It should be noted that while the construction of the dams caused an increase in still water ecosystems, it did come at the cost of some riverine (flowing water) ecosystems as dams act as barriers for movement of aquatic organisms.

In addition to the upstream still water ecosystems created by Rafferty, Grant Devine, and Lake Darling Reservoirs, the J. Clark Salyer National Wildlife Refuge in North Dakota uses a series of small dams to create and enhance unique riparian and aquatic ecosystem habitat. This habitat is used by many species of migratory birds, along with other wildlife.

Channel erosion

The city of Minot reported a decrease in channel erosion after the dams were constructed. Downstream of Bantry, North Dakota, there was a significant improvement with reduced erosion after the dams were in place.

There were no data available to determine the possible effects on erosion for the reach through the city of Estevan, Saskatchewan, or for the reach from Westhope, North Dakota, to Wawanesa, Manitoba.

Effects on protected historic and cultural sites

The analysis indicated that the baseline simulations showed significant improvements in flood protection of historic sites at the city of Minot, and the reach downstream of Westhope, North Dakota. The reaches at Estevan, Saskatchewan, and downstream of Towner around Bantry, North Dakota, also showed improvement, though not as significant as the other reaches. The reach from Westhope, North Dakota, to Wawanesa, Manitoba, also experienced improved protection for Crown Lands illustrated in Figure 18. Historic sites were also inundated less in the baseline simulation for the Manitoba reach as illustrated in Figure 18.

Water quality

Assessment of water quality can consider many different components. Water quality constituents that the ISRB have highlighted over the years as being important include salinity (measured as total dissolved solids, or TDS), the nutrient phosphorus, and dissolved oxygen. Comparison of data upstream and within the reservoirs provides an ability to assess the effect of water quality under the modeled scenarios.

As summarized in Figure 18, the analysis suggested that the baseline simulation results in a decrease in water quality under certain conditions compared to the unregulated simulation. This finding was expected, given that water quality is typically poor to begin with in shallow prairie streams due to the high variability of flows and high frequency of low flow to stagnant water or no flow. In addition, storage of water in the reservoirs can cause the water level in the river to drop during severe droughts, leading to a decline in water quality during certain periods.

Water quality upstream of the Saskatchewan reservoirs varies with flows. Salinity is on average higher in years with lower flows and tends to be lower during the early spring freshet and increases as flows decrease. Nutrient phosphorous concentrations upstream of the reservoir also vary with season and flow. Phosphorus upstream of the reservoirs can be high during the beginning of the spring freshet before decreasing in April and May and then increasing later in the summer when flows are typically very low. Water quality above the reservoirs is important as it affects the quality in both the reservoirs and the river. The reservoirs slow down water movement and store water and water quality will be affected by the mix of the inflowing river water quality. The water quality of reservoir outflow changes depending on this mixture and other processes that occur in the reservoir. Outflow from prairie reservoirs tend to have lower nutrient levels than the inflows. When outflows occur from the reservoirs during drought conditions, the water released will generally have lower average salinity and nutrient levels than would have otherwise occurred.

Dissolved oxygen is a critical water quality component because of its importance to aquatic life. Winter is of particular concern for oxygen levels because ice cover prevents or greatly reduces the potential for water to receive oxygen from the atmosphere. During winter, the volume of liquid water in the Souris River under ice is small, and the natural decomposition of organisms in the river creates a high oxygen demand. This consumption of oxygen can result in low oxygen levels that cannot sustain different species of aquatic life. Winter flow from sources with higher initial oxygen can serve to add oxygen and maintain oxygen levels downstream. While dissolved oxygen levels are highly variable and not only dependent on flow, the data also suggests the dissolved oxygen levels are improved in the baseline condition compared to the unregulated condition.

As illustrated in Figure 18, water quality appears to be better in the unregulated simulation in Manitoba. The PI thresholds appear to be met more often due to no storage occurring in the upper portion of the system. However, this result may be misleading. The J. Clark Salyer refuge remains in the unregulated model, which essentially provides Manitoba with a water supply reservoir during drought conditions when no other water use is occurring in the basin. This, in turn, makes the water quality PIs appear to be advantageous in the unregulated simulation. However, this would unlikely be the case in a truly unregulated environment (i.e., a true “state-of-nature”); without J Clark Salyer reservoir pools, there would likely be many more very low or zero-flow days occurring in the unregulated record than the baseline (as described in Section 4.3.3 Item 4 North Dakota/Manitoba reach).

Recreation

The dams have created more recreation opportunities by creating reservoirs for boating and fishing activities, as well as parks and campsites adjacent to the reservoirs. For example, Estevan has improved accessibility to local campgrounds, compared to the unregulated simulation, while Minot experienced an increase in boating and fishing access with creation of Lake Darling Reservoir. As noted in previous sections, the reservoirs have provided a substantial increase in sport fishing opportunities.

However, the reservoirs can also cause lower flows in the river under some circumstances. For example, if there is drought in the entire basin and the reservoirs are holding water for other uses, there can be less water in the river, leading to an increase in boating hazards in the river. In Saskatchewan, it should be noted the change in recreational boating in the river is likely unaffected by the presence of the reservoirs. It should be noted, however, that the Souris River is typically not conducive to motor boating due to its low flows and shallow water depths in all regions, perhaps except during runoff. Most boating activities in the Souris River would be occasional canoeing and only likely in selected reaches and times, with suitable water flow and depth.

4.3.5 PERFORMANCE OF THE 1989 OPERATING PLAN DURING THE 2011 FLOOD

The 2011 flood was the most significant flood in the last 100 years on the Souris River. Following the 2011 flood, the need to review the 1989 Operating Agreement was highlighted. As part of evaluating the 1989 Operating Plan, the Study team analyzed the performance of the 1989 Operating Plan. One objective of Annex A of the 1989 Operating Plan was to mitigate the 1:100-year event, as developed in 1989. The 1:100-year flood identified in the agreement is 141.6 m^3/s (5,000 ft^3/s) at Minot. For context, the 2011 flood is substantially larger at about 775.9 m^3/s (27,400 ft^3/s), over five times greater than the 1:100-year event based on the 1989 Operating Agreement data.

During the 2011 flood season, reservoir operators followed the operating rules specified in the 1989 Agreement. Each reservoir was drawn down prior to the onset of runoff to the level required by the spring forecast. The snowmelt-driven flood event was then fully captured by the reservoirs, reducing flood damages during the month of April. As rains continued in May, the reservoir system further reduced flood damages in Minot by keeping flow within the levee system. This allowed emergency personnel to build temporary levees and evacuate residents in the floodplain. While attempts were made to release water from the reservoirs and create additional storage, numerous and persistent basin-wide rain events did not allow the reservoirs to be lowered significantly without overtopping the levees in Minot.

If reservoir operators in Canada or the United States had increased flows at Sherwood or Minot beyond the maximum limits specified in the 1989 Agreement in April or May, the levee system in Minot would likely have breached sooner, resulting in greater damages and increase risks to loss of life. If operators would have stored more water in the reservoirs during the flood event, exceeding the maximum allowable flood level, a dam breach may have occurred, leading to even greater human, social, environmental and economic impacts than those witnessed in 2011. Since following the existing operating rules resulted in sufficient storage of the spring, snowmelt-driven flood event and maximized the available storage in the reservoir system to reduce major flood damages in Minot as long as possible, the 1989 Operating Plan is considered to have performed well during the 2011 flood. While major flooding still occurred, there is no operational scenario in which major flooding could have been prevented - the amount of 2011 precipitation that occurred as snow and rain across the basin, the resulting annual runoff volumes, and the extensive duration of time for such high runoff to dissipate from a water-logged and saturated basin, completely overwhelmed the basin's landscape and its existing water resources infrastructure.

4.3.6 LIMITATIONS OF INFRASTRUCTURE

While the infrastructure of the Souris River Project was put in place to benefit water supply and flood control, it should be noted that there are limits to what this water infrastructure can do. The reservoirs have a finite and defined capacity for flood control and water supply. There are limitations to how much the reservoirs can assist in conditions of extreme floods (with excessive water amounts) or droughts (with excessive water scarcity).

For example, when the reservoirs were modeled as if they had been in place for the period of severe drought from 1930 to 1942, the analysis found that the reservoir levels steadily declined because inflow volumes were insufficient to replace water lost from evaporation, outflows, and other uses. If this period of drought had continued for longer, then the reservoirs could have dropped below their lowest outlets and could have been structurally unable to release any water downstream.

For the 2011 flood of record, the analysis showed that, even with the dry dam scenario where the reservoirs were assumed to be completely empty, flooding still occurred throughout the system. The flooding in Minot, North Dakota, would have been reduced, compared to the baseline simulation, but the 2011 flood would still have been one of the most significant floods in the period of record.

4.4 Summary of key findings

Review of the language of the 1989 Operating Plan

With regard to its review of the language of the existing Operating Plan governing management of the Souris River basin waters, as set out in Annex A of the 1989 Agreement, the Study Board identified two sets of issues:

- specific proposed changes in language and data in the 1989 Agreement will help improve the clarity and ongoing relevance of the Operating Plan and ensure consistency in its implementation; and,
- a set of six outstanding issues for which no consensus was reached among the operating agencies; resolution of these issues may be straight forward for some, but others will involve policy considerations and require the attention of the IJC and the Governments of Canada and United States.

Review of the performance of the 1989 Operating Plan

With regard to its evaluation of the performance of the 1989 Operating Plan, the Study Board finds that, overall, the 1989 Operating Plan has performed well in providing flood control and water supply benefits. In particular, the analysis showed:

- The baseline simulation reduces the number of bankfull exceedances compared to the pre-Agreement and unregulated (natural state) simulations at all locations downstream of the Rafferty and Grant Devine Reservoirs, with the one exception at Bantry, North Dakota.
- The pre-Agreement simulation also reduced the number of bankfull exceedances when compared to the unregulated simulation, although to a lesser extent than under the baseline simulation. However, the pre-Agreement simulation did not reduce bankfull exceedances in the reach directly downstream of Rafferty and Grant Devine Reservoirs because no storage existed in either simulation.
- The addition of Grant Devine, Rafferty and Boundary Reservoirs and Lake Darling to the Souris River system provided protection for the spring snowmelt in 2011; however, when high rainfall events occurred throughout the basin in May and June, nearly all flood storage was used, and basin-wide flooding occurred. Analysis showed that even if the reservoirs were "dry," a flood of similar magnitude to the 2011 extreme summer flood could not be mitigated. The reservoirs do provide modest to significant flood protection from the Estevan, Saskatchewan reach to as far downstream as Westhope, North Dakota, and into Manitoba for floods similar in magnitude to the major floods experienced in1969 and 1976.
- Mean monthly streamflows in the baseline simulation generally were less during the spring and summer than in the pre-Agreement and unregulated simulations as a result of water being stored in each of the four reservoirs. Mean monthly streamflows in winter generally were greater in the winter in the baseline simulation as the result of water being released from storage and resulted in a more uniform distribution of streamflow throughout the year.
- Evaluation of the performance of the 1989 Operating Plan showed direct benefits for improved flood control and water supply management (i.e., the basis for the 1989 Agreement). In addition, the evaluation showed that the presence of the Souris River Project reservoirs, as modeled under the baseline simulations, also demonstrated benefits and impacts for indirect or secondary effects including environmental resources, socio-economic components, cultural sites, and water quality.

5 Formulation of Alternative Operating Plan Measures

Section 5 describes the approach used by the Study to formulate alternative Operating Plan measures that have the potential for improving flood control and water supply benefits in the Souris River basin. These alternatives include both amendments to the existing *1989 International Agreement between the Government of Canada and the Government of the United States of America for Water Supply and Flood Control in the Souris River Basin* (the 1989 Agreement), as well as measures that go beyond the provisions of the 1989 Agreement.

The activities described in this section directly address the Governments' Reference Items 1 through 4.

5.1 Overview of Study approach

In undertaking the Study, the Study Board established 19 technical task teams. The teams worked together on four core activities (see Section 2.4, Table 2). The reports of the technical teams are available through the Study's website: www.ijc.org/en/srsb.

- "PF2: HEC-ResSim Alternatives Assessment": https://ijc.org/en/srsb/hec-res-sim-run-and-evaluate-alternatives

Figure 19 illustrates how the work of the various task teams of the Study was coordinated to support development of the Study's findings and recommendations.

Over the course of the Study, *alternatives* were defined as a change or series of changes to how the basin's reservoir system is operated – that is, the levels of reservoirs and the timing of releases affecting flows, or a physical change to one or more of the reservoirs. By varying water levels and flow rates, reservoir operators can affect flood storage, outflow releases, water supply conditions, and river and riparian conditions.

As noted in **Section 2**, the Study addressed the need to develop a range of alternative Operating Plan measures through the integration of several key areas of work by the technical teams: data collection and management; development of runoff sequences; the application of performance indicators (PIs) (see 5.2.3, below); and iterative rounds of modeling and evaluation. The formulation and evaluation of alternatives included engagement activities to obtain the input of the public, Indigenous Nations, government water and resource management agencies, and industry.

Through successive rounds of modeling and evaluation of more than 60 scenarios, Study teams developed a large number of alternative measures and assessed their benefits and impacts at each reservoir and along each reach of the Souris River. The result of this work was a short list of five candidate alternative Operating Plan measures. **Section 6** presents the findings of the detailed evaluations of this final set of alternatives.

The section is presented in two parts:

- Section 5.2 outlines the methodological tools or building blocks of the Study – the data, modeling and evaluation tools developed and used by Study teams.
- Section 5.3 provides an overview of the iterative process of how these methodological tools were applied to formulate the final set of alternative Operating Plan measures.

Brief summaries of the context of the reports of the technical task teams are presented in Appendix 4. The reports are available on the Study's website: www.ijc.org/en/srsb. (For a listing of the Study's main work themes, please see Section 2.4 Table 6 – Study core activities and technical task teams)

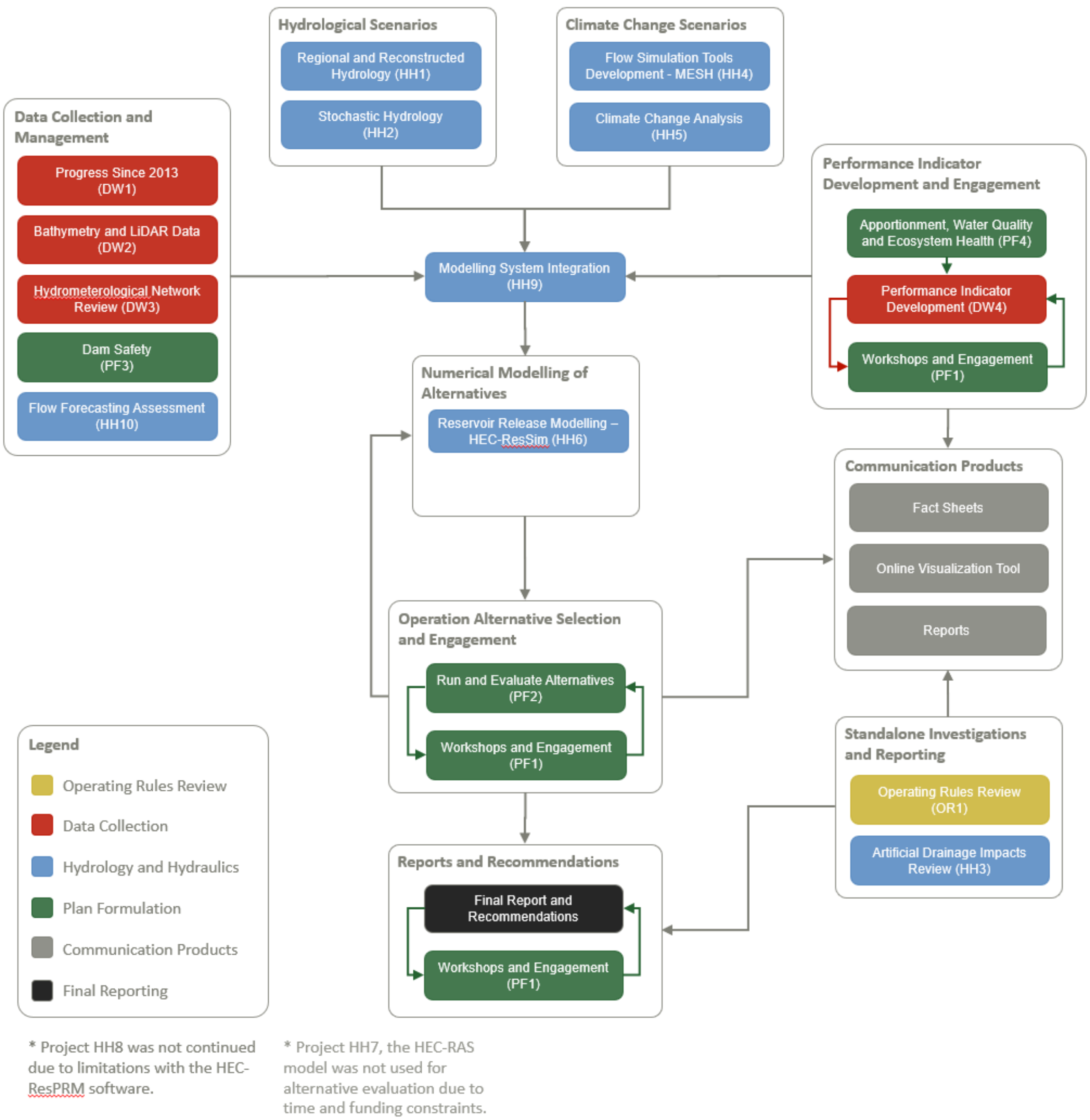

Figure 19 Overview of Study methodology

5.2 Methodological tools

5.2.1 DATA COLLECTION AND ANALYSIS

This section is based on the following reports of Study technical task teams, available on the Study's website: www.ijc.org/en/srsb

- "DW2 Collation and Collection of Bathymetry and LiDAR data for Rafferty Reservoir and Grant Devine Lake Report" https://ijc.org/en/srsb/collation-and-collection-bathymetry-and-lidar-data-rafferty-reservoir-and-grant-devine-lake
- "DW3 Review and Update of the 2013 Hydrometeorological Data Network Improvement Report" https://ijc.org/en/srsb/review-and-update-2013-hydrometeorological-data-network-improvement-report
- "DW4 Data Collection for Performance Indicators Souris River Plan of Study" https://ijc.org/en/srsb/data-collection-performance-indicators-report-and-appendices

One group of Study technical teams reviewed previous hydrologic and meteorological studies and collected, updated, and analyzed key data on the basin's hydrology and meteorology. This included physical data on the Souris River basin, data on each reservoir's elevation, storage, volume and outflow, river flow data, and climate and bathymetric information.

1. Hydrological network review

Image 30 Grant Devine Dam and Reservoir, aerial view

Following the 2011 flood, a group of federal, provincial, and state agencies assessed the existing hydrometeorological data collection and dissemination networks in the Souris River basin to better support current and anticipated needs with respect to emergency preparedness, river flow forecasting and reservoir management for flood risk reduction. In 2013, that group released a report identifying priorities and recommending improvements to the network of precipitation and streamflow gauges within the basin.

The Study reviewed the 2013 report to determine which of those identified priorities and proposed recommendations have been implemented. The objective was to identify any remaining gaps in the networks and to make recommendations for improvements that will support improved water resource management decision making within the basin. The Study's review found that these improvements could include, for example, the addition of precipitation stations and real-time stream gauges in critical areas to provide more consistent year-round data and to increase confidence in forecasts for regulators of the reservoirs.

2. Bathymetric data

The Study's development and testing of alternate Operating Plans required reliable data on the bathymetry of the Rafferty and Grant Devine Reservoirs. Bathymetric data involves the measurement and charting of water depths, channel configurations and cross-sections to describe the width, depth, geometry and alignment of a channel, lake, or reservoir. These data are used to produce capacity curves for the reservoirs, a tool for determining the storage capacity given the water level of the reservoir.

The Grant Devine and Rafferty Reservoirs have been in operation for nearly 30 years. Hydrological conditions in the basin during this period of time have been highly variable and it is possible that bank erosion and sedimentation have affected the capacity of the reservoirs. To assess the impact of erosion and sedimentation on the capacity of the reservoirs, bathymetric and Light Detection and Ranging (LiDAR) data were collected for the development of new area capacity curves for the two reservoirs. (LiDAR is a method for collecting data through the use of laser beams, similar to sonar or radar.) The bathymetry data were collected by the Saskatchewan Water Security Agency (WSA) in 2012, prior to the study, and the LiDAR data were collected as part of the Study.

The new curves developed on the basis of these new data were then compared to the original area capacity curves provided in Annex A of the 1989 Agreement. For the Grant Devine Reservoir, the comparison identified only small differences between the new curve and the one in Annex A.

However, more significant differences were observed between the curves for the Rafferty Reservoir. The discrepancies for the Rafferty Reservoir are likely due to the inability to properly survey the upper parts of the reservoir because of shallow depths and dense weed growth. Therefore, the volume of these areas was not included in the development of the new curves.

As a result, the Study was unable to produce new capacity curves to evaluate possible alternative Operating Plans, though the new data did validate the existing curves provided in Annex A. Therefore, the Study continued to use the existing Annex A capacity curves in the evaluation of alternatives.

3. Flow forecasting assessment

Image 31 Souris River south of Minot, North Dakota, aerial view

Sources of uncertainty

Flood forecasting is a key part of the current Operating Plan for managing flows in the Souris River basin, contained in Annex A of the 1989 Agreement. However, every forecast has some level of uncertainty associated with it, and typically there is a difference between the forecasted value and the observed value. In addition, the need for forecasts in the Souris River basin to be issued months in advance can result in an even greater level of uncertainty, given that key factors, such as the rate of snowpack accumulation, the timing of the spring melt and the melt rate, are all highly variable and unknown at the time the forecasts are developed. Finally, the complex prairie pothole hydrology of the basin adds an additional layer of uncertainty to any forecasting in this region.

The Study technical team investigated these challenges to forecasting, focusing on the period 2009-2016, a timeframe covering the start of formal coordination of forecasts between the Water Security Agency (WSA) in Saskatchewan and the United States National Weather Service (USNWS) in North Dakota. The period also included both high and low runoff events.

Addressing forecasting error

A team undertook a statistical analysis of forecasts compared to observed runoff volumes to examine forecasting accuracy at each location over time. This work lays the foundation for forecasting error to be incorporated into the evaluation of possible alternative Operating Plans; forecasting error was not incorporated as part of this study but could be considered in future adaptive management work.

Understanding antecedent moisture[17]

A related task addressed improving the understanding of antecedent (or prevailing) moisture conditions in the basin. Antecedent conditions before freeze-up, particularly the storage available in wetlands and soil moisture condition, and winter precipitation are among the key contributing factors that determine the severity of floods on the Prairies. The objective was to assess various basin moisture indices that could be used in operational decision making for spring runoff forecasts and reservoir drawdown decisions.

After careful review of various basin moisture indices, the Standardized Precipitation and Evapotranspiration Index (SPEI) was considered the most feasible index for assessing basin moisture conditions. Among other factors, the SPEI approximates the climate water balance *(precipitation – evapotranspiration)*, operates at flexible timescales (thus allowing monitoring of short-term soil moisture conditions), and uses readily available precipitation and temperature data.

Two scenarios, one at the level of the entire Souris River basin and another at the subbasin level, were constructed to assess basin moisture conditions at various scales. Results of the analysis suggested that the SPEI can be a useful tool for water resources planning and management within the basin, though further testing is needed. For example, the analysis found that the SPEI correctly replicated all the historical extreme drought and flood events with SPEI at nine-months timescale having relatively strong correlation with spring runoff. The SPEI index was also able to assist in quantifying the risk of above- and below-normal runoff for the spring period.

5.2.2 HYDROLOGICAL ASSESSMENT

This section is based on the following reports of Study technical task teams, available on the Study's website: www.ijc.org/en/srsb

- "DW3 Review and Update of the 2013 Hydrometeorological Data Network Improvement Report" https://ijc.org/en/srsb/review-and-update-2013-hydrometeorological-data-network-improvement-report
- "HH1 2019 Regional & Reconstructed Hydrology" https://ijc.org/en/srsb/2019-regional-and-reconstructed-hydrology
- "HH2 Stochastic Hydrology Report: Characterization of Historical and Stochastically Generated Climate and Streamflow Conditions in the Souris River Basin, United States and Canada" (available at: https://pubs.er.usgs.gov/publication/sir20215044)
- "HH4, HH5 and HH9 combined report: Climate Change Simulation Tools and Analysis" - Pending report technical review and ISRSB approval.

For the purposes of this study, a runoff sequence is the quantification of the amount of water that enters the Souris River and its reservoirs over a period of time from precipitation, snowmelt and the associated runoff.

The Study needed to evaluate the 1989 Operating Plan (Annex A of the 1989 Agreement) and potential alternative operating measures against a range of runoff sequences.

[17] Antecedent moisture conditions refer to the relative degree of wet or dry basin conditions, which may impact the basin runoff. Wet antecedent conditions lead to an increased percentage of precipitation runoff and dry antecedent conditions lead to a smaller percentage of runoff.

Three types of water supply sequences were originally going to be developed to support the identification and analysis of alternatives: historical sequences; stochastic sequences; and sequences representing climate-changed hydrology. However, due to Study resource constraints and the discovery that there exist few off-the-shelf data products that provide coverage of transboundary watersheds, developing climate-changed hydrology specific to the study area was not feasible.

1. Historical runoff sequences

Historical runoff sequences are the actual inflows recorded in the basin. The objective of this part of the analysis was to have the best practical understanding of this historical record and the basin's responses to hydrological conditions at locations critical to the operation of the Souris River reservoir system. In this way, the Study would have a clear understanding of baseline conditions to help evaluate and compare proposed changes to the 1989 Operating Plan.

The Study's period of record of historical analysis was from 1930 through 2017, an 88-year period. In 2013, the USACE conducted a study to generate historical runoff sequences for the period 1946 to 2012. The Study then used an analysis of the tributary and local flow time series in this existing data and augmented the data by extending it through the full period from 1930-2017. The Study then generated new inflow time series for Rafferty, Boundary, and Grant Devine Reservoirs for the entire 1930-2017 period. These new reservoir inflow time series more explicitly accounted for evaporation and seepage losses from the reservoirs than the original 2013 analysis.

The final datasets represent inflows to, and loss from, the reservoirs, tributary inflows, and local flow hydrographs at critical Souris River locations, including along the main Souris River, along the Des Lacs River, and through the structures in the J. Clark Salyer National Wildlife Refuge (NWR).

2. Stochastic hydrology[18]

A key objective of the Study was to evaluate alternative Operating Plan measures under a wide range of future water supply conditions, including extreme wet and dry conditions.

To address this objective, the Study used stochastic, or randomized, simulation of key hydrological variables. Stochastic modeling is commonly used to help evaluate alternative water management plans or operating rules under a range of water supply conditions.

The United States Geological Survey (USGS), in cooperation with the North Dakota State Water Commission, used previously developed unregulated and regulated streamflow models and data for stochastic streamflow in the Souris River basin to characterize historic climate and streamflow, and support selection of streamflow traces based on their characterization. (A trace is a time series of stochastic streamflow, potential evapotranspiration, or precipitation).

[18] Stochastic hydrologic modeling is helpful to better understand variability over longer time spans.

This modeling generated a large number of potential hydrological scenarios that could represent more severe wet and dry periods than those experienced in the recent past, including rare and even catastrophic flooding and drought events. Due to time and budget constraints, the Study team was not able to run the post process and analyze the entire set of stochastic hydrology traces in using HEC-ResSim. Instead, representative traces, selected based on statistical metrics to represent critical flow conditions to reservoir operation, were used in support of alternative evaluation.

3. Climate change runoff sequences

Future Souris River basin water supplies may differ from supplies experienced in the past due to the potential impacts of human-driven climate change. At the outset of the Study, the intent was to evaluate alternatives using projections of future modeled, climate-changed hydrology. Climate-changed hydrology can be generated using meteorological outputs from global climate models (GCM) downscaled and bias-corrected to be applicable at spatial scales appropriate for water resources management. Downscaled, climate-changed meteorology can then be inputted into hydrologic models to generate projections of future streamflow.

The downscaling and bias-correction process is resource intensive, so the Study was limited to using readily available datasets. A Study team reviewed available downscaled and bias-corrected climate-changed meteorology to determine what could be used to define sequences of climate-changed hydrologic response. It was found that, although there are numerous pre-processed datasets available, the vast majority do not provide coverage of both the United States and Canada. Only one transboundary product was identified. The identified product relies on the output from one GCM, one emissions assumption (RCP 8.5) and reflects the results of a single downscaling/bias-correction technique. To adequately define sequences of climate-changed hydrology to be used in support of decision making and/or to numerically characterize the impacts of climate change on streamflow response, the results, at minimum, must incorporate outputs from an ensemble of GCMs. To adequately reflect the uncertainty associated with projected streamflows, different emissions assumptions, downscaling techniques and hydrologic modeling assumptions should be taken into consideration and reflected in the results derived.

Despite not being able to fully develop and analyze sequences of climate-changed hydrology as part of this Study effort, the Study team generated and successfully tested a workflow that could be adopted to generate such time series in the future. To support future analysis, Environment and Climate Change Canada (ECCC) developed a calibrated, MESH (Modélisation Environnementale, Surface et Hydrologie) surface hydrology model of the Souris River basin, specifically configured to be forced with climate-changed meteorology derived from GCMs. Traces of future meteorology acquired from the bias-corrected and downscaled transboundary product identified by the Study team were used to generate a proof-of-concept run using both MESH and HEC-ResSim to verify that the workflow is robust and can be directly adopted in the future.

5.2.3 MODELING AND EVALUATION TOOLS

The next step was to integrate runoff sequences, basin data and performance indicator (PI) data (see below) into models to allow for the evaluation of alternative Operating Plan measures. This was a highly iterative process. Feedback from the Public Advisory Group (PAG), the Resource and Agency Advisory Group (RAAG) and other interests was critical at this stage to allow the Study to test a large number of alternative Operating Plans and then focus in on a smaller number of likely candidate alternatives. Some alternatives were not considered viable from the outset and were used instead to test and better understand the theoretical limits or constraints of the Souris River system. Other alternatives could be discarded very early on, as preliminary model results indicated that they were likely to result in unacceptable negative impacts to water supply or flood control. Other plans looked more promising and were tested in more detailed and comprehensive models. Section 5.3 provides more details on this process.

1. Modeling tools

This section is based on the following reports of Study technical task teams, available on the Study's website: www.ijc.org/en/srsb

- "HH 6: Reservoir Flow Release Modeling (HEC-ResSim)" https://ijc.org/en/srsb/hecres-sim-model-report
- "HH 7: Reservoir Flow Release Modeling (HEC-RAS)" https://ijc.org/en/srsb/reservoir-flow-release-modelling-hec-ras-report
- "HH 8: PRM Model Development (HEC-ResPRM)" https://ijc.org/en/srsb/hec-prm-model-report
- "HH4, HH5 and HH9 combined report: Climate Change Simulation Tools and Analysis" - Pending report technical review and ISRSB approval.

There were several initiatives related to developing the modeling platforms that were used in the Study. Each of these initiatives related to different aspects of the hydrologic cycle. Meteorological models produce inputs such as temperature and precipitation for hydrological models. Hydrological models characterize land-surface processes and use meteorological inputs to produce land-surface runoff for hydraulic riverine models. Most hydrological models have simplified hydraulic models built in, but more detailed hydraulic models also exist independently. Reservoir models incorporate human-induced hydrology by characterizing reservoir operations in detail, though reservoir models have simplified representations of land-surface hydrology and riverine hydraulics.

The stochastic hydrology effort within the Study (see section 5.2.2, above) made use of an existing water balance based hydrologic model that is relatively simple and easy to use. The focus was on developing meteorological inputs for the hydrological model to capture the historical variability over the last few hundred years that is unavailable from more direct observations, but rather inferred from tree ring and lake sediment records. The MESH model is a more complex hydrological model that more accurately represents the detailed physical processes of the land surface, but requires more detailed inputs and is more difficult to parameterize.

The water balance model applied to produce stochastic hydrology and MESH model were both set up to produce streamflow inputs to the HEC-ResSim reservoir model. The water balance model was used in support of producing stochastically generated traces of potential hydrologic response by re-sampling from observed meteorological records. By stochastically re-sampling from historic precipitation and evapotranspiration records, and modeling the corresponding hydrologic response, a richer sample of the basin's potential streamflow response was generated. Stochastically generated hydrology provides feasible streamflow conditions beyond those presented by direct observation.

The initial intent of developing the MESH model was to produce projected, climate-changed hydrology specific to the Souris River basin by forcing the model with outputs from global climate models (GCMs). Climate-changed hydrology would have offered an additional sequence of potential streamflows that could be used to evaluate reservoir operations. As a result of resource constraints, and a lack of readily available GCM outputs appropriately configured for hydrologic modeling, it was not feasible to generate climate-changed hydrology which could be used for alternative evaluation. The Study team was limited to developing the models required and workflow necessary to generate climate-changed hydrology in the future. A proof-of-concept run was carried out to verify that streamflows based on outputs from GCMs could be modeled.

As explained below, work on both the HEC-RAS and HEC-ResPRM models was initiated, but ultimately neither was used in the Study's detailed development and analysis of alternative Operating Plan measures. However, both models can be useful in future efforts to simulate potential alternative reservoir operations in the basin.

The model system integration task was included to develop ways to couple the various models together. Most modeling efforts focus on one specific element of the hydrological cycle. Only recently have modelers combined the best of the various models into more comprehensive studies such as this one. The model system integration within the Souris Study has focused on coupling the stochastic hydrology and MESH models with the HEC-ResSim reservoir model.

More details on these initiatives are presented below.

Reservoir Flow Release Modeling using HEC-ResSim

A key step in formulating and evaluating alternatives was the development of a reservoir system model including Rafferty Reservoir, Boundary Reservoir, Grant Devine Lake and Lake Darling. The model was designed to simulate levels and flows along the entire length of the Souris River, as well as simulate reservoir operations and hydrologic routing. In addition, it needed to be detailed enough to allow for a reasonable comparison of the existing Operating Plan with potential alternative Operating Plan measures that were developed in the Study.

The reservoir model was constructed using the USACE HEC-ResSim software with input from the other reservoir operating agencies for the Souris River. The model extends from the Saskatchewan reservoirs to the international border crossing near Westhope, North Dakota, and consists of the four major reservoirs (Rafferty Reservoir, Boundary Reservoir, Grant Devine Lake, and Lake Darling), two major diversions (Boundary Diversion Channel and Rafferty Pipeline), the five impoundments at the J. Clark Salyer National Wildlife Refuge in North Dakota and a number of routing reaches.

HEC-ResSim requires relationships describing the physical characteristics of the reservoir, including elevation-area-storage relationships, top-of-dam characteristics, and maximum outlet capacity curves. The HEC-ResSim model also requires inputs describing certain physical processes which result in significant losses from the reservoir over time. These processes, such as evaporation, direct precipitation, and seepage losses are taken into consideration and explicitly modeled when they are assumed to be significant.

Rafferty Reservoir, Boundary Dam, Grant Devine Lake and Lake Darling were modeled to reflect the operating guidelines prescribed by Annex A and Annex B outlined in the 1989 Agreement, as well as the Lake Darling Water Control Manual, historical operations and operating guidelines submitted by the WSA, SaskPower, the United States Fish and Wildlife Service and the USACE. Hydrologic routing reaches link the reservoirs to downstream points of interest.

The HEC-ResSim model is applied by inputting estimated inflow hydrographs above the reservoirs and at various intermediate, local inflow locations along the river. The model then simulates the operation of Rafferty, Boundary, Grant Devine, and Lake Darling Dams and outputs discharge hydrographs at various computation points along the Souris River as well as pool elevation hydrographs at the four major reservoirs. Alternative simulations are run by adjusting the operating rules for Rafferty, Boundary, Grant Devine, and Lake Darling Dams.

The HEC-ResSim model allowed the Study team to model system operations for both individual events and over longer time scales (that is, event or multi-year time frames). It provided sufficient flexibility to test complex operating rules and allowed for the comparison of present-day operations to proposed changes to reservoir operation.

The challenges associated with developing the reservoir model include:

- accurately modeling low flow conditions, accurately accounting for water supply demand and natural channel/reservoir losses;
- realistically simulating operating practices not explicitly laid out in Annex A or B, including summer rainfall operations; and,
- the limited period of record available for model verification (for example, the 1998-2017 period does not include an extreme drought).

Reservoir Flow Release Modeling using HEC-RAS

The 2011 flooding event underscored the need for improved modeling of the Souris River basin. The USACE Hydrologic Engineering Center's River Analysis System (HEC-RAS) model routes flow and determines water surface elevations at different points along a river. A one-dimensional HEC-RAS model can provide average channel velocities and a water surface elevation at a cross section. However, when modeling using two-dimensional areas, the water surface elevation and velocities can be determined at all defined edges of the “cells” that make up the “mesh” of the two-dimensional area.

A Study technical team was established to prepare an updated HEC-RAS model for the Souris River.

The updated HEC-RAS model developed under the Study incorporates data from a 2018 Saskatchewan hydraulic model along with corrections and updates to the previous 2016 version of the model. It includes additional survey data, new and replaced bridges, and improvements to the layout of the model geometry.

Due to the complexity of the model, Study modelers divided the river system into three smaller sub-models:

- from Rafferty Dam to Lake Darling Dam including Long Creek from Boundary dam and Moose Mountain Creek from Grant Devine Dam, in Saskatchewan;
- from Lake Darling Dam to Verendrye, North Dakota including the Des Lacs River; and,
- Verendrye to Westhope, North Dakota, including the Eaton Irrigation District and the J. Clark Salyer National Wildlife Refuge.

Having three smaller, but connected, models allows modelers to investigate a particular area of interest along the river system rather than having to run simulations for the entire river.

The model is currently functional and can be used to simulate how the water surface, and therefore flooding extents, of the Souris River changes for various flood events. This information is vital for detailed floodplain mapping and hydraulic design studies. However, running the HEC-RAS model for every alternative simulation in the Study would have been extremely time-consuming and costly, as the HEC-RAS model is designed to simulate single flood events, not multiple years of hydrologic data. Instead, the Study team analyzed differences in flood extents for each alternative by using Performance Indicators that generalized the relationship between river flow and flood extent for various reaches. Described in more detail later in this report, this approach allowed the Study team to reasonably estimate how changes in flow affected the extent of flooding without running the HEC-RAS model for each alternative simulation.

Prescriptive Reservoir Model Development (HEC-ResPRM)

The HEC-ResPRM effort was developed to help the Study Board relate competing priorities and interests relative to each other and narrow the focus of the operation plan alternatives development. Ideally, the model's benefit/cost functions would help in the evaluation of operation plan measures by providing an objective rating that could be applied to different scenarios. In this way, the HEC-ResPRM model could provide insights that a simulation model alone could not. However, after further review, the available version of the HEC-ResPRM model could not account for apportionment and was not pursued for this Study.

Study technical team members first developed a set of system objectives, as defined by benefit/cost functions at key reaches in the basin. These objectives would, in turn, support the development of a model that could optimize operations for Rafferty Reservoir, Grant Devine Lake, Boundary Reservoir and Lake Darling.

Initial runs of the model highlighted limitations of the HEC-ResPRM software in regard to supporting the HEC-ResPRM development, and in particular the amount of time and effort likely needed to establish and refine functions and trade-off curves for extensive basin-wide objectives that sought to optimize operations. As a result, the Study Board determined that there was not sufficient time or resources to support a fully validated optimization model. Nor was the HEC-ResPRM software equipped to model the system with the level of precision needed to take advantage of the benefits of an optimization approach.

The most important challenge to moving forward with HEC-ResPRM as a tool to analyze alternatives is the high level of difficulty involved in quantifying and reconciling various interests in the basin into trade-off curves, which are a necessary input into the HEC-

ResPRM model. While some performance metrics such as flood damages can be clearly related to a common unit (for example, monetary value), other operational outcomes, such as fish and wildlife habitat or loss of archaeological sites, do not share a common unit of measure.

The model produced by the Study's effort is available for use in the event a future study can dedicate the time and resources necessary to consider an optimization model with HEC-ResPRM. Improvements to the existing HEC-ResPRM software would greatly benefit such an effort.

MESH

The objective in generating the MESH model in support of the Study was to produce climate-changed hydrology specific to the Study area and to offer a tool that could be used to aid in hydrologic modeling of the basin in the future. The MESH model developed as part of the Study can capture the effects of prairie pothole topography and the physical processes related to blowing snow and infiltration into frozen soils. As part of this study effort, a new algorithm was developed to characterize the exceptionally challenging fill-and-spill hydrological processes that are associated with prairie pothole topography. The MESH model was adequately calibrated and validated using streamflow data based upon historic observation.

Because the Souris River basin is a transboundary watershed, few global climate model (GCM) based climate-changed meteorological products are available which have been bias-corrected and downscaled to the scale (in terms of spatial resolution and time step) necessary to support hydrologic modeling of future conditions. Performing post-processing of raw GCM outputs was deemed beyond the scope of this study effort. As such, the data inputs required to generate and fully analyze climate-changed hydrology specific to the study area are not available at this time. A single, downscaled and bias-corrected product was identified, but this single data source is not sufficient to facilitate an evaluation of the effects of climate change on the future hydrology of the basin. A credible climate change analysis would require an ensemble of model runs that account for the various sources of uncertainty present in the modeling chain, such as multiple carbon dioxide emission scenarios, multiple GCMs, a variety of downscaling/bias-correction techniques, multiple hydrologic models, etc.

The downscaled, GCM-based data source identified did support the implementation of a proof-of-concept run that was carried out to verify that the MESH model, along with the HEC-ResSim model generated as part of this study, could be forced with GCM-based realizations of future, climate-changed meteorology. As additional transboundary GCM-based products become available, these can be adopted to model and evaluate future climate-changed hydrology for the Souris River basin.

Besides offering an avenue for future efforts to evaluate climate-changed hydrology, the MESH work done as part of this study illustrates the complexity of hydrologic modeling in the Prairie pothole region and charts a path forward to improve predictability/forecasting in the basin. In the future, MESH parameterization and model calibration/validation could be improved to better capture the interrelationships between soil moisture, distributed storage effects, snow, and evapotranspiration. This can be accomplished by acquiring and incorporating additional data products such as the data collected as part of the National Oceanic and Atmospheric Administration (NOAA) gamma snow survey program and artificial drainage data.

2. Performance indicators

This section is based on the report of Study's technical task team "DW4, Data Collection for Performance Indicators", available on the Study's website: https://ijc.org/en/srsb/data-collection-performance-indicators-report-and-appendices

Purpose

A key component of the Study's methodology involved the development and testing of performance indicators (PIs). The application of PIs helped Study teams evaluate modeled alternatives and compare the results relative to the baseline simulation, which simulates current conditions under the 1989 Operating Plan.

PIs consist of a relationship between a streamflow or reservoir elevation and a corresponding impact on specific basin interests, such as infrastructure, agricultural lands, and ecosystem elements. A PI is typically displayed as a table or two-dimensional curve with flow or stage on the x-axis and an impact or benefit on the y-axis.

Developing the PIs

Given that many impacts from a reservoir Operating Plan will differ from one section, or reach, of the river to another, the Study split the Souris River, from the reservoirs in Saskatchewan to its confluence with the Assiniboine River in Manitoba, into 22 reaches (Figure 20).

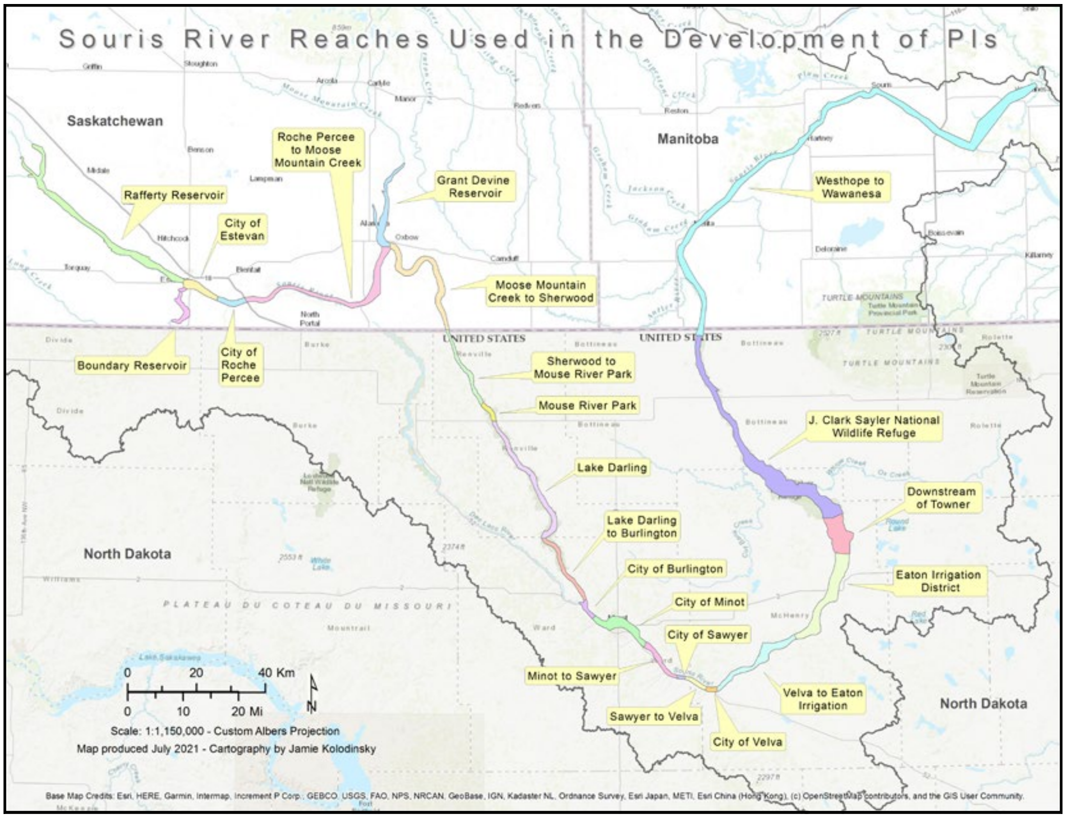

Figure 20 Souris River reaches used in the development of PIs

Next, on the basis of the 2017 Reference to the IJC and the results of public engagement, the Study identified the need to develop PIs in seven key areas: flood control; agriculture; water supply; environmental; cultural; erosion; and recreation.

Two types of PIs were developed:

- *curve-generation PIs*, such as those developed for agricultural damages and water quality, identify a changing relationship between effects on a particular interest and various reservoir elevations or flows in the river; and,
- *flow/elevation threshold PIs*, such as those developed for the inundation of wastewater lagoons, identify effects that occur only when a specific reservoir elevation or flow threshold in the river has been exceeded.

1. Curve-generation PIs

A Study technical team collected available data from various government agencies, industry, and other interests to help relate particular flows and reservoir elevations to potential impacts on basin stakeholders, infrastructure, and ecosystems. The Study's Resource and Agency Advisory Group (RAAG) and Public Advisory Group (PAG) were involved during this data gathering and analysis.

Each PI was developed collaboratively by representatives from Saskatchewan, North Dakota, and Manitoba. To the extent possible, PI functions were created using the same methodology across all three regions, though datasets typically differed from one jurisdiction to another. Due to geographic constraints, differences in available data, and varying degrees of input from interests in the basin, some PIs were developed only for one or two of the three jurisdictions.

The PIs continued to be refined over the course of the Study through ongoing analysis by Study teams and engagement with the PAG, RAAG and Indigenous Nations.

Table 19 lists the curve-generation PIs developed for the Study under the seven themes, along with their associated region. Given that flows and uses along the river vary considerably by location and over time, all PI curves are reach-specific, and many are seasonal in nature.

Table 19 Curve-generation PIs developed for the Study

Performance Indicators			
Study Theme	**Saskatchewan**	**North Dakota**	**Manitoba**
Flood Control	Structural Damages	Structural Damages	Structural Damages
Flood Control	Bridge Inundation	Bridge Detours	Bridge Inundation
Flood Control	Coal Haul Road Damage	-	-
Flood Control	Well Inundation	-	-

Performance Indicators			
Study Theme	**Saskatchewan**	**North Dakota**	**Manitoba**
Agriculture	Agricultural Damages	Agricultural Damages	Agricultural Damages
Water Supply	Permitted Water Use	Permitted Water Use	Permitted Water Use
Water Supply	Boundary SaskPower	-	-
Environmental	Water Quality	Water Quality	Water Quality
Environmental	-	Fish Mortality	Fish Mortality
Environmental	-	Fish & Wildlife Habitat	Fish & Wildlife Habitat
Environmental	Fish Habitat	-	-
Environmental	-	-	Ground Nesting Bird Habitat
Cultural	Historic Site Preservation	Historic Site Preservation	Historic Site Preservation
Cultural	-	-	Crown Lands Inundation
Erosion	-	Channel Erosion	-
Recreation	-	Boating & Fishing Safety	Boating & Fishing Safety
Recreation	Boating & Fishing Access	Boating & Fishing Access	
Recreation	Duck Derby (Estevan)	-	-

Two examples of curve-generation PIs used in the Study are presented below.

Flood control – Bridge inundation, Saskatchewan

Figure 21 illustrates the PI curve developed to identify the effects of various river flow levels on bridge closures in the basin in Saskatchewan. It estimates the number of bridges that would be inundated at a given daily river flow between Roche Percée and Moose Mountain Creek, Saskatchewan.

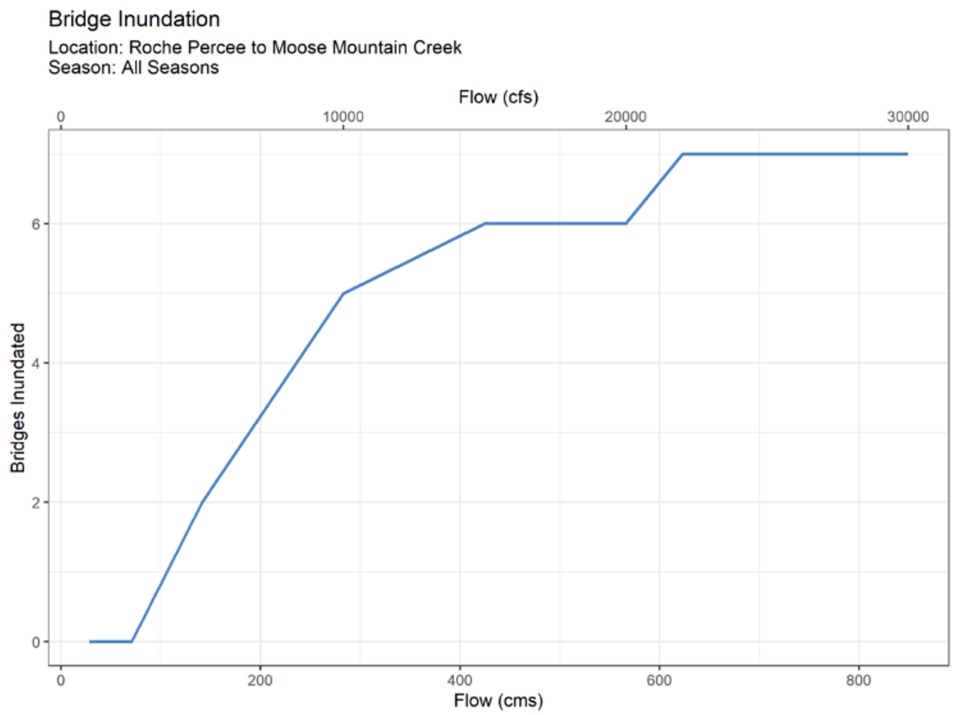

Figure 21 Bridge inundation Performance Indicator for the reach from Roche Percée to Moose Mountain Creek, Saskatchewan

Cultural – Crown Lands inundation in Manitoba

Table 20 illustrates the PI developed to document the inundation of Crown Lands (land owned by the federal or provincial governments) in Manitoba. Access to these lands has Indigenous, recreational and cultural significance. For example, through discussions with the Manitoba Metis Federation, the Study learned that Métis citizens exercise their harvesting rights on unoccupied Crown Land in the basin. As a result, flooding of the lands is a concern.

The PI indicates the estimated area of Crown Land flooded at various flow levels in the Westhope, North Dakota, to Wawanesa, Manitoba reach.

Table 20 Crown Lands inundation PI

Westhope to Wawanesa		
All Seasons		
Flow (m^3/s)	**Flow (cfs)**	**Crown Land Flooded (acres)**
0	0	0
23	800	0
28	1,000	155

Westhope to Wawanesa		
All Seasons		
Flow (m^3/s)	Flow (cfs)	Crown Land Flooded (acres)
57	2,000	275
85	3,000	397
113	4,000	488
142	5,000	534
283	10,000	646
425	15,000	752
566	20,000	864
708	25,000	962
849	30,000	1,047
934	33,000	1,262

2. Flow/elevation threshold PIs

The flow/elevation threshold PI group sought to capture any PIs that would not easily fit into the curve structure described above. Several of these PIs were requested by interest groups in the basin. Similar to the development of the curve-generation PIs, the flow/elevation threshold PIs were independently developed by Study team members in Saskatchewan, North Dakota, and Manitoba.

Table 21 summarizes these flow and elevation thresholds, by Study theme. For example:

- a flow threshold of 20.01 m^3/s (706.7 ft^3/s) at Estevan, Saskatchewan, resulted in the inundation of the city campground;
- a water elevation of 487.9 m (1,600.6 ft) as measured at Lake Darling, North Dakota, resulted in the inundation of a street at Mouse River Park; and,
- a flow threshold of 373.6 m^3/s (13,200 ft^3/s) in the Souris River at Minot, North Dakota, was sufficient to result in the inundation of a section of a major railway in the city.

In evaluating alternative Operating Plan measures, the number of times a given alternative measure met or exceeded these thresholds was counted and used to help determine whether a particular PI is improved at that location. However, different PIs are not directly comparable to each other, as they were not weighted or ranked.

Table 21 Flow/elevation thresholds used in the PI analysis

Flow/Elevation Thresholds					
Study Theme	**Region**	**Reach**	**PI Name**	**Threshold (Metric)**	**Threshold (Imperial)**
Dam Safety	SK	Rafferty Reservoir	Maximum Allowable Flood Level (MAFL)	554.0 m	1,817.6 ft
Dam Safety	SK	Boundary Reservoir	Maximum Allowable Flood Level (MAFL)	560.8 m	1,839.9 ft
Dam Safety	SK	Grant Devine Reservoir	Maximum Allowable Flood Level (MAFL)	567.0 m	1,860.2 ft
Dam Safety	ND	Lake Darling	Maximum Allowable Flood Level (MAFL)	488.0 m	1,601.0 ft
Dam Safety	SK	Rafferty Reservoir	Below Riprap	530.0 m	1,738.8 ft
Flood Control	ND	Mouse River Park	MRP Flood Operations	486.9 m	1,597.5 ft
Flood Control	ND	Mouse River Park	MRP 95th St. Safety	487.9 m	1,600.6 ft
Flood Control	ND	Mouse River Park	MRP Evacuation	489.1 m	1,604.6 ft
Flood Control	ND	Mouse River Park	MRP Levee Safety	488.2 m	1,601.6 ft
Flood Control	ND	City of Burling-ton	Wastewater Lagoon Inundation	467.0 m^3/s	16,500 cfs
Flood Control	ND	City of Minot	BNSF Railroad Inundation	373.6 m^3/s	13,200 cfs
Flood Control	ND	City of Minot	Current Permanent Flood Protection (1% - 1989 Agreement)	141.6 m^3/s	5,000 cfs
Flood Control	ND	City of Minot	1% Annual Exceedance Probability Event (adopt-ed by FEMA in 2019)	283.0 m^3/s	10,000 cfs
Flood Control	ND	City of Minot	Wastewater Lagoon Inundation	849.0 m^3/s	30,000 cfs
Flood Control	ND	Minot to Sawyer	CP Railroad Inundation	251.9 m^3/s	8,900 cfs
Flood Control	ND	City of Sawyer	Wastewater Lagoon Inundation	622.6 m^3/s	22,000 cfs
Flood Control	ND	City of Velva	Wastewater Lagoon Inundation	735.8 m^3/s	26,000 cfs
Flood Control	ND	Eaton Irrigation District	Wastewater Lagoon Inundation	735.8 m^3/s	26,000 cfs

Flow/Elevation Thresholds					
Study Theme	**Region**	**Reach**	**PI Name**	**Threshold (Metric)**	**Threshold (Imperial)**
Flood Control	MB	Westhope to Wawanesa	1% Annual Exceedance Probability Event	574.5 m^3/s	20,300 cfs
Flood Control	MB	Westhope to Wawanesa	0.5% Annual Exceedance Probability Event	792.4 m^3/s	28,000 cfs
Flood Control	All Re-gions	All Reaches	Bankfull Exceedances	Varies	Varies
Recreation	SK	Rafferty Reservoir	Rock Reef Exposure	550.0 m	1,804.5 ft
Recreation	SK	City of Estevan	Campground Inundation	20.01 m^3/s	741.6 cfs
Water Supply	SK	Rafferty Reservoir	Return to Full Supply Level (FSL)	550.5 m	1,806.1 ft
Water Supply	SK	Boundary Reservoir	Return to Full Supply Level (FSL)	560.8 m	1,839.9 ft
Water Supply	SK	Grant Devine Reservoir	Return to Full Supply Level (FSL)	562.0 m	1,843.8 ft
Water Supply	ND	Lake Darling	Return to Full Supply Level (FSL)	486.8 m	1,597.0 ft

One of the key flow/elevation threshold PIs used in evaluating alternative Operating Plan measures was the *Flood control – bankfull exceedances* PI (Table 22). This PI was used to help determine when an alternative measure would result in bankfull exceedances (overflows) at key reaches of the Souris River. The PI identifies the flows that exceed bankfull capacity if the banks have been exceeded for five or more days, thus increasing the reliability of when flows would be exceeding bankfull capacity in an actual flooding event.

Table 22 Flood control - bankfull exceedances threshold PI

Bankfull Exceedance PI		
Reach	**Flow (m^3/s)**	**Flow (cfs)**
City of Estevan	56.6	2,000
City of Roche Percee	56.6	2,000
Roche Percee to Moose Mountain Creek	56.6	2,000
Moose Mountain Creek to Sherwood	90.6	3,200
Sherwood to Mouse River Park	56.6	2,000
Mouse River Park	56.6	2,000
Lake Darling to Burlington	42.5	1,500
City of Burlington	42.5	1,500
Minot to Sawyer	39.6	1,400
City of Sawyer	39.6	1,400
Sawyer to Velva	39.6	1,400
City of Velva	39.6	1,400
Velva to Eaton Irrigation	42.5	1,500
Eaton Irrigation District	17.0	600
Downstream of Towner	8.5	300
J Clark Salyer National Wildlife Refuge	8.5	300
Westhope to Wawanesa	17.0	600

Applying the PIs

Study technical teams had planned to input the PIs into a reservoir optimization model, such as the Hydrologic Engineering Center's Prescriptive Reservoir Model (HEC-ResPRM). The HEC-ResPRM model uses network flow optimization to suggest an idea of the best outcome that can be expected for a system based on prioritization of the system's objectives. However, the Study teams decided against using the HEC-ResPRM model due to the difficulty in creating quantifiable trade-off curves as inputs to the model, the level of effort required to evaluate the results, and the program's inability to model apportionment, which precluded its use in the Study. Instead, the team decided to evaluate alternative measures using the Hydrologic Engineering Center's Reservoir System Simulation Model (HEC-ResSim).

Figure 22 illustrates the application of PIs in the evaluation of alternative Operating Plan measures. The graphic compares the relative performance of the baseline simulation (reflecting the existing 1989 Operating Plan) and a simulation of a sample alternative Operating Plan measure (in this case, one related to winter drawdown targets). It identifies the number of years in the 88-year period of record from 1930-2017 that either the baseline or the alternative would have an advantage in terms of their beneficial effects on the various PIs.

The graphic indicates that in general:

- there is not a large difference between the two simulations in terms of the number of years in which one or the other would have an advantage for any PI;
- the baseline simulation performs relatively well with respect to the number of years with reduced impacts on fish mortality, bridge inundation, fish and wildlife habitat and historic sites; and,
- the sample alternative shows an advantage in terms of the number of years with reduced bankfull exceedances, reduced agricultural damages, channel erosion damages and boating and fishing safety risks.

It is important to note the PIs developed in the Study, while reasonably quantitative, may not produce output data that truly reflect the effects seen at all locations in a given reach. However, given that the PIs were developed with the support of subject matter experts in the basin and accurately captured observed trends within each reach, the Study Board concludes that the PIs provide a useful way to evaluate the effects of various alternatives by comparing how individual PIs change with different scenarios. As stated earlier, the PIs are not weighted, and impacts or benefits to one PI are not "equal in value" to a different PI. Accordingly, the PIs cannot be compared to each other.

Section 6 presents a more detailed discussion of the evaluation of the final set of alternative Operating Plan measures.

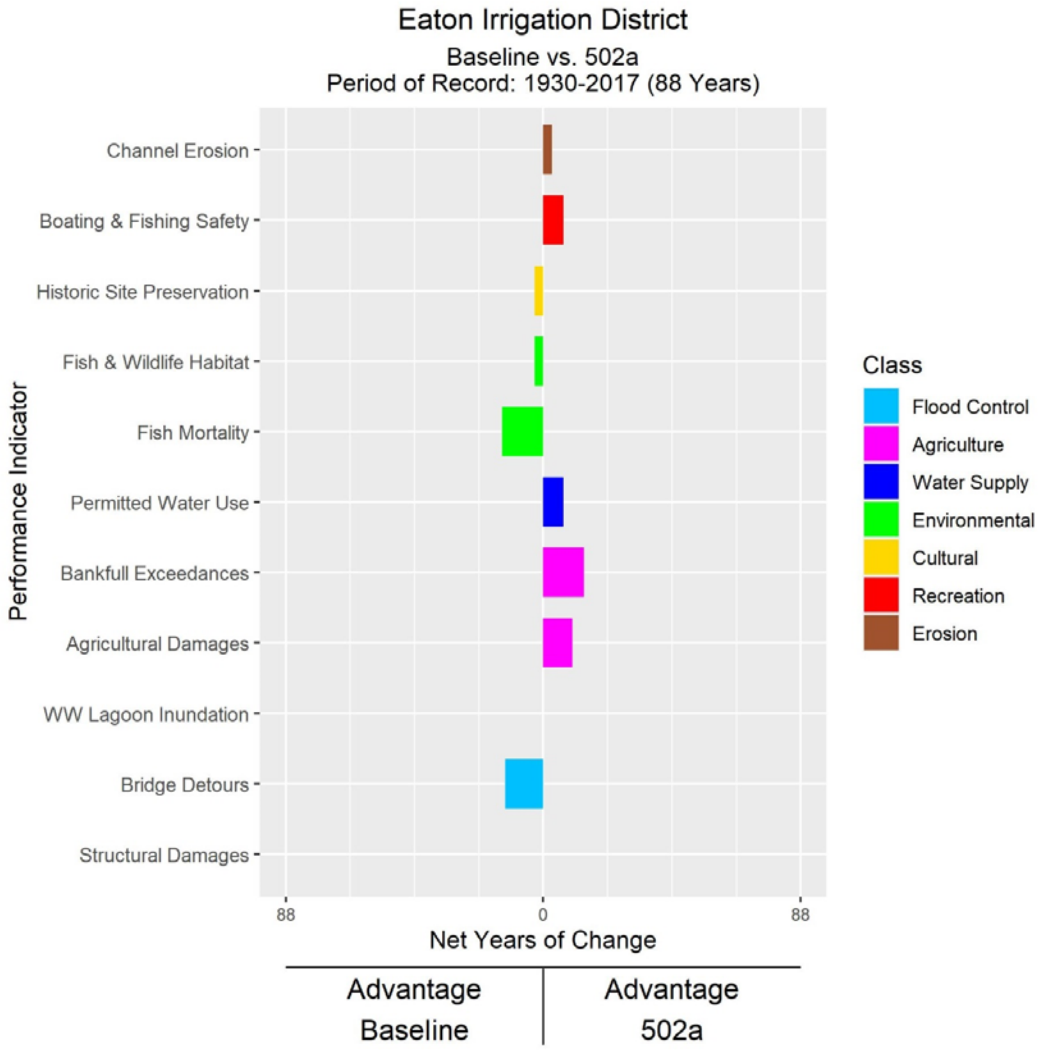

Figure 22 Example of the application of PIs: summary of evaluation, baseline vs sample alternative, Eaton Irrigation District reach, North Dakota; Scenario 50-2a represents the winter drawdown alternative measure

3. Visualization tool

A key step in evaluating possible alternative Operating Plan measures for the Souris River basin was the development and application of an innovative hydrologic visualization tool to help the Study Board, PAG, RAAG, and members of the public better understand and compare the impacts on certain areas of the basin from different plans. The tool, developed by the USGS, presents graphical representations of reservoir surface elevations and streamflow at various reaches of the river under a particular simulation. The tool:

- displays model output for discharge at stream locations or elevation (stage) at each reservoir site as an interactive hydrograph;
- plots multiple alternative scenarios on a single interactive plot;
- identifies impacts on specific PIs;

- compares the impacts of the scenario to baseline (current operating agreement) conditions; and,
- allows users to download the resulting data.

The visualization tool was used by the Study teams, the PAG, and the RAAG to review and assess possible alternatives, and to focus in on specific reaches and PIs. Successive rounds of feedback helped modify alternatives to reduce unacceptable impacts and narrow the evaluation process to a manageable number of realistic alternatives.

Figure 23 illustrates an example of the use of the visualization tool. The extreme flood of 2011 is visually compared to other large floods in 1969 and the 1970s for the Souris River at Sherwood, North Dakota, under the current operating agreement, as indicated in the baseline simulation in the figure. Another example of how the tool can be used is shown in the inset, where streamflow for the baseline is compared to the unregulated alternative (that is, with all major reservoirs removed). As indicated in the figure, the unregulated streamflow is much greater than baseline streamflow (that is, with all four reservoirs in operation) in April and May. By late June, all reservoir storage was full and only small differences exist between the baseline and unregulated peaks.

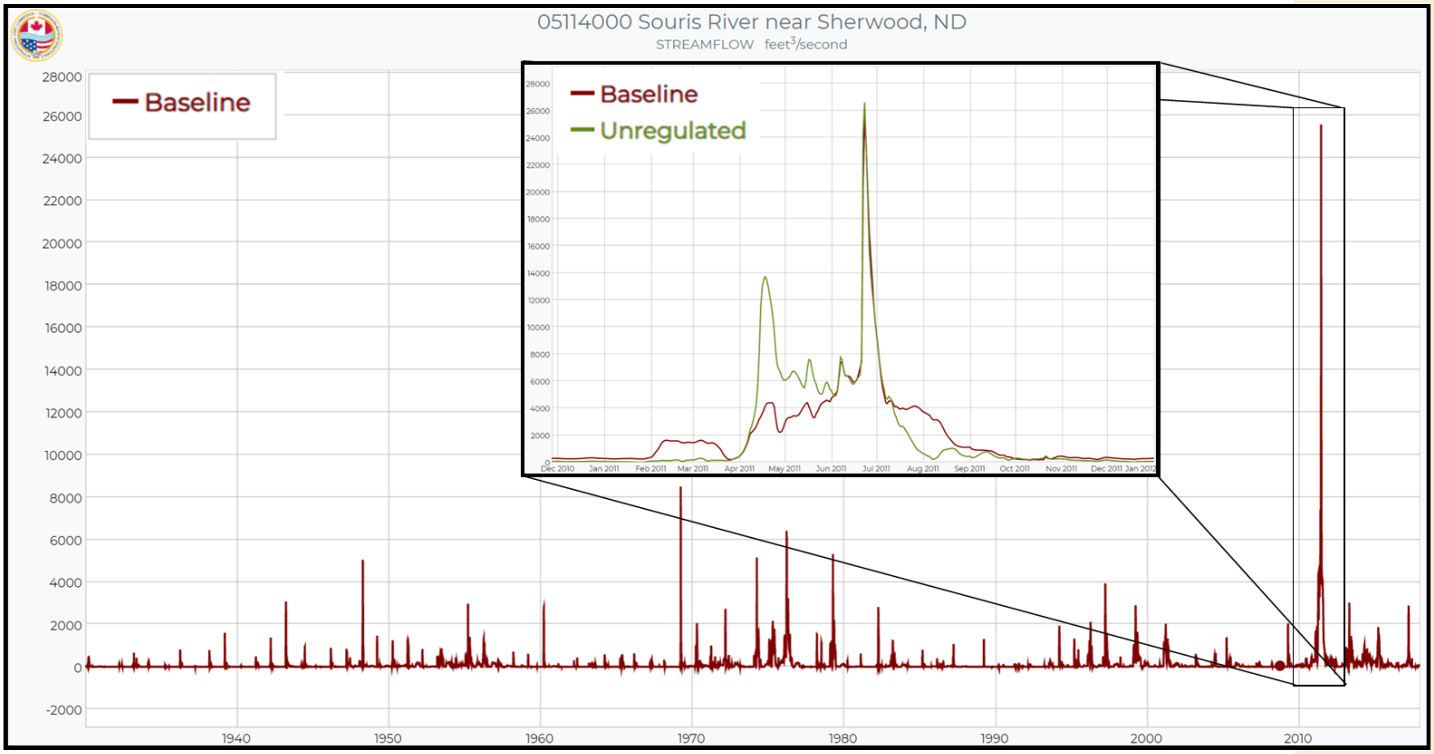

Figure 23 Example of the hydrologic visualization tool. Daily streamflow for baseline conditions from 1930 to 2017 and daily streamflow for baseline compared to unregulated conditions from December 2010 through January 2012 at the Souris River near Sherwood, North Dakota

4. Apportionment, water quality and aquatic ecosystem health

The focus of the 2017 Reference from the Governments of Canada and the United States to the IJC was to investigate and make recommendations regarding improvements to the Operating Plan contained in the 1989 Agreement with respect to flooding and water supply risks in the Souris River basin; however, the Reference also directed the IJC's study to consider the implications of any proposed improvements to the Operating Plan on apportionment as well as water quality and aquatic ecosystem health of the Souris River.

A detailed analysis of potential impacts of alternatives on water quality and aquatic ecosystem health was beyond the scope of the Study; it was not possible to fully assess how various alternatives would impact biological, chemical, and physical aquatic and riparian ecosystems. However, the Study did prepare a higher-level overview assessment to provide guidance on how several of the Study's outcomes or products, particularly the integrated modeling system, could be modified and applied in the future to address these concerns. The Study developed a series of water quality PIs to help evaluate potential alternative operating measures (see Section 8.2.2 for further discussion on water quality matters).

Image 32 Wetland at J Clark Salyer National Wildlife Refuge, North Dakota

5.3 Developing alternative Operating Plan measures

This section is based on the following reports of Study technical task teams, available on the Study's website: www.ijc.org/en/srsb :

- "PF2 HEC-ResSim Alternatives Assessment": https://ijc.org/en/srsb/hec-res-sim-run-and-evaluate-alternatives

5.3.1 OVERVIEW

The Study technical team responsible for formulating plans undertook its work through five phases, building on knowledge from each phase, and incorporating feedback from technical experts, the PAG, RAAG and Indigenous Nations.

Figure 24 illustrates the general process by which alternatives were developed, reviewed, and refined over the course of the Study. Using the hydrological data and runoff sequences developed earlier in the Study, the technical team modeled the Souris River basin to simulate a range of reservoir Operating Plan measures. Each alternative was evaluated against the PIs and an evolving set of screening criteria. For example, over the course of the analysis, the screening criteria included such factors as the degree to which the particular alternative was likely to:

- support the water supply and flood control objectives set out in the 1989 Agreement;
- affect water shortages or flood risk when compared to existing 1989 Agreement;
- be implemented relatively easily by reservoir operators; and,
- provide resilience to the potential future impacts of climate change.

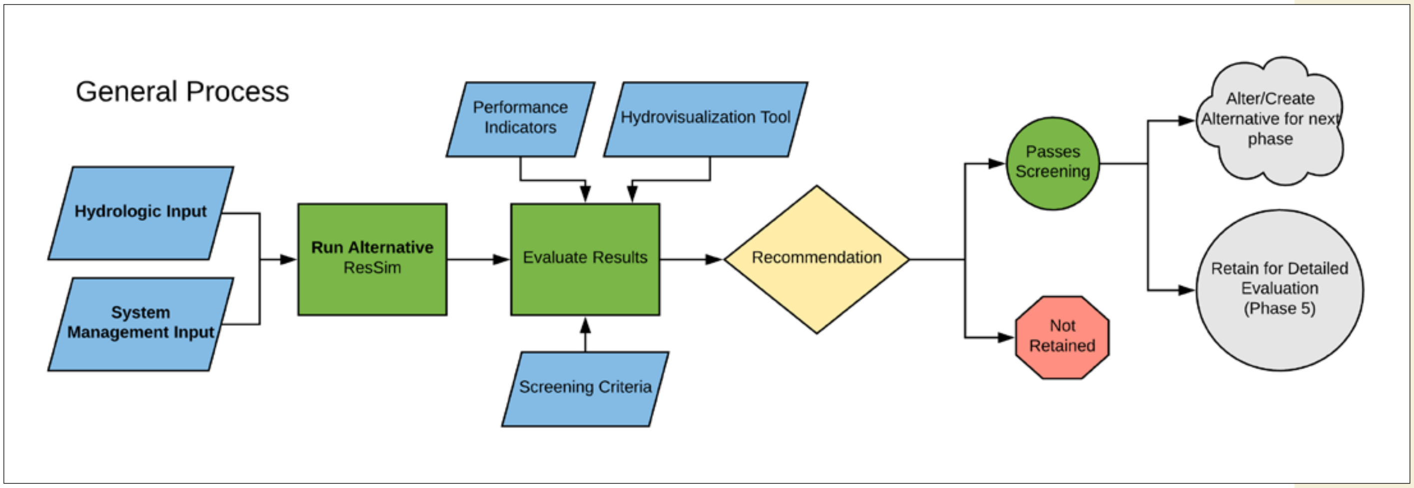

Figure 24 Overview of modeling and review process

The hydrological visualization tool allowed for a comparison of alternative simulation results at specific locations in the Souris River basin, including the impacts on specific PIs under varying water supply conditions. Through this process, proposed alternatives were either rejected, for example because they would fail to meet one or more of the various screening criteria or retained for further refinement and analysis.

In this way, the Study team was able to develop and test a relatively large number of possible Operating Plans, and then narrow down the list to a small number that could be considered as realistic alternatives to the existing Operating Plan under the 1989 Agreement.

The following presents a summary of the Study's work through the five phases of developing alternative Operating Plan measures. For a more detailed discussion, see PF2 HEC-ResSim Alternatives Assessment and associated reports available on the Study's website: www.ijc.org/en/srsb.

5.3.2 PHASE 1

The first step in the process of identifying and evaluating possible changes to the 1989 Operating Plan was to seek feedback regarding current operations and desired changes relating to flood control and water supply from the many interests in the Souris River basin. In particular, the Study team sought input from the PAG, the RAAG and the International Souris River Board (ISRB). For example, both the PAG and the RAAG expressed interest in adding flexibility to the revised Operating Plan and assessing the efficacy of the apportionment agreement. There was also interest in maintaining higher riverine flows to support water quality.

Based on the recommendations and concerns expressed by basin interests, a set of 11 specific operational changes was developed to serve as the building blocks for subsequent analysis. These building blocks included changes in operations affecting minimum flows, spring drawdown, summer flows, apportionment shift, and agricultural flooding. Table 23 summarizes the objectives of these operational changes.

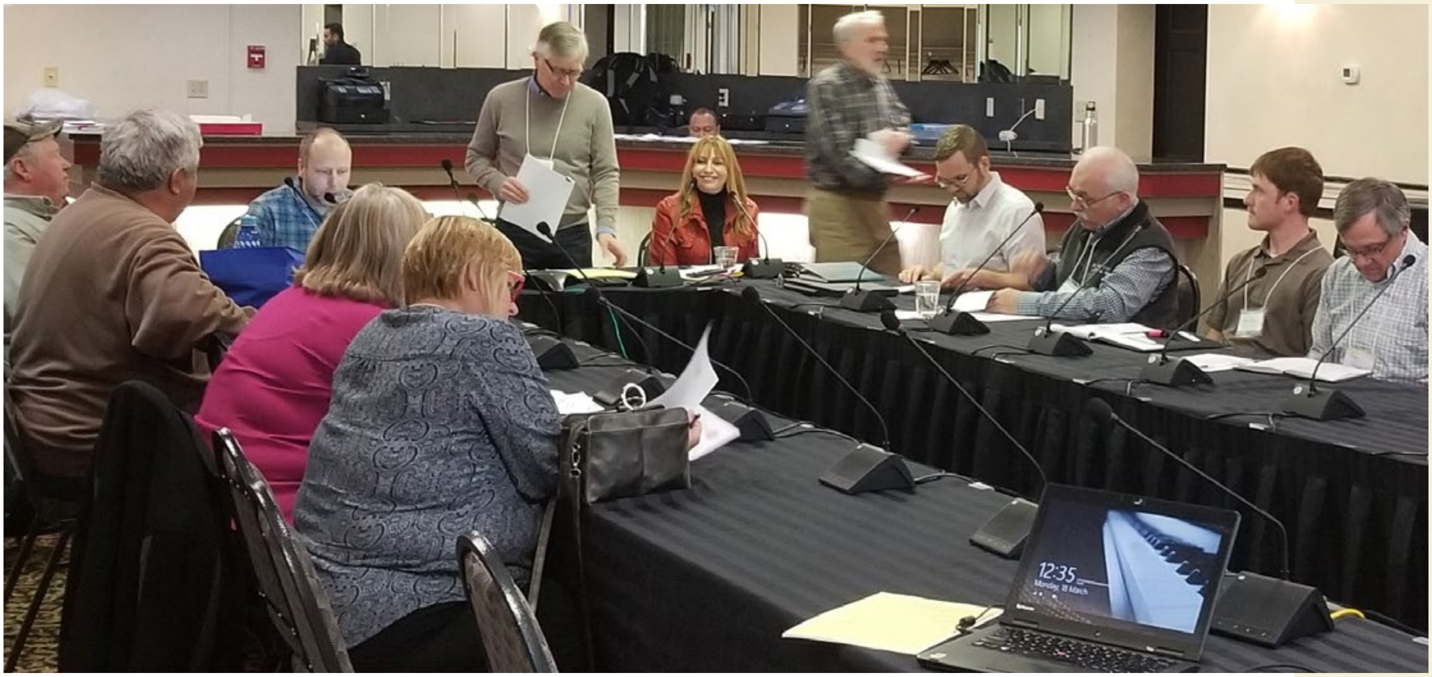

Image 33 Public Advisory Group workshop, March 2018

Table 23 Initial set of operational changes

Operational Change	Description
Baseline 1989 Operating Plan	Baseline reference under existing 1989 Operating Plan
1. WSA Dam Safety	Reference case to ensure dam safety of Rafferty and Grant Devine reservoirs
2. Saskatchewan Full Entitlement	Reference case to determine how much water can be allocated on a firm basis (without shortages) to Saskatchewan
3. Full Supply Level (FSL)	Reference case to assess the maximum water supply benefits that the Souris River Project could provide if held at FSL when possible
4. Dry Dam	Reference case to assess the maximum flood control benefits that the Souris River Project could provide if operated as dry dams
5. Pre-Agreement	Reference case to simulate basin conditions under the 1959 Interim Measures
6. Unregulated	Reference case to simulate state of nature conditions, prior to any regulation structures
7. Minimum Flows	Apply minimum flow rules at key locations to benefit fish and wildlife
8. Spring Drawdown	Assess the impact of altering pre-flood drawdown targets
9. Apportionment Shift	Change the start of the apportionment year from Jan. 1st to Nov. 1st in an effort to reduce surplus delivered to North Dakota
10. Summer Rainfall	Better define summer rainfall operations
11. Agricultural Flooding	Minimize agricultural impacts by limiting flows downstream of Lake Darling at Bantry, North Dakota

5.3.3 PHASE 2

The Study team then undertook reservoir simulation modeling of the building block operational changes to compare them against the baseline operations under the 1989 Agreement.

Several of the changes, such as the Dry Dam and Full Supply Level cases, were included as reference cases (i.e., “bookend” cases), essentially for information only, to help identify the limits or constraints to managing waters in the basin. In addition, the Study team modeled the unregulated conditions and the pre-agreement conditions in the Souris River basin to evaluate the performance of the existing 1989 Operating Plan.

Image 34   Grant Devine Spillway

This initial modeling identified those areas of possible changes in operations that appeared to be promising and worthy of further analysis. These operational changes related to minimum flows, spring drawdown, apportionment year shift, summer flood operations and agricultural flooding.

Through this initial round of evaluation, the Study team concluded that:

- The management of water supply and flood control benefits in the Souris River basin is highly constrained. That is, significant benefits in one area of water supply or flood control cannot be achieved without a loss of benefits in the other. For example, an effort to maximize water supply benefits by keeping the dams as close as possible to their full supply levels resulted in a significant increase in flooding of agricultural lands.
- Significant flooding during 2011 could not have been prevented by the existing infrastructure in the basin. Even if all the dams were empty prior to the 2011 flood season (eliminating all water supply benefits of the reservoirs), peak flow at Minot would have been approximately 425 m^3/s (15,000 ft^3/s), which is much higher than the current levee capacity of 142 m^3/s (5,000 ft^3/s).
- The existing plan under the 1989 Agreement works well in relation to water supply and flood control. There are no major operational changes that will result in significant improvements in both water supply and flood control benefits across the basin.
- The impacts of any single operational change in the basin are often localized rather than system wide. There is no single basin-wide measure that can be introduced that will address the challenges across the basin.
- The complexity and localized nature of the basin suggests that adaptive management may play a key role in future efforts to improve water supply and flood control benefits.

Because the dry dam scenario (with empty reservoirs prior to 2011) still resulted in major flooding throughout the basin, the study team opted to focus its efforts in subsequent phases on operational changes that would reduce flood risk during events smaller than the 2011 flood of record. Given the current flood protection infrastructure and water supply needs of the basin, any change to the 1989 Operating Plan that would have significantly altered the outcome of the 2011 flood is not possible. However, as water supply needs change and additional flood protection infrastructure is built (e.g., channel modifications, enhanced reservoir storage capacity), it may be necessary to reevaluate how the reservoirs are operated during extreme events similar to the 2011 flood.

5.3.4 PHASE 3

During Phase 3, the Study team refined the list of possible changes that showed promise. This analysis involved nearly 40 versions of the changes and included testing the changes under a wide range of possible climatic conditions. The versions of the operational changes were grouped under seven key areas: minimum flows; spring drawdown; normal drawdown targets; spring flood targets; apportionment year shift; summer flood operations; and agricultural flooding.

The analysis confirmed that there was no single, basin-wide operational change that could result in improved flood control and water supply benefits. Rather, the team concluded that it needed to explore the potential for more flexible alternative Operating Plans that could target specific conditions or certain time periods. As a result, two areas of operational change were identified as requiring further analysis:

- ***summer operations to limit agricultural impacts:*** The team concluded that there may be benefits to a more robust summer Operating Plan than is currently included in the 1989 Agreement. Two pool elevation-dependent summer operating rules, one designed to minimize summer flood peaks and another designed to minimize duration of summer flooding, were targeted for further evaluation;
- ***normal drawdown based on antecedent conditions:*** The analysis suggested that normal drawdown targets should be based on antecedent fall conditions. Greater normal drawdowns under wet conditions, as well as lesser normal drawdown targets under dry conditions, needed to be evaluated.

At the same time, three areas of operational changes were identified as not meriting further consideration:

- ***higher minimum flows in Saskatchewan:*** Increasing minimum flow thresholds were found to increase water supply risk in Saskatchewan during drought periods and endanger reservoir fisheries. There was also concern that reservoir operators may be legally obligated to maintain minimum flows year-round if a riverine fishery becomes established below Rafferty, Boundary, or Grant Devine Reservoirs. The team determined that year-round minimum flows could not be maintained without an unacceptable increase in water supply risk.
- ***higher minimum flows in North Dakota:*** To minimize risk to Lake Darling's water supply, any increased minimum flow requirement must be tied to reservoir pool elevation. However, there were insufficient data available to determine how minimum flows should relate to pool elevation.

- ***increased spring drawdowns:*** The analysis found that drawing down the reservoirs further prior to a large flood event did not significantly reduce flood damages due to physical capacity and outlet limitations.

5.3.5 PHASE 4

In Phase 4, the Study team combined various possible specific operational changes into distinct alternative Operating Plan measures. Each alternative consisted of different modifications to the:

- normal, winter drawdown schedule;
- spring maximum flow limits; and,
- summer operating rules.

The alternative Operating Plan measures were relatively similar, involving only minor adjustments to the current operating rules under certain conditions or at specific times of the year. Therefore, impacts to PIs were limited when viewing the simulation results for the entire 1930-2017 period. Typically, the analysis suggested that beneficial changes in one PI could be achieved only at the expense of impacts to another.

Given the similarity between alternative Operating Plan measures, the team concluded that there was a need to undertake even more detailed analysis in Phase 5 to identify and compare the likely results of the alternatives, with emphasis placed on identifying how each alternative measure performed during specific times of the year or under specific flood/drought conditions.

5.3.6 PHASE 5

In the final phase of the plan formulation analysis, the Study team concluded the formulation of the most promising alternative operational plan measures to improve upon the existing 1989 Agreement. These were grouped around possible operational changes regarding:

- variable normal drawdown targets based on antecedent conditions;
- extending the end date of the normal drawdown at Rafferty, Grant Devine, and Lake Darling Reservoirs to March 1;
- modifying allowable flows during the late winter and spring during non-flood and small to moderate flood years;
- shifting the apportionment year to the period starting Nov. 1 through Oct. 31 (from the existing period of calculating apportionment from Jan. 1 to Dec. 31) and,
- adopting a summer operating plan in which maximum allowable flows are based on reservoir pool elevations.

Through this final round of formulation, testing and refinement, the technical team identified a set of five alternative Operating Plan measures. Two of the measures had two options. Table 24 summarizes the objectives of these alternatives.

Section 6 presents the Study Board’s detailed evaluation of this final set of alternatives.

Table 24 Summary of alternative Operating Plan measures

Alternative Operating Plan Measures	Objective
1. Winter Drawdown Elevation Targets (Two options)	Allows for changes in winter storage in reservoirs, for im-proved operations that account for antecedent soil moisture and watershed basin conditions
2. Winter Drawdown Extension to March 1	Extends reservoir drawdown date from Feb 1 (1989 Agree-ment) to March 1, providing additional river flow for im-proved environmental benefits during February
3. Lower Spring Maximum Flow Limits	Reduces the spring flow limits during small/moderate flood years and non-flood years to reduce flood peaks and agricul-tural flood risk in riverine reaches in North Dakota
4. Summer Operations (Two options)	Provides operators improved guidance for reservoir storage and river flow during summer months that balances down-stream flood risk with adverse effects of high reservoir pool elevations
5. Apportionment Year Shift to a Water Year (for this study, the Water Year is defined as Nov. 1 to Oct. 31)	Changes the apportionment calculations from a Calendar Year (Jan. 1 to Dec. 31) to a Water Year (Nov. 1 to Oct. 31) to ensure flood protection releases in November and December are credited towards apportionment

5.4 Summary

The Study addressed the need to develop a range of alternative Operating Plan measures through the integration of several key areas of work by the technical teams: data collection and management; development of runoff sequences; the application of PIs; and iterative rounds of modeling and evaluation. The evaluation of alternatives included engagement activities to obtain the input of the public, Indigenous Nations, government water and resource management agencies, and industry.

A first step was to review existing hydrological and meteorological studies and collect, update, and analyze key data on the basin's hydrology and meteorology needed to support the modeling of alternatives. This included physical data on the Souris River basin, data on each reservoir's elevation, storage, volume and outflow, river flow data, and climate and bathymetric information.

Study Teams also developed a set of water supply sequences as input to the modeling and testing of alternatives. These included time series representing historic water supply conditions in the basin, going back to 1930; and stochastically generated flow scenarios, some of which were selected for analysis. Developing projections of future, climate-changed hydrology was originally part of the Study scope, but due to limited resources and data availability, this was not feasible. Although climate-changed hydrology could not be applied to test alternatives or characterize future hydrologic conditions, a workflow was developed using projections based on the outputs from one global climate model (GCM). A proof-of-concept analysis was conducted to verify that the workflow defined could be adopted to evaluate the effects of climate change on future flows should the resources and input data necessary become available.

The next step was to integrate the runoff sequences, basin data and PI data into models to formulate a wide range of alternative Operating Plan measures. The plan formulation process was highly iterative, carried out over five phases. Each phase built on the findings of the previous phase, with new or modified alternatives being formulated at each phase. Throughout this process, a hydrological visualization tool allowed Study participants to compare alternative simulation results at specific locations in the Souris River basin under varying water supply conditions.

Image 35 Lake Darling Dam and Reservoir

Figure 25 illustrates how the initial ideas on the evaluation of specific operational changes in the early phases supported the formulation of new alternative Operating Plan measures in the subsequent phases of analysis. Six of the initial group of operational changes were modeled primarily to provide insights into the limits and constraints to managing water supplies in the basin and thereby support additional modeling in subsequent phases. Some of these areas of operational change, such as those associated with minimum flows or spring drawdown, were rejected, as they failed to meet flood management and water supply criteria or resulted in unacceptable impacts to flood control or water supply. Other areas of operational change, such as those associated with normal drawdown targets, spring maximum flow limits and summer operating rules, proved more promising and were refined through further modeling. They formed the basis of the final set of five alternative operating measures (plus two options) that have the potential to provide marginal or incremental improvements for flood control and water supply benefits to the interests in the Souris River basin.

Section 6 provides a detailed description and the Study Board's evaluation of this final group of alternative Operating Plan measures.

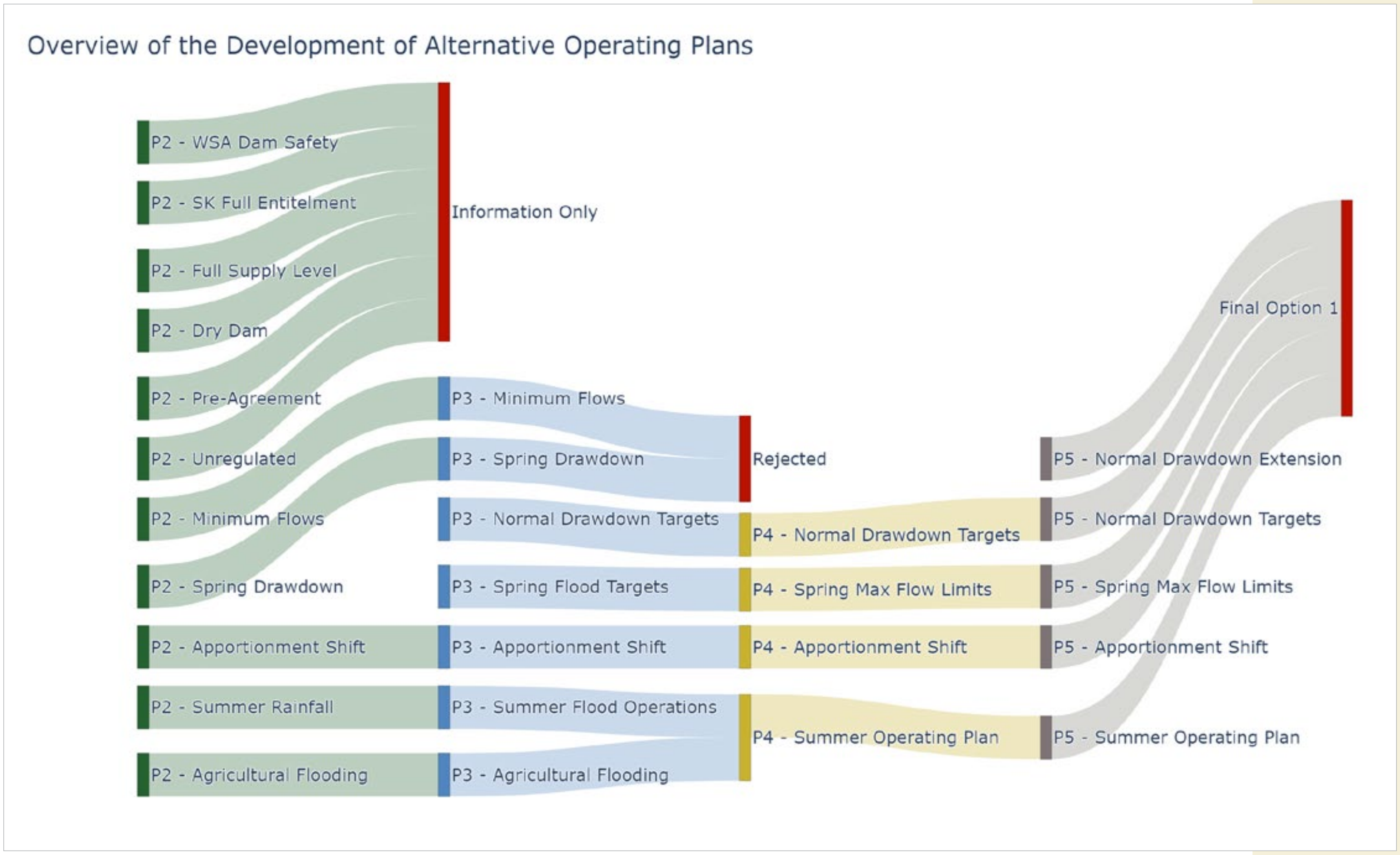

Figure 25 Overview of the development of alternative Operating Plan measures

6 Evaluation of the Alternative Operating Plan Measures

This section is based on the following reports of Study technical task teams, available on the Study's website: www.ijc.org/en/srsb *:*

- "PF2 HEC-ResSIM Alternatives Assessment": https://ijc.org/en/srsb/hec-res-sim-run-and-evaluate-alternatives
- "DW4 Data Collection for Performance Indicators Souris River Plan of Study": https://ijc.org/en/srsb/data-collection-performance-indicators-report-and-appendices

Section 6 presents the Study Board's overview and evaluation of the final set of possible changes to the 1989 Operating Plan developed to provide improved flood control and water supply benefits to the interests in the Souris River basin.

The activities described in this section directly address the Governments' Reference Items 1 through 10.

6.1 Introduction

The Souris River flow is highly variable and intermittent; the Souris River watershed is typically water scarce. The basin experiences wide climate variability and is occasionally exposed to extreme flooding events. The dams and water control structures on the Souris River are designed and operated to improve water supply and flood protection.

The Souris River is a narrow, shallow channel in a predominantly semi-arid region. Significant portions of the prairie pothole topography within the basin do not contribute inflow into the river. Its dominant hydrological event is snowmelt runoff (which is highly variable from year to year); precipitation contributions from rain runoff into the river are marginal, and often minimal especially in late summer, fall and winter, and particularly so in much of the upper reaches. The river's natural characteristics commonly leave it incapable of sustaining fish or diverse aquatic ecosystems. The Souris River is naturally water scarce, and the dominant climate-driven force is evaporation and evapotranspiration.

The Souris River basin is naturally exposed to frequent periods of water scarcity and drought (which can last from months to years in duration), leaving the river with poor water quality and little to no flow. However, during wet or extremely wet periods, the basin can experience high runoff events which may cause severe or even extreme flooding. The anomalous 2011 spring runoff and summer rain events were the largest on record and caused extensive flooding over the flat prairie topography.

Improving flood protection and water supply management by changing flow releases from the river's constructed reservoirs is constrained by the basin's natural characteristics and by the existing water infrastructure. Although reservoir storage is sufficient to mitigate floods in most years, the finite amount of reservoir storage cannot mitigate extreme flood events like those that occurred in spring and summer of 2011. Nor can the finite amount of reservoir storage augment river flow during extreme periods of water scarcity, particularly when they last for months or years in duration. Furthermore, even if more reservoir storage were available, there would be significant natural resource challenges for storing water (e.g., limited precipitation and runoff, high evaporation, and seepage losses, etc.). Reservoir storage cannot mitigate all flood events, nor can it augment river flow during all drought periods.

6.2 Study approach

As discussed in Section 5, the Study's analysis concluded that, overall, the existing 1989 Agreement with its Operating Plan has performed well in providing flood control and water supply benefits in the Souris River basin. Thus, the development and evaluation of alternative Operating Plan measures focused on the potential benefits of relatively minor modifications or adjustments to the existing Operating Plan at specific times of the year, rather than entirely new Operating Plans.

After a phased series of investigations and the completion of more than 60 sets of simulated hydrological analyses, the most promising suite of options was identified under Phase 5 of the Plan Formulation work. This section describes these options as "alternative measures" (i.e., potential alternatives to the 1989 Agreement).

Through the detailed formulation and evaluation process described in Section 5, the Study identified a set of five alternative measures (as well as several options within those measures) that could be considered as viable alternatives to the operating rules established under the 1989 Agreement. Each has a particular focus aimed at improving flood control and/or water supply benefits in the basin. Table 25 describes the 1989 Operating Rules with Possible Alternative Measures.

Table 25 1989 Operating Rules and Possible Alternative Measures

Operating Rules Established within the 1989 Agreement	Possible Alternative Measures
Winter Drawdown Elevation Targets Reservoirs are drawn down prior to February 1 to meet specified reser-voir elevations	**Winter Drawdown Elevation Targets** Option 1 requires less draw-down than 1989 in most years, with potential for no drawdown in dry years Option 2 requires the same drawdown as 1989 in most years, with potential for greater drawdown in wet years
Winter Drawdown Date February 1 is the target date for winter drawdown of reservoirs	**Winter Drawdown Extension** March 1 is the target date for winter drawdown of reservoirs
Spring Maximum Flow Spring maximum flow rules are specified in the 1989 Agreement	Lower Spring Maximum Flow Spring flow limits are less than what is established in the 1989 Agreement during small to moderate floods

Operating Rules Established within the 1989 Agreement	Possible Alternative Measures
Summer Operating Plan The 1989 Agreement states maximum flow limits of 11 m^3/s (400 ft^3/s) and 14 m^3/s (500 ft^3/s) at Sherwood and Minot, North Dakota, re-spectively; no specific rules are stated when summer flows exceed these amounts	**Summer Operating Plan for small to moderate floods** Option 1 establishes additional flow rules but generally relies on operator discretion during flood events Option 2 establishes additional de-fined flow rules (less operator flexibility than Option 1)
Apportionment from Saskatchewan to North Dakota The 1989 Agreement calculates annual apportionment on a Calendar Year (January to December); reservoir draw-down releases (in excess of Calendar Year apportionment corrections) in November-December are not credited towards annual apportionment obligations	**Apportionment Shift to Water Year (November to October)** Annual apportionment calculations are determined from November to October (i.e., not by Calendar Year); reservoir drawdown releases in November-December are credited towards annual apportion-ment calculations

The alternative measures were evaluated seasonally and are further described below:

1. **Winter Drawdown Elevation Targets** (two options largely affecting reservoir elevations and flows in November and December) to build greater flexibility into reservoir operations by varying reservoir elevation targets according to antecedent moisture conditions in the basin
2. **Winter Drawdown Extension** to March 1 (rather than February 1) to provide additional river flow for improved environmental benefits during February
3. **Lower Spring Maximum Flow Limits** to reduce flood peaks and agricultural flood risk during small to moderate floods in riverine reaches in North Dakota (i.e., floods under 57-85 m^3/s or 2,000 to 3,000 ft^3/s)
4. **Summer Operating Plan** (two options with different flow limits) to help reservoir operators better manage summer reservoir operations under all conditions
5. **Apportionment Shift to a Water Year** (November to October) to change how apportionment is accounted by shifting from a Calendar Year (January to December per the 1989 Agreement) to a Water Year (November 1 to October 31) to ensure flood protection releases in November and December are credited towards apportionment.

Figure 26 presents a graphic overview of this set of alternative measures compared to operations under the existing 1989 Agreement. The figure illustrates the time of year that each alternative measure changes the operation of the reservoir system along with a short description of the alternative measure and current operations under the 1989 Agreement. Note the Apportionment Shift to a Water Year (November to October) is shown below the calendar because the timing of changes to reservoir operations for this alternative measure can vary from year to year.

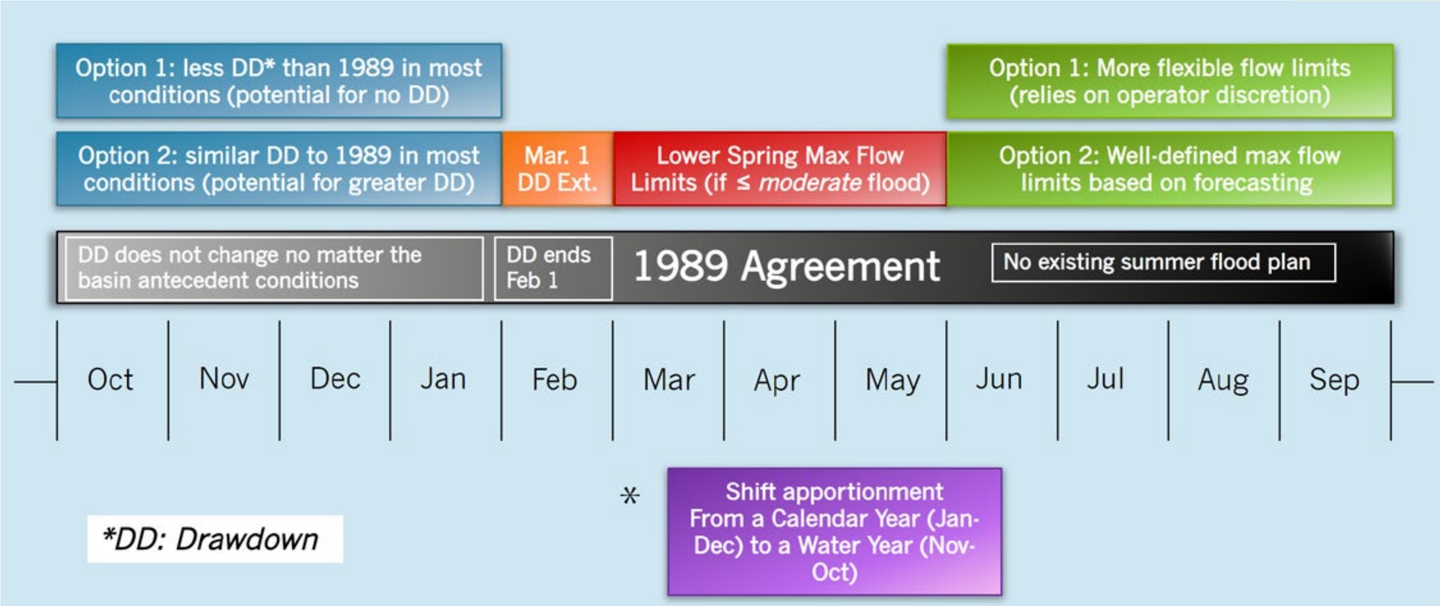

Figure 26 Sequencing and timing of alternative measures compared to operations under the existing 1989 Agreement

The alternatives were evaluated in detail, through a series of workshops with members of the Study Board, the Public Advisory Group (PAG) and the Resource and Agency Advisory Group (RAAG), using the visualization tool described in Section 5.2.3. Input was also received from Indigenous Nations with current and/or ancestral interests in the Souris River basin. Broader public and industry engagement occurred to gather additional input for management of the Souris River.

The Study's in-depth modeling and comparisons included scenarios to evaluate the alternative Operating Plans under a wide range of possible extreme climate conditions and reconstructed streamflow observed from the period of record (88 years). For selected scenarios, additional analysis was completed using extreme events from 10,000 years of stochastically generated streamflow data (i.e., using stochastic hydrology analysis to model a wider range of probable hydrological variables).

The findings presented in this section are based on the extensive modeling and evaluation work of the Study's Plan Formulation technical team. The methodology used by the technical team included statistical analysis of the HEC-ResSim model results, evaluation of performance indicators, and engineering judgement based on in-depth discussions with reservoir operators, diverse stakeholders, Indigenous Nations, and other experienced engineers and hydrologists in the basin.

For each finding, important model results and contextual details are included that support the statement. To gain a more thorough understanding of the benefits and impacts associated with each alternative measure, readers are advised to review the PF2 HEC-ResSIM Alternatives Assessment report and its associated appendices along with the interactive Hydrologic Visualization Tool. These resources are available through the Study's IJC website: www.ijc.org/en/srb.

6.3 Overview of the 1989 Operating Plan

The hydrological research by the Study supports the conclusion that the 1989 Agreement is effective in achieving its intended objectives of flood protection and water supply benefits. Based on the modeling that was completed, only marginal benefits to water supply and flood protection could be identified. This is due to the constraints of the basin's natural characteristics and the river system's existing water infrastructure.

The existing operating rules defined in the 1989 Agreement are summarized as follows:

Normal Drawdown: Rafferty, Grant Devine, and Lake Darling Reservoirs are drawn down over the summer, fall, and winter months such that they are at their normal drawdown elevations by Feb. 1.

Spring Drawdown: Every 15 days, beginning Feb. 1, a spring runoff forecast is conducted. If necessary, the reservoirs are drawn down below the normal Feb. 1 drawdown elevation to contain the spring runoff volume. The magnitude of each reservoir's spring drawdown depends on the reservoir's forecasted inflow volume and is determined using Plates A-1 through A-4 in Annex A of the 1989 Agreement.

Full Supply Level: When the reservoirs are not being drawn down, they are operated to maintain Full Supply Level (FSL), to the extent possible while releasing water for downstream needs and meeting apportionment.

Maximum Flow Limits: In the spring, if a flood is declared, the maximum allowable flows at Sherwood and Minot, North Dakota, are set based on the forecasted, 30-day unregulated volume at Sherwood using Plates A-5 and A-6 in Annex A. After Lake Darling's Reservoir pool has fallen below 487.1 m (1598 ft) and the flow at Minot has fallen below 14 m^3/s (500 ft^3/s), the maximum allowable flow at Sherwood is reduced to 11 m^3/s (400 ft^3/s), and the maximum allowable flow at Minot is reduced to 14 m^3/s (500 ft^3/s) for the remainder of the summer.

Minimum Flow Limits: A minimum flow of 0.113 m^3/s (4 ft^3/s) must be maintained at Sherwood, North Dakota, whenever such a flow would have naturally occurred without the reservoir system in place.

Apportionment: Each year, Saskatchewan must pass either 40 percent of the flow, when natural flows at Sherwood, North Dakota, are greater than 50,000 dam^3 (40,500 acre-feet) or 50 percent when flows are below this threshold, to the State of North Dakota, as described in Annex B. All apportionment computations are made according to Calendar Year (Jan. 1 to Dec. 31).

Minimum flows from Saskatchewan to North Dakota: The Agreement also states that Saskatchewan release minimum flows if occurring "in a state of nature" and "so far as is practicable," at not less than 0.113 m^3/s (4 ft^3/s) at Sherwood Crossing, described in Annex B.[19]

[19] See Annex B (Year 2000 amendment to the 1989 Agreement) in the **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** (Annex A and B are in the report Appendices): https://www.ijc.org/sites/default/files/Souris%20River%20Basin%20Plan%20of%20Study.pdf

Minimum flows from North Dakota to Manitoba: While originally not part of the 1989 Agreement, an apportionment agreement exists for minimum flows between North Dakota and Manitoba. The current *Agreement*[20] states that, except "during periods of severe drought" North Dakota shall deliver to Manitoba during June to October of each year a volume of 6,069 acre-feet (7,486 dam^3) "of water at the Westhope Crossing regulated so far as practicable at the rate of twenty (20) cubic feet per second" (0.57 m^3/s).

In summary, the 1989 Agreement is deemed to be very effective for flood protection and water supply. Yet, while considering the Souris River basin's constraints of its natural ecology and human-built water infrastructure, improvements in flow operations are possible.

The set of Phase 5 options described in this section as alternative measures will potentially provide incremental benefits. Five alternative measures are identified and compared to the 1989 Agreement. These alternative measures should be considered to maximize operational performance, and to address Indigenous Nations and diverse stakeholders' interests in attaining improvements, even if they are marginal in scale and/or scope.

6.4 Alternative Measure 1: Winter Drawdown Targets – Options 1 and 2

6.4.1 INTRODUCTION

The 1989 Agreement reservoir drawdown is designed to achieve specified target elevations by Feb. 1 (no adjustment is made for basin conditions). This alternative measure changes the reservoir drawdown elevations to manage elevation targets based on the basin's soil moisture conditions in fall and early winter. Figure 27 shows the seasonal change for the timing of Alternative Measure 1.

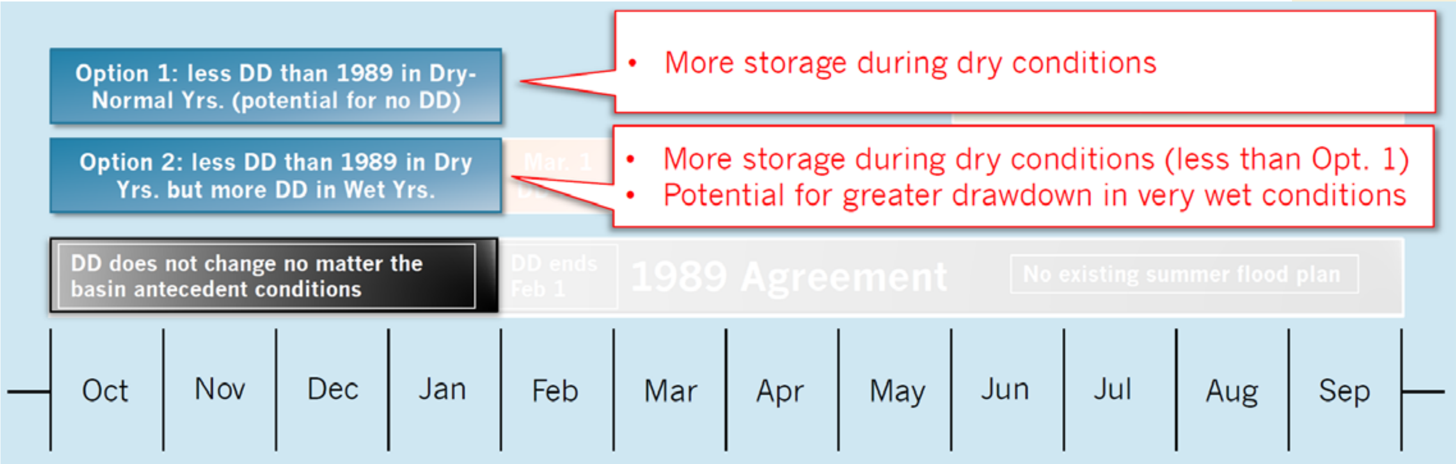

Figure 27 Alternative Measure 1 – Winter Drawdown Target Options:

[20] See International Souris River Board Mandate: https://ijc.org/en/srb/who/mandate. The minimum flow rules were established in the ***1959 Interim Measures***. The most current version is the **December 2000 Amendment to the Agreement Between Canada and the United States for the Water Supply and Flood Control of the Souris River Basin**.

6.4.2 OBJECTIVES OF THIS CHANGE IN OPERATIONS

Two operating measure options seek to build greater flexibility into reservoir operations by varying reservoir elevation targets according to antecedent moisture conditions in the basin.

Under the 1989 Agreement, each reservoir must be at or below a specific pool elevation by Feb. 1. These pool elevation targets do not change from year to year.

The options would allow the Feb. 1 elevations to vary according to whether watershed conditions are classified as "Dry", "Normal", or "Wet". Figure 28 depicts the reservoir levels for the two options and the 1989 Agreement.

Under Option 1, the Feb. 1 elevation targets are higher than what is specified by the 1989 Agreement during Dry and Normal years. During Wet years, the February 1st targets are equivalent to what is specified in the 1989 Agreement. Since the February 1st targets are higher than what is currently required during dry and normal years, Option 1 is deemed to be focused on water supply benefits.

Under Option 2, the Feb.1 elevation targets are higher than what is specified by the 1989 agreement during Dry years, equal to the 1989 Agreement during Normal years, and lower than the 1989 Agreement during Wet years. The Feb. 1 elevation targets in Option 2 are lower than the current requirements during Wet years and lower than Option 1 in all years; Option 2 is deemed to be focused on flood control (for some river reaches), and fish and wildlife benefits.

6.4.3 SUMMARY OF FINDINGS FOR THIS CHANGE

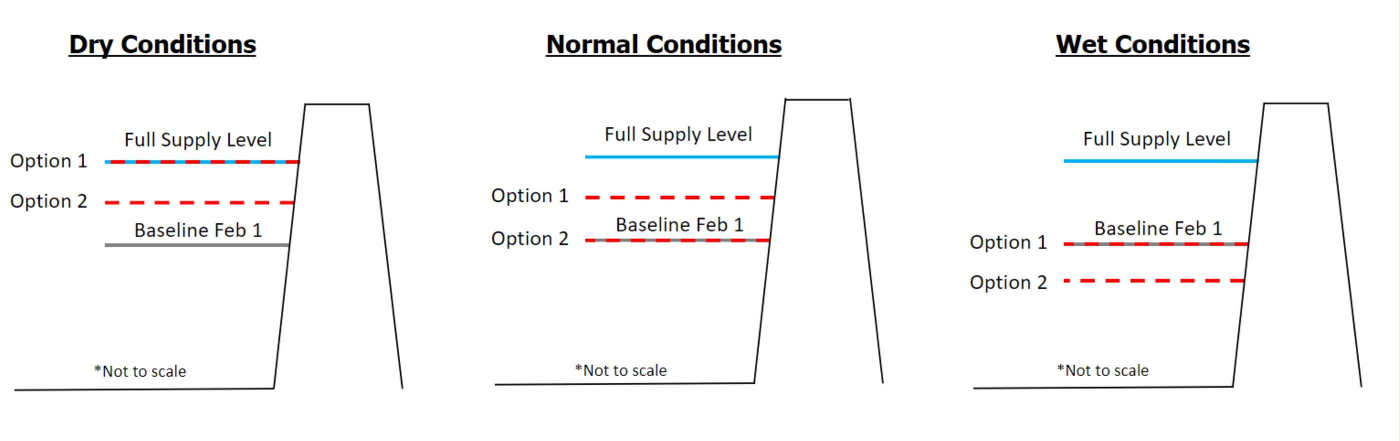

Figure 28 Winter options for adjusting reservoir levels based on antecedent basin conditions

Option 1

How is this change beneficial compared to the 1989 Agreement?

- Winter drawdown targets are based on antecedent soil moisture conditions in the basin, improving operations by adjusting for Dry, Normal, or Wet conditions
    - PAG and RAAG members expressed interest in more flexibility to manage for basin conditions, increasing winter releases when conditions are wet and decreasing releases when conditions are dry
    - PAG and Indigenous Nations expressed interest in mimicking the natural hydrograph in all alternatives (where possible)
- Allows the reservoirs to hold more water over the winter when conditions are dry or normal; this benefits water supply at the reservoirs
    - Model simulations showed average pool increases at Rafferty, Grant Devine, and Lake Darling Reservoirs of 0.32 m (1.1 ft), 0.26 m (0.8 ft), 0.09 m (0.3 ft), respectively
    - Model simulations showed Rafferty, Grant Devine, and Lake Darling Reservoirs remained higher than they would have under 1989 Agreement conditions in nine out of 88, 13 out of 88, and five out of 88 years, respectively
    - Allows for a more natural hydrograph
      – Lower flows over the winter months more closely mimic natural flow conditions

What is negatively impacted by this change?

- In most years, lower flows occur during winter (November-January) than currently established by the 1989 Agreement
    - Model simulations showed average winter flow (Nov-Jan) at Sherwood of 1.3 m^3/s (47 ft^3/s) under Option 1 and 1.6 m^3/s (57 ft^3/s) under the 1989 Agreement
    - Model simulations showed average winter flow (Nov-Jan) at Westhope of 1.0 m^3/s (35 ft^3/s) under Option 1 and 1.4 m^3/s (48 ft^3/s) under the 1989 Agreement
- The winter drawdown target selected in November-December may not provide optimal flood risk reduction during the spring if basin conditions change significantly over the winter months
    - Model simulations showed average flow for Feb. 1 - March 15 at Sherwood of 15.8 m^3/s (558 ft^3/s) under Option 1 and 13.2 m^3/s (477 ft^3/s) under the 1989 Agreement
    - Model simulations showed average flow for Feb. 1 – March 15 at Minot of 18.3 m^3/s (645 ft^3/s) under Option 1 and 15.3 m^3/s (540 ft^3/s) under the 1989 Agreement

How can the negative impacts of this change be mitigated?

- There is no clear path for mitigating negative impacts related to lower winter flows. Under the 1989 Agreement, winter flows are likely higher than necessary to accomplish the objectives of the Agreement
    - Flows from winter drawdowns are often higher than necessary to support channel maintenance activities and natural fish habitat. Model simulations show a number of years where winter flow was reduced, but spring flood risk management objectives were still achieved
- The winter drawdown targets should be reevaluated on some earlier dates/frequency prior to Feb. 1, accounting for basin conditions, precipitation, weather, and snowpack
    - If basin conditions change over winter (e.g., dry fall conditions but heavy snowpack and deep frost depths) spring flood risk could be lowered if winter drawdown targets were allowed to change accordingly

Option 2

How is this change beneficial compared to the 1989 Agreement?

- Winter drawdown targets are based on antecedent soil moisture conditions in the basin, improving operations by adjusting for Dry, Normal, or Wet conditions
    - PAG and RAAG members expressed interest in more flexibility to manage for basin conditions, increasing winter releases when conditions are wet and decreasing releases when conditions are dry
    - PAG and Indigenous Nations expressed interest in mimicking the natural hydrograph in all alternatives (where possible)
- Allows the reservoirs to hold slightly more water over the winter when conditions are dry; this can benefit water supply at the reservoirs
    - Model simulations showed average pool increase at Rafferty, Grant Devine, and Lake Darling Reservoirs of 0.01 m (0.03 ft), 0.09 m (0.3 ft), 0.07 m (0.2 ft) compared to the 1989 Agreement, respectively
    - Model simulations showed Rafferty, Grant Devine, and Lake Darling Reservoirs remained higher than they would have under 1989 Agreement conditions in three out of 88, eight out of 88, and three out of 88 years, respectively
- Requires the reservoirs to be drawn down below the target specified in the 1989 Agreement when conditions are wet; this may decrease flood risk associated with a pre-flood, spring drawdown
    - Model simulations showed, during flood years, average flow at Sherwood and Minot during the model's spring drawdown period (Feb. 1 - March 15) decreased by approximately 4 percent under Option 2

What is negatively impacted by this change?

- In dry years, lower flows would occur during winter (November-January) than are currently established by the 1989 Agreement
    - While average winter flows under Option 2 are generally comparable to winter flows under the 1989 Agreement, visual inspection of the model results indicates lower flows could occur in dry years
- Increased risk to water supply at the reservoirs if basin conditions are wet in the fall but significant runoff does not occur in the spring
    - Model simulations showed Rafferty, Grant Devine, and Lake Darling Reservoirs did not recover to the same elevation as the 1989 Agreement simulation following a "wet" winter drawdown in four out of 88 years[21]

How can the negative impacts of this change be mitigated?

- There is no clear path for mitigating negative impacts related to lower winter flows. Under the 1989 Agreement, winter flows are likely higher than necessary to accomplish the objectives of the Agreement
    - Flows from winter drawdowns are often higher than necessary to support channel maintenance activities and natural fish habitat. Model simulations show a number of years where winter flow was reduced, but spring flood risk management objectives were still achieved
- The winter drawdown targets should be reevaluated on some earlier dates/ frequency prior to Feb. 1, accounting for basin conditions, precipitation, weather, and snowpack. To reduce risk to water supply, the reservoirs should not be drawn down below the targets specified in the 1989 Agreement unless significant precipitation/snowfall occurs over the winter and significant spring runoff is likely
    - It is not clear exactly what the protocol and methodology should be for determining when basin conditions are such that significant spring runoff should be considered "likely." However, it is important the decision be made using the best available tools with cooperation of the reservoir operators and forecasting agencies

[21] For additional context to understand how options affect water supply security in Saskatchewan: The baseline modeled simulations for Rafferty showed 25 years of intentional winter drawdown, with 13 of those years failing to fill with the successive year's spring freshet. Option 1 had 20 years of drawdown with nine years failing to fill from the next year's spring freshet. Option 2 had 24 years of drawdown with 15 years failing to fill from next year's spring freshet. There is also a risk that reservoirs will not recover from additional drawdowns. For example, in 2012 the reservoirs did not recover after 2011's severe spring and summer flooding (i.e., the subsequent year after the wettest year on record).

Conclusions

Both options use antecedent soil moisture conditions in the basin to determine winter drawdown elevation targets based on dry, normal, or wet basin conditions. In both, the reservoirs are not required to be drawn down as far over the winter when conditions are dry. This improves water supply at the reservoirs but reduces river flow during the winter, which could negatively affect fish habitat and water quality in the river (this is actually closer to the river's natural state which is low flow to no flow in winter months).

Under Option 1, reservoir water supply benefits are greatest, although winter flows are also the lowest of the three considerations: Option 1, Option 2, and 1989 Agreement. Under Option 2, reservoir water supply benefits are smaller, and winter flows are similar to what they would be under the 1989 Agreement. Under Option 2 (during wet years), there is also some water supply risk of drawing down the reservoirs further than what is required by the 1989 Agreement, as there is a risk of not receiving adequate runoff in the spring. This risk could be lowered somewhat by revisiting the drawdown targets throughout the winter and not performing the full drawdown unless snowpack suggests high spring runoff. However, mitigation of this risk is limited, as spring runoff forecasts are difficult to accurately estimate during winter months.

Bottom Line: *While flow during the winter months has potential to increase water quality and improve fish habitat, it is not clear that the winter flows resulting from the 1989 Agreement are optimal. While no data has been collected to quantify the "optimum" winter flow to support fish habitat and mitigate spring ice impacts, there is evidence that suggests lower winter flows than those required by the 1989 Agreement would not have significant environmental impacts or affect spring flood risk management.*

If lower winter flows than are currently prescribed by the 1989 Agreement are considered acceptable, Option 1 is likely favorable, as it provides the most water supply benefit. If maintaining the winter flows established under the 1989 Agreement is a high priority, Option 2 largely achieves this while still offering some water supply benefits during dry years.

6.5 Alternative Measure 2: Winter Drawdown Extension to March 1

6.5.1 OBJECTIVES OF THIS CHANGE IN OPERATIONS

This alternative measure seeks to increase flows in the river during the month of February, when the reservoirs are above their normal drawdown levels, to provide improved environmental benefits and reduce the risks to infrastructure and property from ice jams.

Under the 1989 Agreement, each reservoir must be at or below a specific pool elevation by Feb. 1. After this date, flood forecasting begins, and the reservoirs may be drawn down further if a significant flood is forecasted.

The proposed operational measure shifts the normal drawdown target date from Feb.1 to March 1. The date flood forecasting begins (Feb. 1) would not change. For context, winter drawdowns occurred in approximately 50 percent of years in the historical record. Figure 29 shows the seasonal change for the timing of Alternative Measure 2.

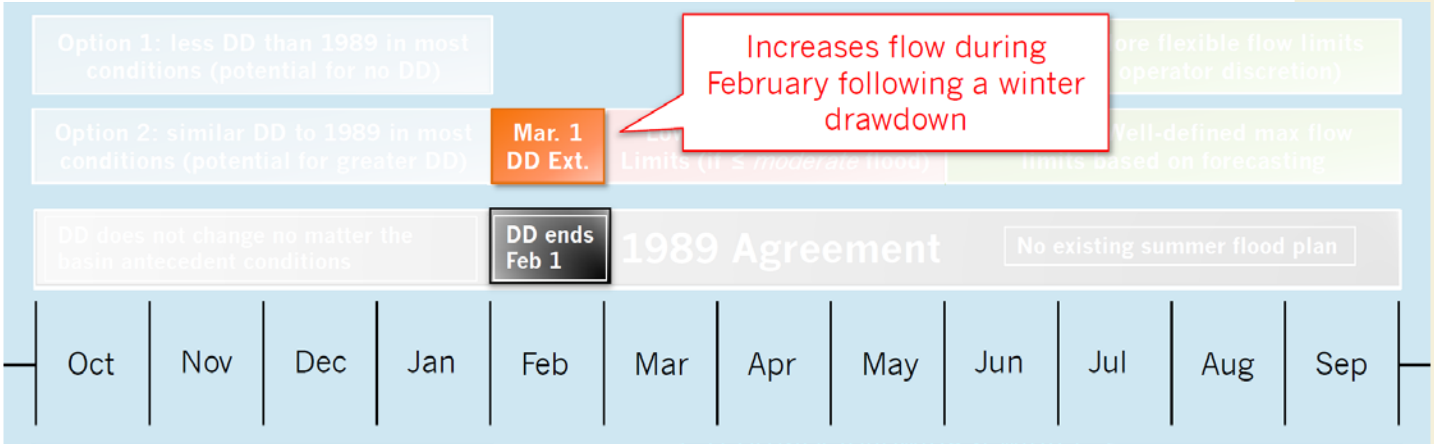

Figure 29 Alternative Measure 2 – Winter Drawdown Extension to March 1

6.5.2 SUMMARY OF FINDINGS OF THIS CHANGE

Figure 30 provides an example of how the March 1 extension changes the Lake Darling Outflow in comparison to the 1989 Agreement Baseline.

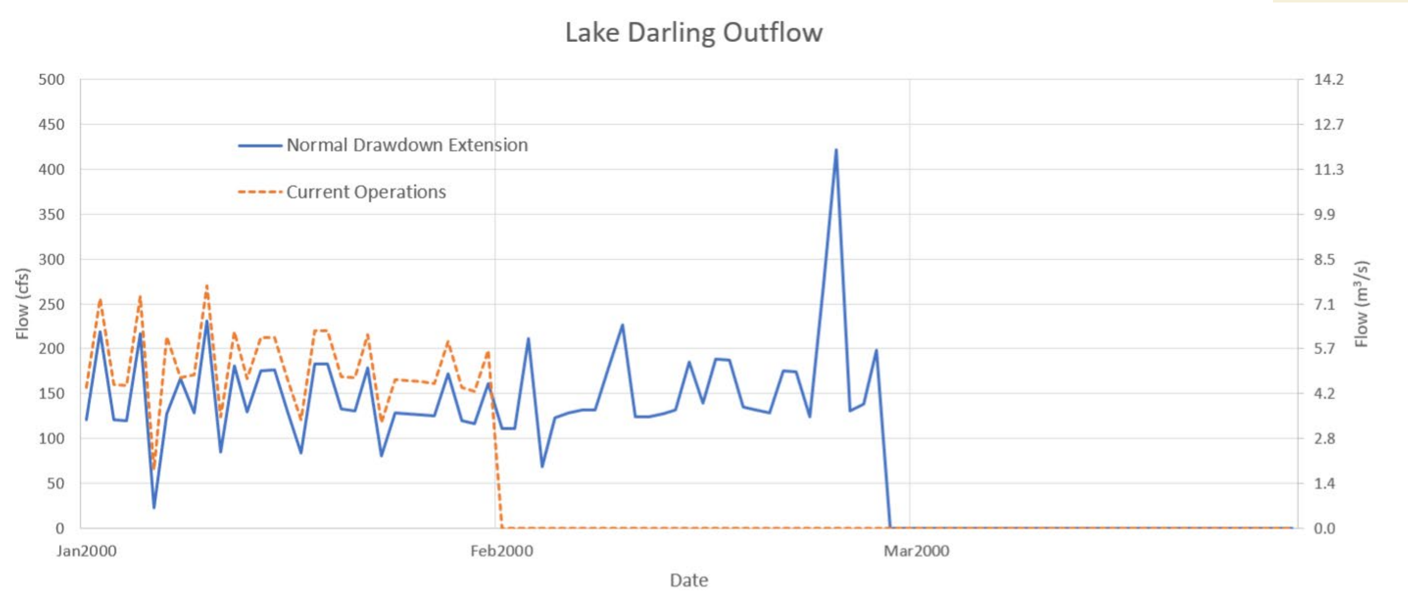

Figure 30 Example of how the March 1 drawdown extension changes the Lake Darling Outflow

How is this change beneficial compared to the 1989 Agreement?

- Improves water quality in February
    - Water quality performance indicators at Sherwood and Westhope showed improvement when the winter drawdown was extended to March 1
- Improves fish habitat in February
    - Fish habitat/mortality performance indicators showed improvement in Saskatchewan, North Dakota, and Manitoba when the winter drawdown was extended to March 1
- May reduce ice jams in February and March
    - By maintaining flow in February more often, there is a lower likelihood of ice forming in the channel. During some recent flood events, channel ice has been exacerbated during early spring flooding
- Assists in managing releases for apportionment purposes
    - By extending the winter drawdown to March 1, a larger percentage of drawdown releases will occur after Jan. 1 and will be counted towards Saskatchewan's apportionment obligation to North Dakota (as the apportionment year is currently defined)
    - The apportionment volume delivered to North Dakota does not change

What is negatively impacted by this change?

- May increase risk of higher flows during a spring drawdown
    - Modeling simulations showed a 7-9 percent increase in spring drawdown flow in three out of 22 flood years

How can the negative impacts of this change be mitigated?

- The extension of the drawdown from Feb. 1 to March 1 should be reevaluated prior to Feb. 1. If a large flood is imminent, the drawdown date should revert to Feb. 1 (as per the 1989 Agreement). This approach would reduce the negative risks associated with the March 1 extension to almost zero.
    - The three flood years that showed an increase in flow during the spring drawdown period during the alternative simulation were three of the largest flood years on record. It is assumed these floods could be forecasted with some certainty during the winter months, and operators would not extend the winter drawdown to March 1 if the forecasting agencies saw potential for a very large spring flood event
- The forecasting agencies (National Weather Service, Water Security Agency) should be responsible for reevaluating basin conditions over the winter in coordination with the reservoir operators.

Conclusions

The drawdown date in the 1989 Agreement ensures the reservoirs are at their normal drawdown targets by Feb. 1. However, in many years, the lack of releases during February leads to poor water quality and fish habitat during February. By extending the drawdown date to March 1, flow is maintained in the river during February in many years, benefiting water quality and fish habitat. The negative impacts associated with this change are minimal and can be mitigated.

6.6 Alternative Measure 3: Lower Spring Maximum Flow Limits

6.6.1 OBJECTIVES OF THIS CHANGE IN OPERATIONS

This alternative Operating Plan measure seeks to reduce flood peaks downstream of Minot during small to moderate flood events, while slightly increasing reservoir levels during those years.

While the maximum flow limits prescribed by the 1989 Agreement reduce flood risk during the spring period, the maximum flow limits at Minot, North Dakota, are slightly higher than bankfull capacity throughout some reaches in North Dakota. This can result in flooding of agricultural lands and damage productivity.

Under the 1989 Agreement, maximum flow limits are set at Sherwood and Minot, North Dakota, during the spring, based on forecasted runoff. This alternative measure consists of lowering the spring maximum flow limits at these locations when the forecasted flood is considered "moderate" or smaller. Figure 31 shows the seasonal change for the timing for Alternative Measure 3.

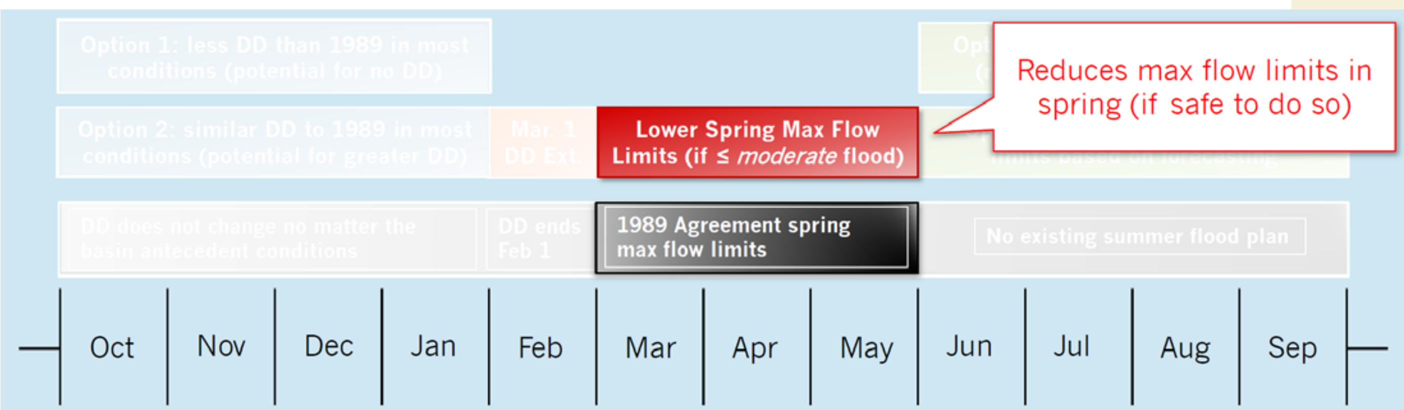

Figure 31 Alternative Measure 3 – Lower Spring Maximum Flow Limits

In the historical record, small to moderate flood events have occurred in about 15 percent of years. This represents about half of all years in which a "flood year" would have been declared by the ISRB. Floods classified as "small to moderate" have historically resulted in peak flows of approximately 57-85 m^3/s (2,000-3,000 ft^3/s) at Minot, North Dakota.

The lower maximum flow limits adopted under this alternative measure were suggested by the North Dakota Souris River Joint Board after a number of public engagement meetings with farmers in North Dakota.

6.6.2 SUMMARY OF FINDINGS FOR THIS CHANGE

How is this change beneficial compared to the 1989 Agreement?

- Decreases flooding from small to moderate floods in the majority of rural reaches of the Souris River during May
    - In most rural reaches, the agricultural damages performance indicator showed improvement during small to moderate flood years. The magnitude of improvement varied by reach and was most significant near Verendrye, North Dakota
- Decreases flood risk during small to moderate floods in the range of 57-85 m^3/s (2,000 3,000 ft^3/s) at Minot, North Dakota
    - Occurs approximately 11 out of 22 of flood years; in total, this change affects river flows in 13 out of 88 years
- There is no change to the amount of water delivered to Manitoba
    - Lowering spring maximum flow limits does not increase or decrease the total volume of water that is delivered to Manitoba over the course of the year

What is negatively impacted by this change?

- May infrequently increase risk of reaching Maximum Allowable Flood Level at Lake Darling Reservoir if a late spring flood on the Souris River occurs at the same time as a late spring flood on the Des Lacs River
    - In modeling simulations, this occurred in two out of 88 years
- Reservoirs must spend more time above FSL in the spring
    - In modeling simulations, reservoirs rose an average of 0.08 m (0.25 ft) at Rafferty, 0.3 m (1 ft) at Grant Devine, and 0.3 m (1 ft) at Lake Darling relative to the 1989 Agreement.
- May infrequently increase the duration of out of bank flooding in areas of North Dakota and Manitoba with very low ($\leq$ 17 m^3/s or 600 ft^3/s) bankfull capacity
    - In modeling simulations, this occurred in three to seven out of 88 years
- Storage used for smaller floods may not be available for larger floods
    - In general, whenever the pool elevation of a reservoir increases, the amount of storage available in the reservoir decreases
    - There may be increased risks if large floods occur with less available reservoir storage capacity

- This may be a less natural hydrograph than what is desired in the 1989 agreement (Annex B)
    - To reduce flood peaks, water must be stored at the reservoir and released over a longer period of time. This leads to flow in the river for a longer duration than would have occurred naturally

How can the negative impacts of this change be mitigated?

- To mitigate the risk of reaching Maximum Allowable Flood Level at Lake Darling Reservoir, lower maximum flow limits should not be pursued until either the flood peak on the Souris River has passed through Lake Darling or the flood peak on the Des Lacs River has passed through Minot
    - Model simulations showed during small to moderate flood events, when the timing of the flood peak into Lake Darling and the flood peak on the Des Lacs River did not coincide, Lake Darling did not reach Maximum Allowable Flood Level
- At Rafferty and Grant Devine Reservoirs, the higher reservoir elevations that result from lower maximum flow limits do not approach Maximum Allowable Flood Level in the years modeled:
    - Model simulations did not show Rafferty or Grant Devine reaching Maximum Allowable Flood Level due to lower spring maximum flow limits (zero out of 88 years)
    - To better understand the trade-offs of using reservoir storage for smaller floods, additional risk analyses would be required
- There is no clear path for mitigating negative impacts related to increased duration of out of bank flows in areas with very low bankfull capacity other than river channel modifications
    - Bankfull capacity of the Souris River decreases in some downstream reaches; reservoir operations that decrease peak flow can reduce the duration of flooding in upstream reaches but increase the duration of flooding in downstream reaches. This is a trade-off.

Conclusions

While the maximum flow limits prescribed by the 1989 Agreement reduce flood risk during the spring period, the maximum flow limits at Minot are slightly higher than bankfull capacity throughout a large reach of North Dakota. This can result in flooding of agricultural lands and damage productivity. This proposed change would reduce negative impacts of flooding from small to moderate floods downstream of Minot.

6.7 Alternative Measure 4: Summer Operations - Options 1 and 2

6.7.1 OBJECTIVES OF THIS CHANGE IN OPERATIONS

The two summer operating options seek to help reservoir operators better manage summer operations under all conditions and balance flood risk reduction in riverine reaches with flood risk reduction at the reservoirs. Figure 32 shows the seasonal change of timing for Alternative Measure 4.

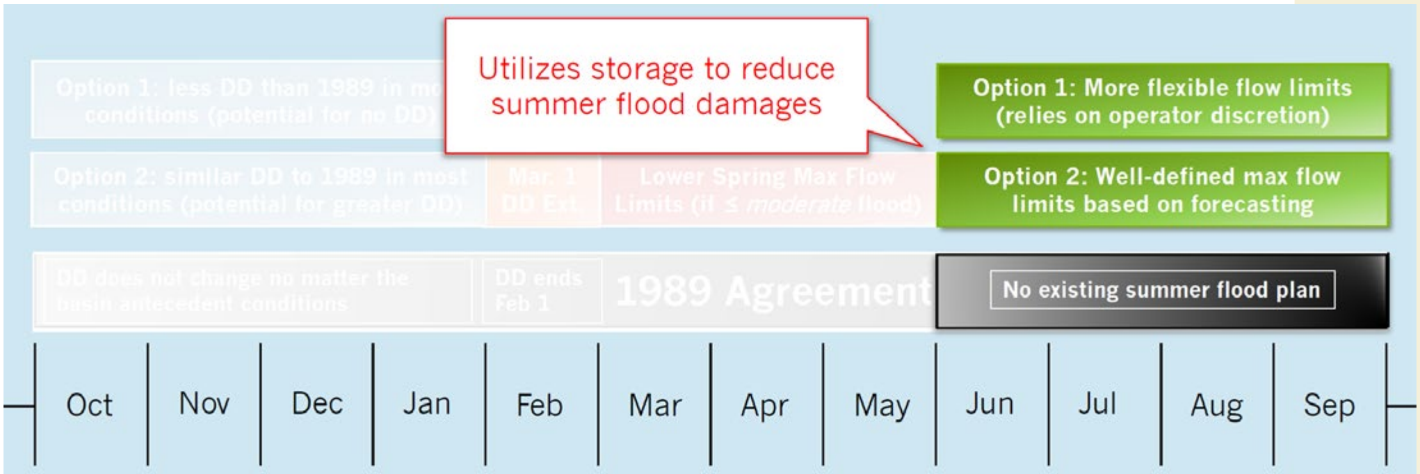

Figure 32 Alternative Measure 4 - Summer Operations Options

The 1989 Agreement requires maximum flow limits of 11 m^3/s (400 ft^3/s) and 14 m^3/s (500 ft^3/s) at Sherwood and Minot, North Dakota, respectively, during the summer months. However, there are no specific operating rules specifying reservoir operations during summer flood events when those maximum flow limits cannot be reasonably maintained. With no detailed summer operating plan, reservoir operators typically use forecasting tools to determine whether to use storage in the reservoir to limit downstream flood damages or make larger releases to decrease the risk of the reservoir reaching Maximum Allowable Flood Level. If the operators decide to use storage to limit downstream flood damages, then they typically try to keep flows in the river below specific flooding thresholds.

Under both options, reservoir operators would use approximately 20 percent of reservoir storage above Full Supply Level to maintain maximum flow limits of 4.5 m^3/s (160 ft^3/s) and 5.7 m^3/s (200 ft^3/s) at Sherwood and Minot, North Dakota, respectively, during the summer months. Both plans would also allow flows to gradually increase as the reservoir pools rise above approximately 20 percent of storage during a flood event. The two options differ in how quickly reservoir operators are allowed to increase releases to a state where inflow equals outflow.

Under Option 1, summer flows are largely determined by the upstream reservoir operator and reservoir operators are given more flexibility to increase releases during a flood event.

Under Option 2, maximum flow limits are strictly defined, and reservoir operators are given less flexibility to increase releases during a flood event.

6.7.2 SUMMARY OF FINDINGS FOR THIS CHANGE

Option 1

How is this change beneficial compared to the 1989 Agreement?

- Provides a more robust summer operating plan to manage summer flood events; summer operations currently described in the 1989 Agreement do not adequately manage summer floods that experience flows greater than 11 m^3/s (400 ft^3/s) at Sherwood and 14 m^3/s (500 ft^3/s) at Minot
    - The operating rules in the 1989 Agreement lack specificity when the summer maximum flow limits cannot be met, nor contained within natural channel capacities in some reaches
- The proposed summer plan can be used under all conditions and trades/balances flood risk reduction in riverine reaches with flood risk reduction at the reservoirs
    - The proposed plan values the positive benefits of downstream flood protection while accepting some negative impacts (trade-offs) associated with reservoir pool elevations above Full Supply Level during the summer months (e.g., flooding of habitat, boat ramps, oil wells, and archaeological sites, as well as reduced storage capacity for large flood events)

What is negatively impacted by this change?

- In most cases, reservoir operators are not required to prioritize downstream flood risk management during a summer flood event, leaving agricultural lands at risk of flooding
    - After the reservoirs have used approximately 20 percent of storage above Full Supply Level, maximum flow limits greatly increase
- Discharges from the Canadian reservoirs to the U.S., Lake Darling, and downstream areas could be higher than flow limits established under the 1989 Agreement under some conditions
    - In the 1989 Agreement, maximum flow limits were defined as 11 m^3/s (400 ft^3/s) at Sherwood and 14 m^3/s (500 ft^3/s) at Minot. Under the proposed plan, maximum flow limits can be increased above those limits after the reservoirs have used approximately 20 percent of storage above Full Supply Level

How can the negative impacts of this change be mitigated?

- Generally, reservoir operators attempt to reduce downstream flood damages when feasible. Option 1 provides operators more flexibility than Option 2
    - When operating to reduce flood damages, reservoir operators typically attempt to keep releases below thresholds known to cause flood impacts and do not discharge water at a higher rate than what is entering the reservoir

Option 2

How is this change beneficial compared to the 1989 Agreement?

- Provides a more robust summer operating plan to manage summer flood events; summer operations currently described in the 1989 Agreement do not adequately manage summer floods that require flows greater than 11 m^3/s (400 ft^3/s) at Sherwood and 14 m^3/s (500 ft^3/s) at Minot
    - The operating rules in the 1989 Agreement lack specificity when the summer maximum flow limits cannot be met for managing summer flood events
- The proposed summer plan can be used under all conditions and trades/balances flood risk reduction in riverine reaches with flood risk reduction at the reservoirs
    - The proposed plan values the positive benefits of downstream flood protection while accepting some negative impacts (trade-offs) associated with reservoir pool elevations above Full Supply Level during the summer months (e.g., flooding of habitat, boat ramps, oil wells, and archaeological sites, as well as reduced storage capacity for large flood events)

What is negatively impacted by this change?

- There is a risk Option 2 may delay reservoir releases that may be needed to properly manage large summer flood events
    - If a large flood is imminent, it may be more efficient to increase releases from the reservoir at the beginning of the flood event to avoid releasing a much higher amount during the peak of the flood event. If maximum flow limits are strictly defined based on current pool elevations, operators may not be allowed to increase releases at the beginning of a flood event
- Discharges from the Canadian reservoirs to the U.S., Lake Darling, and downstream areas could be higher than flow limits established under the 1989 Agreement under some conditions
    - In the 1989 Agreement, maximum flow limits were defined as 11 m^3/s (400 ft^3/s) at Sherwood and 14 m^3/s (500 ft^3/s) at Minot. Under the proposed plan, maximum flow limits can be increased above those limits after the reservoirs have used approximately 20 percent of storage above Full Supply Level

How can the negative impacts of this change be mitigated?

- The summer operating plan can use flood forecasting to mitigate the loss of reservoir storage during a large summer flood event
    - If summer maximum flow limits are allowed to increase in response to a forecasted flood, operators can make flow releases at the beginning of the flood event to reduce the need to release larger flows during the peak of the flood event

Conclusions

With no detailed summer operating plan, a reservoir operator would use forecasting tools to determine whether to use storage in the reservoir to limit downstream flood damages or make larger releases to decrease the risk of the reservoir reaching Maximum Allowable Flood Level. If the operator decided to use storage to limit downstream flood damages, they would try to keep flow in the river below specific thresholds that are known to cause flooding.

Under Option 1, reservoir operators would likely use forecasting tools to reduce flood damages from summer events, if possible, although they would not be required to do so unless the reservoir was near Full Supply Level. Since maximum flow limits are higher under Option 1 than Option 2, operators have more flexibility to make larger releases and therefore minimize the risk of the reservoir rising to Maximum Allowable Flood Level. Under Option 2, the agreement would prescribe that the reservoir operators use forecasting tools to reduce flood damages from summer events when possible. However, the agreement would also allow the operators to increase releases in advance of large flood events if warranted to limit the risk of rising to Maximum Allowable Flood Level.

Bottom Line: *In practice, both options will likely result in similar reservoir operations. Option 1 gives the operators the most flexibility but puts them at higher risk of negative public perception when flooding occurs. Option 2 takes some flexibility away from the operators but is likely to have higher public support.*

6.8 Alternative Measure 5: Apportionment Shift from Calendar Year (January to December) to a Water Year[22] (November to October)

6.8.1 OBJECTIVES OF THIS CHANGE IN OPERATIONS

Annual apportionment percentages for water sharing from Saskatchewan to North Dakota were stated in the 1989 Agreement. However, the period for their calculation was not clearly defined. In an amendment in December 2000, Annex B of the Agreement clarified that any reference to “annual” or “year” in the Agreement was understood to mean the period from Jan. 1 to Dec. 31. Hence, apportionment calculations currently are calculated on a Calendar-Year basis.

Annex A and B establish minimum apportionment conditions based on 50 and 40 percent of annual natural flow as measured at the Sherwood, North Dakota crossing. The first 50,000 decameters^3 (40,400 acre-feet) are to be delivered “so far as is practicable” between Jan. 1 and May 31 to ensure North Dakota receives 50 percent of the rate and volume of flow that would have occurred in a state of nature.

[22] The alternative measures labeled in this Study for apportionment calculations by Water Year begin Nov. 1 and extend to Oct. 31. The 1989 Agreement is based on apportionment calculations by Calendar Year (Jan. 1 to Dec. 31). The Study’s term of Water Year (Nov. 1 – Oct. 31) was selected to adjust for flows during November and December and is different than the 1989 Agreement’s definition of Water Year (Oct. 1 to Sept. 30).

In general (except in flood years), the timing of flow releases is also to follow a "pattern which would have occurred in a state of nature" and to the extent possible, to "coincide with periods of beneficial use in North Dakota." The Agreement also states that Saskatchewan release minimum flows if occurring "in a state of nature" and "so far as is practicable", at not less than 0.113 m^3/s (4 ft^3/s) at Sherwood Crossing (Annex B).

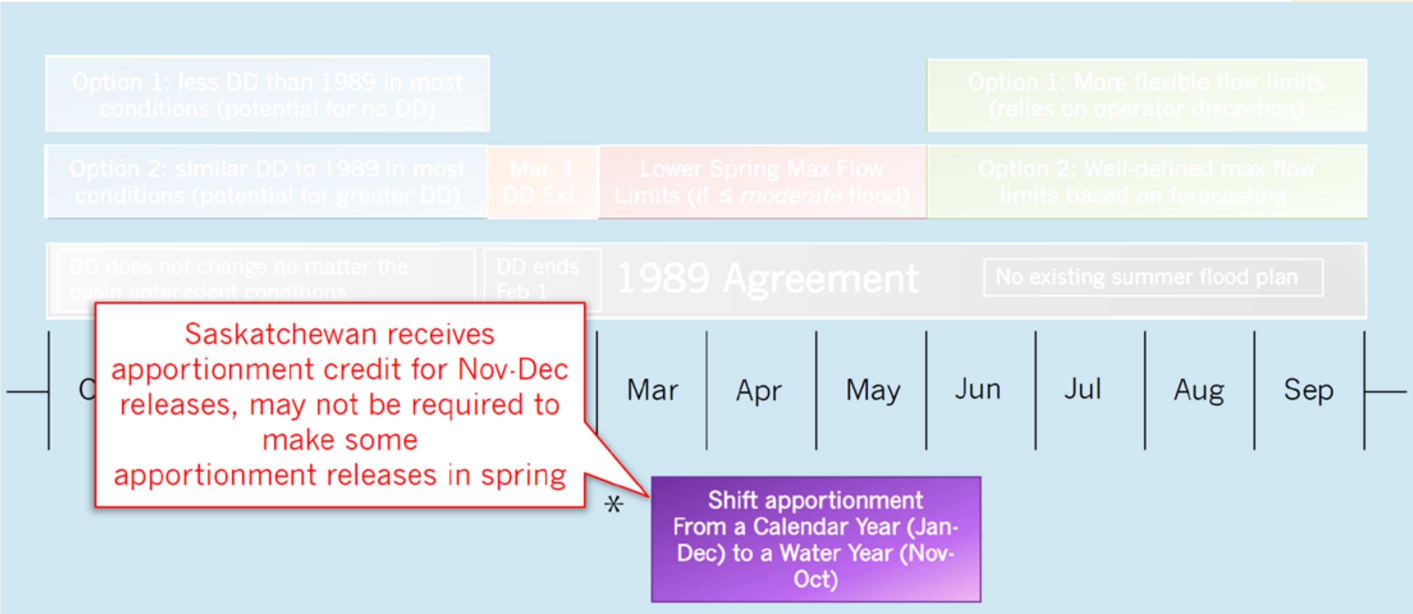

Figure 33 Alternative Measure 5 Apportionment Shift: Changes the calculation of apportionment from a Calendar Year (January to December) to Water Year (November to October)

This alternative measure (Figure 33) shifts the apportionment year determination from a Calendar Year to a Water Year (November to October); the proposed change ensures releases in November and December are included in the apportionment calculation, aligning the apportionment year calculations with the system's operating year[23].

6.8.2 SUMMARY OF FINDINGS FOR THIS CHANGE

How is this change beneficial compared to the 1989 Agreement?

- Saskatchewan receives apportionment credit for all water released over all winter months (including November-December) to support flood operations in the spring

[23] Under the current 1989 Agreement, reservoir drawdowns and releases during Nov-Dec that are in excess of current year apportionment corrections, are not included in the Calendar Year's apportionment calculations. In some wetter years, releases beyond apportionment corrections in Nov.-Dec. are desirable to achieve spring drawdown targets gradually. The current agreement incentivizes holding off releasing such water until January to ensure the flow is calculated and credited towards apportionment. This may lead to higher discharges in Jan.-Feb., a less than "natural" condition during the coldest winter months, potentially leading to ice issues and other problems.

- When a drawdown is required to achieve flood control, the apportionment shift allows Saskatchewan to be more successful in retaining its 50 percent apportionment entitlement; North Dakota and Manitoba can receive a flood risk reduction and water management benefit when water is released more gradually starting in November and December

- Decreases the likelihood of Saskatchewan delivering more water to North Dakota than is required by the apportionment agreement

  - Model simulations showed, by the end of the 1930-2017 period, Saskatchewan had delivered 26,000 dam^3 (21,000 acre-feet) less water to North Dakota when the apportionment year was shifted while still meeting its apportionment obligations each year

- Slightly increases the water stored at Grant Devine

  - Model simulations showed, during 1930-2017, a maximum increase of 2 percent more volume

  - Model simulations showed, during 34 wet fall-dry spring years out of 10,000 stochastic years:
    - verage of 2 percent more volume
    - Maximum of 7 percent more volume

What is negatively impacted by this change?

- Slightly decreases the water stored at Lake Darling

  - Model simulations showed, during 1930-2017, a maximum decrease of less than 1 percent less volume

  - Model simulations showed, during 34 wet fall-dry spring years out of 10,000 stochastic years:
    - Average of 1 percent less volume
    - Maximum of 5 percent less volume

- Shifts the timing of when apportioned water is delivered to North Dakota, crediting water delivered during early winter drawdown (November – December), and reducing apportionment delivery after the spring freshet

  - *Note on implications at Lake Darling*: If Lake Darling is below its winter drawdown elevation in the fall, water delivered from Saskatchewan to North Dakota during November and December can be stored in Lake Darling and distributed to water users during the spring and summer. However, if Lake Darling's pool is being drawn down during November and December, it cannot store water released from Saskatchewan at that time. Therefore, that apportionment water is less "useful" from North Dakota's perspective, as it cannot be used during the spring and summer months for irrigation

  - *Note on implications at J. Clark Salyer NWR:* The J. Clark Salyer National Wildlife Refuge pools typically are not drawn down over the winter months. Therefore, apportioned water that cannot be stored by Lake Darling will still be stored in North Dakota prior to reaching Manitoba. Accordingly, the apportionment year shift has a very limited effect on water delivered to Manitoba

How can the negative impacts of this change be mitigated?

- There is no clear path for mitigating minor negative impacts to North Dakota
    - Impacts are considered minor due to the rarity of significant change observed in model simulations, as well as the small decreases in storage volume at Lake Darling when change did occur due to the apportionment year shift

Conclusions

During most years, shifting the apportionment determination from a Calendar Year (January to December) to a Water Year (November to October) would result in very little change to river flows and reservoir elevations. Saskatchewan may be able to retain slightly more water at Grant Devine if the apportionment year is shifted (six out of 88 years.), and water supply benefits may accrue in subsequent years. North Dakota would still receive all of its apportioned share of water, but it may receive more of that water during the winter months (including November to December) in some years.

6.9 CONSIDERATIONS FOR IMPLEMENTING ALTERNATIVE MEASURES

While the 1989 Agreement is, and remains, a proven and effective Operating Plan, the International Souris River Basin Study Board concludes that incremental improvements from the alternative measures discussed in this section would:

- provide more operational flexibility based on use of forecasting tools and increased frequency of communication throughout the reservoir system;
- result in regional benefits for flood protection, water supply, environmental and ecosystem health; and,
- provide incremental improvement for some of the concerns raised by Indigenous Nations, the PAG and RAAG (*e.g.,* reducing risks of flooding river reaches in small to moderate floods, preserving river water quality and natural ecology within system constraints, providing flexibility for reservoir operations suited to basin conditions, etc.)

Additional technical analyses would be useful in refining the knowledge of potential operational options; however, critical decisions for selection from the suite of alternative measures require analyses founded on a thorough understanding of trade-offs for governments, Indigenous Nations, stakeholders, and the International Joint Commission.

6.9.1 SUMMARIZING POTENTIAL TRADE-OFFS – EXAMPLES FOR CONSIDERATION BY DECISION-MAKERS

The alternative measures provided by the Study Board list options that show some promise for incremental improvements in operations. These options require a thorough assessment of potential trade-offs should the 1989 Agreement be modified. Governments must also consider the implications of not changing the 1989 Agreement. Table 26 provides some examples of the trade-offs (these examples are not exhaustive but demonstrate the types and range of impacts).

Table 26 Selected Examples of Trade-offs if the 1989 Agreement is changed-

Alternative Measure from Phase 5 Options	Selected Examples of Trade-offs if the 1989 Agreement is changed
Winter Drawdown Elevation Targets	• Benefits to water supply (maintaining reservoirs closer to FSL) with impacts to river flow (changes in flow and timing) • Increased river flows may improve water quality (ecological bene-fits), but this is not what is common in the basin's natural state (often-times there is minimal flow or no flow in the river in winter; shifts in aquatic ecosystems may result) • Flood control benefits of lower winter drawdown targets have been questioned or may be marginal, as model simulations showed limited reduction in flood peaks under Option 2 • Option 2 provides some water supply benefits but may result in less water security for Saskatchewan in some years.
Winter Drawdown Extension to March 1st	• Extending the drawdown date shortens the timing for flood manage-ment
Lower Spring Maximum Flow Limits	• Operational changes that use storage within reservoir Maximum Al-lowable Flood Levels could result in increasing risks to dams should larger floods occur when reservoirs are storing more water (these risks to dams have not been fully characterized by the study) • Producers in North Dakota desire less flooding, yet there may be merit in "short durations" of pastureland spring flooding (e.g., short duration spring flooding may be beneficial as a natural flood irrigation); crop producers do not want water-logged land prior to seeding crops
Summer Operating Plan	• Using reservoir storage to reduce flood risk of downstream reaches could result in less storage available for larger summer flood events • Maximizing operator flexibility generally allows for efficient reservoir operation, but a lack of rigid rules and transparency in operations may lead to more negative public perception of operations. • Operational changes that use storage within reservoir Maximum Al-lowable Flood Levels could result in increasing risks to dams should larger floods occur when reservoirs are storing more water (these risks have not been fully characterized by the study)
Apportionment Shift to a Water Year (No-vember to October)	• From Saskatchewan's perspective, the apportionment calculation is more equitable, and promotes good water management practices; water released in November and December may also decrease flood-ing risk to North Dakota and Manitoba • Increased November-December releases keep the river flowing longer in fall, benefiting aquatic ecosystems • From North Dakota's perspective, there are timing implications if more apportionment water is received in November and December rather than in spring and summer of the following hydrologic year (e.g., North Dakota expressed concern on unknown impacts the appor-tionment shift may have on delivering minimum flows to Manitoba from June to October) • From Manitoba's perspective, concerns are similar to North Dako-ta's; potential negative impacts from a shift in apportionment are likely less significant the greater the distance downstream (the unknown is whether minimum flows from June to October would be affected).

The implications of not changing the 1989 Agreement:

The Study has conducted extensive engagement with PAG, RAAG and Indigenous Nations. Accordingly, there is significant public, resource agency and Indigenous Nations expectations that their concerns and interests will be addressed by making deliberate improvements to the 1989 Agreement. While the 1989 Agreement achieves flood protection and water supply management benefits, improvements and greater operational flexibility are possible, even within the basin's constraints. Not making changes (even if they only achieve marginal or incremental benefits) may be a concern to many stakeholders and Indigenous Nations.

Figure 34 shows diverse water interests, including stakeholder and rights' holders (Indigenous Nations) interests across the Souris River basin.

Figure 34 Diverse water uses exist across the Souris River

6.9.2 EXAMPLES OF ALTERNATIVE MEASURES, SEQUENCED OPTIONS AND IMPACTS ON PERFORMANCE INDICATORS BY REGION AND RESERVOIR

The plan formulation research produced a series of summary graphics showing how sequenced operational changes have positive or negative impacts, using "performance indicators" (PIs). These graphics are provided in Appendix 6 (Summary of Application of Performance Indicators in the Evaluation of Alternative Operating Plan Measures). The PIs demonstrate how different sequencing of options may result in beneficial changes or negative impacts.

Appendix 6 is provided to demonstrate how materials developed by the Study can be used to inform governments as they consider trade-offs with possible operational changes. The graphics show various combinations and depict beneficial or negative impacts of PIs, allowing for a qualitative review of individual PIs when comparing combinations of options as scenarios. The PIs are not weighted and impacts or benefits to one are not "equal in value" to another; accordingly, the PIs cannot be compared to each other. Assessing how PIs are affected by flow changes requires comparison of how different scenarios affect a single PI. Possible future operational plans must therefore consider the benefits and impacts of the changes with an appropriate weighting applied to balance the trade-offs, considering appropriate risks, sensitivity analyses, and resilience factors. The Study Board makes no recommendation on a preference for depicted sequencing of combinations of options presented in Appendix 6. The PI graphics are presented as possibilities of yearly sequencing; analysis of trade-offs by the governments must be considered before making changes to the 1989 Agreement. (See also: the description on Performance Indicators, their development and application as described in Section 5.2.3 Modeling and evaluation tools)

6.9.3 KEY FACTORS TO BE CONSIDERED BY GOVERNMENTS

The Study Board identified the following key factors that will require clear understanding and consideration by governments should the 1989 Agreement be modified:

1. The 1989 Agreement (with Annex A and B) has performed well for balancing water supply and flood protection for the Souris River Basin. (See Section 4.3 Evaluation of the performance of the 1989 Operating Plan).
2. The ISRSB research completed extensive analyses and developed numerous new analytical techniques and tools to better understand the existing Souris River flow operations and possible alternatives for improvement of operations. These analyses and tools have significant value and importance in guiding application for any future operational changes, and for better understanding of the value and importance of the existing 1989 Agreement.
3. After modeling over 60 scenarios, this section presents the most promising suite of alternative options. The findings are based on statistical analysis of hydrologic model results, engineering judgement, evaluation, and comparison of Performance Indicators for the river reaches and reservoirs, and discussions with stakeholders, Indigenous Nations, and technical experts in the Souris River Basin.
4. While each alternative measure has been analyzed with a detailed reservoir model and a range of historical and stochastically generated hydrologic inputs, it is not yet clear whether additional analyses are necessary to appropriately quantify risks and determine the water users' and the basin's resiliency for all trade-offs. If necessary, additional analyses could include reservoir simulations or risk analyses using flow forecast uncertainty, climate-changed hydrology and/or a greater number of stochastic inputs. In addition, while the alternative measures presented show merit, more discussion and planning are needed to determine the exact processes that should be used to further consider any operational changes.
5. The IJC and Governments of Canada and the United States will need to determine an appropriate path forward to implement changes. Key factors will also require resolving issues related to current hydrology and dam safety approaches and addressing any issues prior to changing the 1989 Operating Plan (these were beyond the scope of the ISRSB).

6.9.4 CONCLUSIONS ON POSSIBLE ALTERNATIVE MEASURES TO THE 1989 AGREEMENT:

As described in this section, the Study Board concludes that the implementation of any of the alternative measures would necessitate trade-offs among flood control, water supply security and impacts on other key components within the river system and the Souris River basin. While a particular measure would reduce risks of flooding in one area, it could lead to impacts such as reduced winter flows, higher reservoir levels or increased water supply risk in other reaches of the river. Governments, stakeholders, and Indigenous Nations must recognize there are trade-offs with any mix of benefits; steps will also be required to mitigate negative impacts where and whenever possible.

Ultimately, trade-offs include benefits or impacts to natural ecological systems as well as human systems and diverse interests: rural-urban, agriculture, power generation, other industry, stakeholder interests (Public, Public Advisory Group and Resource and Agency Advisory Group), Indigenous Nations, watershed organizations, other special groups, and regional and local interests. Figure 35 shows diverse human interests in the Souris River Basin.

Figure 35 Human interests across the Souris River basin

Furthermore, it is not clear whether any of the five alternative measures are preferable when compared to each other (ranking and weighted comparisons may be required), nor in some cases when compared to the existing 1989 Operating Plan measures (e.g., there is uncertainty how apportionment shift may impact downstream flows and related issues). There are differing priorities and perspectives for how the changes will affect the natural and human systems in the basin. A few diverse examples are noted below:

- water users in Saskatchewan are highly sensitive to water supply impacts, as Rafferty, Grant Devine and Boundary Reservoirs play a large role in water supply security for Saskatchewan's southeast regional economy and Saskatchewan's energy production. The reservoirs also provide water supply for multiple uses and ecological needs in a region where drought is the dominant natural hazard risk;
- in North Dakota, stakeholders have expressed strong concerns about urban and rural flooding. The river's channel capacity is very limited in some reaches[24]. Impacts on Indigenous Nations' interests, agricultural production systems and on aquatic and riparian ecology are also concerns;

[24] By definition, a river channel is not able to convey flood flows, which spill into the landscape. The Souris River has some reaches with very low channel capacity; such reaches may begin flooding before other reaches.

- in Manitoba, while flooding remains a concern, regulatory actions have somewhat limited flood risk damages. Stakeholders expressed concerns about water scarcity (minimum flows and apportionment), impacts on Indigenous Nations, cultural impacts, reductions in water quantity and water quality, impacts to fish habitat and other environmental impacts;
- stakeholders and Indigenous Nations have broad concerns on water, some of which may be outside the purview or scope of the operation of the Souris River system of reservoirs (e.g., overland flooding in portions of the basin that do not contribute flow into the river; ground water contamination from land use, industry, or other human activities, etc.); and,
- surface and subsurface drainage of land within the basin have also been raised by stakeholders as potentially having impacts on Souris River water quality and supply, but these effects are not fully understood, as there are limited studies on these issues

In summary, the Study team has documented through extensive analyses, the merits and effectiveness of the 1989 Agreement, in providing flood protection and water supply, within the constraints of the natural and human-built water infrastructure systems of the Souris River. The Study team identified the most promising alternative measures to incrementally improve international water management of the Souris River. Selecting the best options will need to consider the full suite of alternative measures, options within the measures, and seasonal sequencing, culminating in choices to replace or remain within established 1989 rules. The challenge requires careful analysis of trade-offs. Future decisions by the Governments of Canada and the United States to improve upon the 1989 Agreement are possible. The most promising alternative measures for operational changes must be determined by finding the best and most balanced options for Canada and the United States, Saskatchewan, North Dakota, Manitoba, and the citizens in the basin, including Indigenous Nations, and diverse stakeholders who have vested interests in the Souris River.

7 Climate Variability and Change in the Souris River Basin

Image 36 Souris River, November 2016

Section 7 summarizes the Study Board's perspectives with respect to addressing the likely future effects of climate variability and change on the management of water flows and levels in the Souris River basin.

For more detailed information, including the literature and studies reviewed as part of the analysis, see the report of the Study technical team's "HH4, HH5 and HH9 combined report: Climate Change Simulation Tools and Analysis" - Pending report technical review and ISRSB approval.

7.1 Study objectives and approach

Human-driven climate change introduces another driver of uncertainty in a river basin that already experiences considerable natural, long-term, inter-annual and seasonal variability in precipitation, temperatures and flows. Infrastructure design and water resource management are generally based on the assumption that past hydro-climatological records are the best indicators of plausible future conditions. This is known as the concept of "stationarity." However, both human driven climate change and natural long-term variability in climate can undermine the validity of this assumption resulting in nonstationary conditions that present a challenge to applying the techniques typically applied in support of water resources decision making. For example, in the future, warmer winters in the region could lead to earlier snowmelt. As was experienced in 2011, more intense and frequent spring and summer rainfall events could increase the risk of major flooding. More severe droughts in the basin could increase seasonal demands for irrigation, jeopardize critical habitat and impact other water uses in the basin, such as recreation and power generation. It is no longer sufficient nor reasonable, from a water resources management and planning perspective, to assume that the future climate conditions and hydrology at any given location will be like those experienced in the past period of instrumental record.

Understanding how such changes to the hydrometeorology of the Souris River basin could affect the quantity and timing of runoff is critical to basin interests. In response, the Study Board established a binational technical team to assess the likely effects of climate change and natural climate variability on the hydrometeorological variables of interest in the basin. Throughout the Study, the technical team worked closely with the Study's Climate Advisory Group (CAG), made up of experts from government agencies and academic institutions in Canada and the United States.

To identify the implications that changing hydroclimatic conditions have to the Study's objective of improving flood control and water supply operations in the basin, the technical team undertook several steps, as a first attempt to characterize the basin's future vulnerabilities to climate change. First, the team carried out a literature review at a regional scale summarizing trends in hydrometeorological variables relevant to the Souris River basin. The literature review focused on research characterizing trends in observed, historically collected data, paleoclimate data and modeled projections of future climate-changed hydrometeorology. The team also conducted a statistical analysis to determine trends and identify nonstationarities in observed streamflow, precipitation and temperature datasets collected in the basin. In addition to carrying out statistical analysis of observed datasets, the team analyzed projected, future, precipitation and temperature datasets produced by several global and regional climate models (GCMs and RCMs). Finally, the team evaluated the data and modeling methods available to analyze climate-changed hydrology at a basin scale. The team selected meteorological output from an RCM as the best available dataset available to model future climate-changed hydrology for the Souris River.

In addressing the question of climate variability and change, the Study Board recognizes that there is considerable uncertainty associated with potential climate futures, particularly in a basin such as the Souris, located in a region of North America that has historically experienced a great deal of natural climate variability. In addition to the challenges the basin's natural climate variability presents to understanding future climate, there are many uncertainties associated with the climate projections derived from GCMs and RCMs. Despite these uncertainties, these models are the best tools available that can provide a consistent means of exploring plausible climate futures.

7.2 Literature Review[25]

The review of recent literature is presented in two parts. The first focuses on characterization of observed trends in time series data, as well as insights gained from paleo records to provide for an understanding of past hydroclimatic conditions in the basin and to characterize changes in hydrometeorology that are already being observed in the region. The second part of the literature review summarizes studies that have applied GCMs or RCMs to assess possible hydroclimatic futures based on assumed projections of future greenhouse gas emissions.

7.2.1 OBSERVED TRENDS IN TEMPERATURE, PRECIPITATION AND STREAMFLOW RESPONSE

Several, recent studies examine climate trends based on the observed record in both the United States and Canada at a national or regional scale. Observed records from stations within the Souris River basin are included in these large-scale studies. No studies specifically focused on the Souris River basin were identified as part of the literature reviewed.

Temperature

Recent studies have concluded that average annual temperatures in the United States and Canada are increasing. In both countries, the most significant increases are occurring in winter. One study found that annual average temperatures observed throughout North Dakota have increased faster than the rest of the United States over the past 130 years. Temperature change has resulted in a small, but apparent shift in seasonality in the region encompassing the Souris River basin, with spring warming occurring a few days earlier than in the past and later first freezes in the fall. Additionally, the observed warming has resulted in a decrease in the proportion of total precipitation falling as snow.

Precipitation

There are conflicting results in historical precipitation trends in the region encompassing the Souris, Red River of the North and Rainy river basins. Some studies suggest increasing trends in total precipitation and extreme events, while others have found evidence of decreasing trends. If Canada is considered as a whole, precipitation is generally increasing. This is also true of the Canadian prairies where an increase of about seven percent in annual precipitation is noted. However, other studies have shown a statistically significant decrease in winter precipitation in British Columbia, Alberta and Saskatchewan. Seasonally, winter precipitation appears to be decreasing, while spring, summer and fall precipitation appears to be increasing. Based on the available data, there do not appear to be detectable trends in short duration, extreme precipitation events for Canada as a whole.

There are conflicting results in historical precipitation trends in the region encompassing the Souris, Red River of the North and Rainy river basins. Some studies suggest increasing

[25] The literature review synthesizes work that is documented in academic literature. Citations of this work can be found in the more detailed Climate Change Analysis task report.

trends in total precipitation and extreme events, while others have found evidence of decreasing trends. If Canada is considered as a whole, precipitation is generally increasing. This is also true of the Canadian prairies where an increase of about seven percent in annual precipitation is noted. However, other studies have shown a statistically significant decrease in winter precipitation in British Columbia, Alberta and Saskatchewan.

Seasonally, winter precipitation appears to be decreasing, while spring, summer and fall precipitation appears to be increasing. Based on the available data, there do not appear to be detectable trends in short duration, extreme precipitation events for Canada as a whole.

Image 37 Flooding in Minot, North Dakota, 2011

For the continental United States, some studies have suggested that average annual precipitation is increasing. However, there is not a strong consensus in the literature for average precipitation trends. Relative to evidence of changes in average precipitation, there is more consensus in the literature reviewed indicating that the heaviest one percent of observed precipitation events (99^{th} percentile of the distribution) in the United States have increased. The largest increases in heavy precipitation events have occurred in the Midwest and Northeast.

Hydrology

There is little consensus concerning trends in observed annual streamflow in the region encompassing the Souris River basin. No significant trends are observed within streamflow records recorded within the Canadian central prairies, although increases in annual discharge are observed in North Dakota and parts of southern and northern

Manitoba. Declines in mean daily flow were found in natural streams throughout Alberta and southwestern Saskatchewan. Summer flows have been generally declining over most regions of Canada. Several studies of observed precipitation-runoff response indicate that the seasonal timing of peak streamflow has changed, with spring peak streamflow following snowmelt occurring earlier and an increase in the rainfall fraction of precipitation.

Paleoclimate

The technical team reviewed two studies that investigated paleoclimate[26] in the region through an examination of tree-ring chronologies. Paleo studies provide insight into the degree of long-term natural climate variability in the region (compared to change driven by anthropogenic or human-induced forcings). These studies suggest that the climate in the region encompassing the Souris River basin is highly variable both from year-to-year and at a decade scale. Based on paleo evidence, the climate fluctuates cycl-ically between dry and wet states. Within any given 100-year subset of the paleoclimate record, conditions reflect considerable hydroclimatic variability in the basin and long-term persistence in hydroclimatic trends. Tree ring records indicate that a series of “mega droughts” occurred in the region prior to the 20th century. These “mega-droughts” were of longer duration and more severe than the historic 1930s drought period. Additionally, extreme precipitation observed within the past 20 years appears to be similar in magnitude to the scale of precipitation events reflected in tree ring records.

7.2.2 PROJECTED FUTURE HYDROCLIMATIC TRENDS

Several recent climate change studies based on both GCM and RCM output provide relevant information for the Souris River basin. Most recent climate change studies use output from the GCMs generated as part of the fifth phase of the Coupled Model Intercomparison Project (CMIP5). The experiments carried out as part of CMIP5 use greenhouse gas emissions scenarios known as Representative Concentration Pathways (RCPs), which describe the change in radiative forcing at the end of the current century (2100), as compared with pre-industrial conditions. Three RCPs are most often used: RCP2.6, a low-emissions scenario, RCP4.5, a moderate-emissions scenario and RCP8.5, a high-emissions scenario.

Many regional impact assessments require climate information at finer spatial scales than a GCM can provide. To overcome this limitation, dynamical and statistical techniques (known as ‘downscaling’) have been developed to translate the GCM output into finer spatial (and sometimes temporal) scale more suitable for regionally specific applications such as water resources planning studies.

RCMs have higher spatial resolution than GCMs and are used to dynamically downscale global climate simulations to better represent the underlying topography and model some meteorological processes more directly, such as convective precipitation. Most RCMs have a spatial resolution between 25 and 50 km (15.5 and 31 mi).

[26] Paleoclimatology refers to the study of past climate through proxy data but for which no historical recorded instrumental measurements were taken. It is generally used to better understand hydro-climate variability over longer durations of time, extending back hundreds of years or even millennia. Paleoclimate is inferred from the study of tree rings, lake sediments, glacier ice, or other types of proxy data.

Temperature

Analyses carried out across the Prairies in Canada and for the Great Plains region in the United States indicate that average annual temperature is projected to increase significantly by 2100. All studies reviewed present similar results in terms of the direction and magnitude of temperature changes. This change translates into a substantial increase in the occurrence of extremely hot seasons over North America throughout periods of the 21st century.

Precipitation

Relative to projection of future temperature, there is less consensus in the directionality and magnitude of change in trends of projected precipitation. The coarse spatial resolution of GCMs means that they are not always able to capture the processes and physical features of the earth system, which operate at smaller spatial scales and are important for the formation of precipitation. This is generally most problematic in spring and summer when convective precipitation becomes more important, as these weather systems cannot be directly represented in a coarser resolution model.

The majority of GCM based studies indicate that annual mean precipitation is projected to increase in the region encompassing the Souris River basin by the end of the 21st century. The most significant increases are projected to occur in winter, while decreases in precipitation are projected for the summer months. A comparison of these projections with estimates of natural variability indicates that the projected changes in winter precipitation for the region encompassing the Souris River basin are large compared to natural variability, while projected decreases in summer precipitation are smaller than the range of natural variability.

In Canada, multiple studies suggest that extreme precipitation is projected to increase in terms of both frequency and magnitude. Extreme precipitation, currently with a return period of 20 years,[27] averaged for Canada, is projected to become a once in about a 10-year event by midcentury, and a once in about a 5-year event by the end of the century. For the Prairie region, the more extreme annual maximum 24-hour precipitation events, with annual chances of exceedance of ten percent or less are projected to increase in magnitude by about ten percent by midcentury, and 20 percent by the end of the century. Several studies reviewed indicate that heavy precipitation events in the United States are projected to increase in terms of both frequency and intensity. In North Dakota, increases in the total annual precipitation falling during the heaviest one percent of events are projected to be between 20 and 40 percent higher than present day amounts by the end of the century.

Hydrology

Studies focused on analyzing trends in projected hydrology offer mixed results. It is difficult to develop conclusions related to projected hydrology (streamflow response) given the significant uncertainties associated with GCMs. Additional uncertainty is generated when these climate models are combined with hydrologic models that carry their own uncertainty.

[27] A return period of 20 years is a 1:20-year probability of recurrence, or a five percent probability of occurrence in a given year. A 1:10-year event has a ten percent probability of recurrence every year. A 1:5-year event has a 20 percent chance of occurrence in a given year.

Several studies indicate that with continued warming and the associated reductions in snow cover, changes are projected in the seasonality of streamflow. Potential changes include increased winter flows, earlier spring freshets and reduced summer flows. Currently, the majority of the major floods in the region are snowmelt driven. In the future, reductions in snow cover snowmelt driven floods could become less pronounced relative to rainfall driven floods, resulting in a shift in the seasonality of annual peak flows (shift from early spring to late spring/summer/fall). This shift could be accelerated by concurrent increases in the frequency and intensity of rainfall events. However, as a result of potential, concurrent increases in evaporation and other feedback mechanisms, it is not clear how changes in climate will affect the overall spatial and seasonal distribution of water in the Souris River basin. Studies focused on changes in future drought frequency point to variable changes in drought frequency and intensity throughout North America.

RCM based projections of hydrometeorology

Results based on RCMs (Regional Climate Models) are generally consistent with the trends projected based on GCMs (Global Circulation Models). RCM-based analysis indicates that dry periods are projected to become drier and wet periods to become wetter. Extreme precipitation events are projected to increase both in frequency and intensity. In terms of runoff, RCM-based results indicate a shift to earlier spring runoff and a drier late summer. Total runoff (surface and subsurface) showed increasing inter-annual variability in the future. In some cases, this implied an increase in the occurrence of extreme dry conditions.

7.2.3 SUMMARY OF RESEARCH LITERATURE REVIEW

This literature review has considered recent publications focused on updating trends in observed data as well as future projections from GCMs and RCMs for the Souris River basin, with the main findings summarized in Table 31. It should be noted that many of the conclusions are taken from regional scale studies which encompass the Souris River basin. Observations show that the annual-average climate of the Souris River basin is becoming warmer and wetter, although there have been some decreases in winter precipitation. Warmer conditions have resulted in earlier spring freshet and later fall freeze up. There has been a steady observed decline in the ratio of snow to total precipitation, indicating that flow regimes may be changing from snowmelt-to- rainfall-dominated. In recent years, some of the most significant flood events have occurred due to late spring/early summer rainfall events, after the peak runoff from snowmelt.

Table 27 Summary of trends and changes in temperature, precipitation and streamflow for the Souris River basin (by literature review)

Variable		Historic Observations		Future Projections		
		Direction	Notes	Confidence	Direction	Notes
Temperature		↑	Greatest warming in winter and spring in Souris River Basic, spring warming occurring a few days earlier/later first freeze in fall	HIGH	↑	Increasing for all RCP scenarios with substantial increases during hotter seasons
Precipitation	Annual	↑	Annual precipitation has increased	MEDIUM	↑	Annual average precipitation projected to increase
	Winter	↓	Decline in the Canadian praries in winter (6%)	MEDIUM	↑	Larger increase in winter precipitation towards end of century
	Spring	↑	Spring precipitation has increased	MEDIUM	●	No projected change
	Fall	↑	Fall precipitation has increased	MEDIUM	●	No projected change
	Summer	↑	Summer precipitation has increased	MEDIUM	↓	Slight decline in summer precipitation, particularly under moderate to high emissions scenarios
	Phase (Snowfall/ Rain)	↓	Ratio of snowfall to total precipitation steadily and significantly decreasing	n/a	n/a	n/a
	Extremes	↑	U.S. showing increase in intensity and frequency of heavy precipitation events while Canadian analysis showing no detectable trends	HIGH	↑	Extreme precipitation to increase, even where total precipitation projected to decrease, precipitation intensity projected to increase
Streamflow	Annual	↑	No significant trends in central praries, although increases in annual discharge in North Dakota, southern and northern Manitoba	MEDIUM	↑	Total runoff indicates increasing inter-annual variability
	Summer	↓	Summer flow generally declining	MEDIUM	↓	Drier during late summer
	Spring Peak Timing	←	Spring peak occurring earlier	HIGH	←	Earlier spring runoff projected

7.3 Observed hydrometeorological data

The Study's technical team carried out a statistical analysis of observed hydrometeorological records collected in the Souris River basin to build upon the insights gained from the regional-scale research reviewed and summarized in the preceding section. Statistical analysis consists of applying a series of non-parametric tests targeted at detecting nonstationarities in time series data. Tests identify statistically significant changes in sample mean, standard deviation and/or overall statistical distribution. In addition to testing for nonstationarities, several tests were applied to evaluate datasets for monotonic trends.

It should be noted that it is difficult to conclusively attribute detected trends and nonstationarities to human-driven climate change due to other factors such as natural, long-term, persistent climate trends and changes in watershed characteristics. The length of observed hydrometeorological data also can affect the results.

Streamflow

The analysis found that streamflow records collected along tributaries (Long Creek, Des Lacs River, Wintering River, and Antler River) to the Souris River indicate little evidence of trends or nonstationarities in annual peak streamflow. To evaluate whether mainstem, Souris River flows demonstrate evidence of changing statistical properties, a simulated, unregulated streamflow record was analyzed at Minot, North Dakota. By assessing an unregulated record, the impacts of the Souris River Project flood control reservoirs are removed. Because the reservoirs came online at different points in the period of analysis (1930 to 2017) their operation introduces a known source of nonstationarity into the streamflow records collected downstream. Removing the impacts of the reservoirs ensures that any detected nonstationarities or trends can be attributed to a driver besides these significant water management structures. The unregulated, annual peak streamflow record at Minot, North Dakota, exhibits a nonstationarity in 1941. However, when the unregulated record at Minot is shortened to the period of 1942 to 2017, no nonstationarities are detected. This indicates that post-1941, the peak streamflow record at Minot can be considered homogenous.

When peak streamflows are analyzed seasonally, there is no evidence of nonstationarity in spring peak flows, though there is some evidence indicating that peak flows are changing in both summer and fall. For both the Wintering River and the Souris River (unregulated-Minot), an increasing trend is observed in peak, fall flows with a nonstationarity observed in the 1940s. Both time series analyzed also exhibit a statistically significant increasing trend within their peak, summer streamflow records. For the Antler River, no statistically significant trends are evident in seasonal peak flows. A strong nonstationarity is observed in 2008 for fall peak flows.

Both the annual, average streamflow record recorded along the Wintering River and the approximation of annual, average unregulated flows generated for Minot, North Dakota, exhibit strong evidence of an increasing trend and nonstationarities in 1941. If the average annual streamflow records are considered seasonally, then increasing trends are observed on the Souris River at Minot and along the Wintering River in spring, summer and fall. Nonstationarities in summer and fall average streamflow, and annual streamflow, are detected in the early 1940s at both locations. There are no statistically significant trends in average streamflow observed along the Antler River.

In general, there is little evidence indicating that annual peak flows are decreasing or increasing in the Souris River basin. There is evidence that peak flows are increasing in summer and fall. There is strong evidence of nonstationarity and increasing trends in average streamflow both for the time series defined for the Souris River at Minot (unregulated) and the observed flows recorded along the Wintering River. These trends persist regardless of whether the records are assessed seasonally or annually.

Temperature and precipitation

The Study team analyzed trends and nonstationarities in observed temperature and precipitation records at two locations in the basin: at Minot, North Dakota (Minot Experimental Station & Minot International Airport Station) and at the Yellow Grass Climate Station (located approximately 80 km (50 mi) southeast of Regina, Saskatchewan). Both sites have records starting prior to 1930.

The analysis found that the annual maximum temperature record at Minot exhibits a decreasing trend annually, as well as for the summer and winter seasons. Nonstationarities are indicated in both the annual maximum and summer maximum temperature datasets in 1942. Average temperatures observed at Minot indicate an increasing trend in the annual record, as well as for the winter, spring and summer seasons. However, apart from the spring season (1975), no nonstationarities were detected. In contrast, the Yellow Grass record did not show any trends or nonstationarities in the annual maximum record and indicated an increasing trend only in fall maximum temperatures and a nonstationarity only in the winter temperature record (1986). Minimum temperatures are increasing at both the North Dakota and Saskatchewan sites. This is observed annually, and for the annual minimum winter and summer records. An increasing trend is also observed in the spring minimum temperatures at Minot. However, nonstationarities were only identified within the Minot record (1939 minimum annual/winter temperatures). This may imply that the region is becoming "less cold."

No trends or nonstationarities are identified when the maximum annual three-day precipitation volume is assessed at either the Minot Experimental Station or the Yellow Grass Station. At Minot, the three-day average precipitation records and annual cumulative precipitation record contain a statistically significant increasing trend and evidence of nonstationarity in 1962. No nonstationarities are indicated within the Yellow Grass records, but the annual average three-day precipitation record and annual cumulative precipitation record do exhibit increasing trends.

7.4 Analyzing future hydrometeorology in the basin

The Study's technical team applied state-of-the art hydro-climate modeling products to analyze trends in projected meteorological outputs and outline a process that can be directly adopted as part of subsequent modeling efforts to project future climate-changed hydrology specific to the Souris River basin. The projections of future climate incorporated into this analysis use RCP 8.5 to represent "business as usual" future levels of greenhouse gas emissions. RCP 8.5 assumes no major divergence from current year-to-year increases in emissions.

7.4.1 CHARACTERIZING POTENTIAL FUTURE CLIMATE CONDITIONS

The technical team used a delta-based (comparative) approach to assess raw temperature and precipitation outputs from 12 GCM models to characterize future climate predictions in the area encompassing the Souris River basin. The team also conducted a similar analysis of changes in projected meteorology using a dataset generated through RCM dynamic downscaling of GCM based projections. An array of GCM model outputs is used in both cases to provide insight into the range of potential future meteorological conditions. By evaluating output based on an ensemble of models, rather than a singular realization of future conditions, the uncertainty associated with projected, modeled climate-changed meteorology is acknowledged. Some of this uncertainty is revealed through the range of the projections produced. Ideally, uncertainty in several aspects of the modeling chain is considered. These include uncertainty associated with the emission scenarios, the climate models, the initial conditions of the climate models, the downscaling methods used, the hydrologic models, and the hydrologic model parameters.

When comparing the outputs from the 12 GCM models, the difference between meteorological outputs modeled for the historic simulation period, where greenhouse gas emission concentrations were assumed to be consistent with historical levels, are compared to future projections of temperature and precipitation modeled using RCP 8.5. The historic and projected simulation time periods included years from 1950 to 2005 and 2006 to 2100, respectively.

Data were analyzed both annually and seasonally. An average of all GCM-based model results indicates an increase in future annual temperatures relative to the historic period, with changes in spring and winter temperatures being the most significant increases. At the same time, accumulated precipitation volumes, on average, are expected to increase in the future in spring and winter, while a slight decrease is anticipated for the summer. Fall precipitation totals are projected to be almost unchanged.

Although, there are numerous GCMs available which produce projections of future climatic conditions at a coarse spatial resolution, prior to application to a watershed scale hydrologic model, GCM-based meteorological data must be spatially downscaled (i.e., adjusted from a larger regional scale to be applicable to a smaller spatial region) and bias-corrected to be consistent with observed meteorological data. Raw GCM-based outputs are also only appropriately applied when considered at longer time scales (often, monthly minimum). GCM outputs must be appropriately disaggregated to finer time steps to be consistent with the computation intervals applied for hydrologic modeling.

The downscaling and bias-correction process is resource intensive and thus, only readily available downscaled and bias-corrected datasets were considered as part of the Study. The Study's CAG was consulted to identify available downscaled datasets for the region. Typically, readily available, statistically downscaled GCM and dynamically downscaled RCM outputs are constrained by geographic borders and very few transnational products are readily available. For this study, downscaled outputs from the Second Generation Canadian Earth System Model (CanESM2) are adopted using ECCC's Canadian Centre for Climate Modelling and Analysis (CCCma) Regional Climate Model (CanRCM4). The RCM dynamically downscaled projections incorporated into this assessment span to the Canadian-United States border and thus can be directly used to model hydrologic response in the Souris River basin. Adopted RCM projections are subsequently bias-corrected using the best available gridded, long-record product for the region encompassing the Souris River (WFDEI-GEM-CaPA abbreviated as WGC). The projections used for this Study, referred to as the CanRCM4-WGC dataset, represent a subset of a 50-member ensemble generated using CMIP5 protocols under RCP8.5. The adopted subset of 15 members was applied (as opposed to the full ensemble) because those were the only realizations publicly available at the time of the Study. The 15 realizations reveal some of the uncertainty associated with using different atmospheric conditions to initialize the RCM model runs.

A comparison of bias-corrected future and historic period RCM outputs was analyzed for the Souris basin for the period from 1951 to 2100. The historic simulation period is defined as 1951 to 2005 and the future period is defined as 2006 to 2100. Data were analyzed annually and seasonally. The comparison between past (historic simulation) and future (projected) model simulations showed a consistent increase in temperature for all seasons, and an increase in precipitation for all seasons except for summer which showed a slight decrease.

7.4.2 HYDROLOGICAL MODEL DEVELOPMENT

To develop the tools necessary to model future climate-changed hydrology in the Souris River basin, the technical team developed a hydrologic model for the basin. The Souris River basin presents several challenges to hydrologic modeling. The basin is difficult to model because its contributing drainage area can vary considerably because of antecedent moisture conditions and/or precipitation event magnitude and duration. As noted in Section 1, the topography of this region is characterized by the presence of shallow wetlands, called potholes or kettles. As a result of the natural storage these features provide, during small to moderate rainfall events, the basin has an extremely low runoff ratio. During more extreme runoff events, natural storage becomes saturated, resulting in increased hydraulic connectivity and a considerably higher runoff ratio. The 2011 June-July flood of record illustrates these effects. Prior to the event of record, the Souris River basin experienced a wet summer and fall in late 2010. Higher-than-normal snow cover in the basin further contributed to saturated basin conditions. The 2011 event was characterized by a sequence of significant rainfall events. These conditions resulted in a dramatic increase in the percentage of precipitation contributing to the peak 2011 runoff response.

In addition, blowing snow is common in the Souris River basin and results in increased sublimation (evaporation from snow to the atmosphere) and wind redistribution from wind-swept areas to wind-sheltered areas. Exposed areas can lose 30 to 75 percent of their annual snowfall due to this sublimation and redistribution, significantly affecting surface hydrology and the energy cycle. Most hydrological models do not account for these processes. Finally, frozen soils have a significant influence on the contribution of snowmelt runoff to streamflow. Meltwater infiltration into frozen soils is a complex process that is difficult to model.

Given these concerns, the Study team selected the MESH model ("Modélisation Environnementale, Surface et Hydrologie") to model the Souris River basin. MESH is a distributed parameter model, meaning it uses parameters derived based on geospatial data to simulate hydrologic processes. The MESH model incorporates algorithms that represent variable contributing drainage area, blowing snow, blowing snow sublimation, and infiltration into frozen soil.

Setting up and applying MESH requires several different data inputs. At a minimum, the model requires a basin-wide digital elevation model (DEM) and a land cover classification dataset. In addition, model development requires historical streamflow observations and meteorological forcing data (temperature, precipitation, incoming shortwave radiation, incoming longwave radiation, specific humidity, barometric pressure, and wind speed). Meteorological inputs required for model calibration and validation were adopted from ECCC's Regional Deterministic Reforecast System (RDRS).

The MESH model covers the full extent of the Souris River basin and is configured to model unregulated basin conditions. The model was calibrated to two gauges on Moose Mountain Creek (Saskatchewan) using streamflow recorded by ECCC from Jan. 1, 2008 to Dec. 31, 2011. Calibration results were validated at the same two locations using observed data collected between Jan. 1, 2012 to Dec. 31, 2017.

Because MESH is a distributed parameter model, calibration consists of modifying the relationships assumed between basin geospatial characteristics and resulting hydrologic response. It is assumed that once calibrated, these relationships can be applied throughout the full extents of the model being developed. This was confirmed by validating that the model could subsequently replicate unregulated streamflow response at 13 locations throughout the entire basin from Jan. 1, 2008 to Dec. 31, 2017. For locations impacted by the Souris River Project reservoirs, the unregulated reconstructed hydrology products (HH1) were used to validate the model. In addition to comparing hydrograph response, results were evaluated using the same set of statistical metrics used by the USGS to evaluate how well the USGS water balance model (HH2) was able to reproduce the reconstructed unregulated hydrologic response. Although the model was only calibrated to two gauges on Moose Mountain Creek, the results were satisfactory throughout the Souris River basin, particularly when considering the complex hydrological process of the basin and compared to the USGS model of the region.

Image 38 Souris River near Velva, North Dakota, in summer

7.4.3 CLIMATE CHANGE HYDROLOGICAL ANALYSIS

As noted in Section 7.4.1, only one readily available source of transboundary, downscaled and bias-corrected climate projections was identified (CanRCM4-WGC). This product represents results derived from one GCM. To appropriately characterize projections of future climate-changed hydrology in the Souris River basin, additional downscaled and bias-corrected products would need to be generated and/or acquired. Analysis would need to be generated to characterize and communicate the considerable uncertainty associated with future projections of climate-changed hydrology. In addition to needing to include a larger ensemble of projections as part of the analysis, additional work would need to be carried out before projected, climate-changed hydrology could be compared to what has been observed historically. This would consist of comparing hydrology generated using CanRCM4-WGC inputs for the historic simulation period (1951 to 2005) to observed streamflow time series for the same period. Based on such a comparison, necessary post-processing steps would need to be defined and applied.

A proof-of-concept run was carried out to develop a workflow and verify that the CanRCM4-WGC outputs could be used to force the MESH model and generate an ensemble of projections of future, climate-changed hydrology. This proof-of-concept assessment was extended to include coupling with the Study HEC-ResSim model. By establishing this workflow, the Study team has developed a tool which can be used to support more in-depth assessments of the impacts of climate-change on the Souris River basin's hydrology in the future. However, because the work done as part of this Study, to date, represents only a component of the analysis required to generate climate-changed hydrology specific to the Study area, output from the proof-of-concept run does not support an assessment of expected future flows or water management practices in the Souris River basin. To support this sort of evaluation, at minimum a larger ensemble of bias-corrected forcings would be required, along with additional post-processing of the streamflows generated. Ideally, insight into further sources of uncertainty in the modeling chain would be examined by assessing results derived using multiple emission scenarios (RCPs), a variety of downscaling/bias-correction techniques, several different hydrologic modeling platforms and variation in hydrologic model parameters.

7.5 Summary of key findings for changing hydroclimate conditions

To identify the implications of changing hydroclimatic conditions in the Souris River basin to flood control and water supply operations, the Study undertook a comprehensive review of recently published literature summarizing regional trends in observed and projected hydrometeorological datasets. The literature review also addresses long-term trends in the region's climate by summarizing regionally specific investigations of paleoclimate. In addition to summarizing research conducted by others, the Study team assessed trends and nonstationarities in observed data collected in the Souris River basin, itself. Currently, the best approach to modeling future hydroclimatology in the context of water management is to use outputs from an array of GCMs that have been downscaled and bias corrected. As part of this Study effort, GCM/RCM outputs specific to the Souris River basin were analyzed.

Based on the analysis presented in this section, the Study identified the following key findings:

- Both a review of recently published literature summarizing regional trends in historic temperatures and precipitation data, as well as an assessment of trends in observed meteorological data collected in the Souris River basin, indicate that temperatures in the Souris River basin have been increasing. Both the literature review and observed precipitation records also point to some evidence of increasing precipitation trends. However, how this translates into a change in the observed runoff response is less clear. Both the literature reviewed and an investigation of trends and nonstationarities in observed streamflows in the Souris River basin presented variable results.
- Based on the literature review, warmer conditions have resulted in earlier spring freshet and later fall freeze-up in the region encompassing the Souris River basin. There has been a steady observed decline in the ratio of snow to total precipitation. In recent years, some of the highest flows and flood events have been associated with rain events in late spring/early summer, after the peak runoff from snowmelt.
- As illustrated by both the observed record and tree-ring based paleorecords, there is evidence of long-term persistent climate trends in the Souris River basin. The Souris River basin's climate is significantly influenced by natural climate variability.
- In general, GCM and RCM based projections of future climatic conditions in the region encompassing the Souris River indicate that recent trends in temperature are likely to continue. Both the literature review and the GCM/RCM model outputs analyzed specific to the Souris River basin indicate that, by the end of this century, the climate in the region will be significantly warmer. There is more uncertainty associated with projected precipitation. Recent research and analysis conducted as part of this study both indicate that annual average precipitation is likely to increase by 2100. Seasonally, increases in winter precipitation and declines in summer precipitation are projected. There is less consensus in trends in fall and spring precipitation projections.
- The literature reviewed and the observed precipitation data analyzed indicate mixed results with regards to trends in historically observed extreme precipitation event magnitudes. The literature review indicates that, based on an evaluation of numerous GCM-based study results, extreme precipitation events are projected to increase in both magnitude and frequency in the future.
- Studies that were reviewed focused on analyzing trends in projected hydrology offer mixed results. It is difficult to develop conclusions related to projected hydrology (streamflow response) because of the significant uncertainties associated with GCMs.

7.6 Implications of changing hydroclimate for future water management in the basin

Based on scientific evidence spanning back to the 18th century, the hydroclimate of the Souris River basin has been highly variable and subject to long-term persistent climate trends. Based on modeled future projections of temperature and precipitation, there is also evidence that human-driven climate change is impacting the basin. However, how human-driven climate change will impact the basin's hydrology is highly uncertain. Both natural variability and the ambiguity associated with how human-driven climate change will impact basin hydrology presents a challenge to generating an effective and sustainable long-term plan for water management in the basin.

- Hydrometerological monitoring will be critical to tracking the basin's current climate state and in identifying any trends that start to materialize in basin meterology and streamflow response. Thus, the maintence of the existing meterological and streamflow gauge network is critical to enabling water managers to be responsive to shifts in hydroclimatic conditions. Consideration should be given to expanding the network of gauges currently in operation.
- There remains a need to increase the understanding of how future climate and runoff response will be affected by climate change, and how additional data resources can be used and improved modeling can be undertaken to guide decisions as science evolves. The water management plan being proposed as a part of this study is targeted at reducing flood risk and securing water supply for the full range of conditions exhibited by the basin's observed hydroclimatic record.Thus, determining whether or not human-driven climate change is creating hydroclimatic conditions which fall outside of the range of natural variability as exhibited in the historic record is imperitative to understanding and evaluating the robustness of the management plan being proposed.
- As new GCMs and mechanisms for downscaling and bias correction become available, these data sources can be used along with the workflow defined as part of this Study effort to further understand future hydroclimatic conditions in the basin. Currently, many downscaled projections of future meteorology do not provide continuous, transboundary coverage between the United States and Canada. The Study Board and the IJC should advocate for the generation of products which support the assessment of future climate-changed hydroclimatic conditions in transboundary watersheds like the Souris River basin.
- Because there is considerable future residual risk to the Operating Plan being proposed, as a result of both natural climate variability and human-driven climate change, adaptive management options need to be included in the Operating Plan being proposed for the Souris basin. An adaptive management approach would consist of a re-evaluation of certain aspects of the Operating Plan should certain hydrometeorological conditions begin to materialize in either the observed record or in model-based evaluations of future climate and hydrology. Consistent with the IJC's adaptive management approach, stakeholders should take into consideration the lead times required to make a change to the current water management approach. Taking these lead times into consideration, thresholds of change in observed and/or projected hydrometeorological conditions should be identified at which a required change to the basin's management plan should be triggered.

8 Other Water Management Considerations in the Basin

Section 8 presents the Study Board's perspectives with respect to several important water management issues in the basin.

8.1 Artificial drainage in the basin

The analysis presented here is based on the technical task team report "HH3, Souris River Basin Artificial Drainage Impacts Review", available on the Study's website: www.ijc.org/en/srsb.

- "HH3 Souris River Basin Artificial Drainage Impacts Review" https://ijc.org/en/srsb/artifical-drainage-report

During the review and comment meetings leading up to the Governments' Reference to the IJC in 2017 (Appendix 2), there was considerable interest in the Souris River basin regarding the issue of agricultural drainage impacts. Some have suggested that the drainage of marshes, potholes, and other wetlands – undertaken to allow increased or more efficient agricultural production – may have contributed to the severity of flooding in the basin.

As a result of these public concerns, a review of the impacts of artificial drainage from the basin was added to the Study's work plan. The Study aimed to gain a better understanding of the possible impacts of this artificial drainage in the basin on transboundary water flows.

The Study addressed this objective through four tasks:

- reviewing legislation and agricultural practices in the basin related to water drainage;
- reviewing the science related to artificial drainage;
- quantifying the extent of artificial drainage in the basin; and,
- determining the potential influence of this drainage on transboundary flows.

In addressing these tasks, the Study's hydrology and hydraulics technical team worked closely with an HH3 Working Group committee of representatives from the three state/provincial water management agencies, the Saskatchewan Water Security Agency (WSA), the North Dakota State Water Commission (NDSWC), and Manitoba Agriculture and Resource Development (formerly Manitoba Sustainable Development). The HH3 Working Group retained an external consultant with funding from the Canadian Section of the IJC to undertake the scope of work. The Study's approach and preliminary findings were reviewed by the PAG. The Study considered both *surface drainage and sub-surface drainage in the basin*.

Surface drainage moves excess water off fields by natural runoff or by constructed channels. The goals are to minimize crop damage from water ponding after a precipitation event and control runoff without causing erosion. However, surface drainage can lead to erosion and filling in of ditches, as well as impacts on water quality because the water is not filtered through soil.

Subsurface drainage, typically with tile drainage (buried pipe drains), is installed to remove groundwater from low-lying wet areas. The purpose is to lower the water table to increase the productivity of the drained land, as water tables that are close to the surface can restrict seeding operations and impede crop growth.

Key findings

1. Review of legislation and current practices

Regarding current agricultural practices in the basin, surface drainage is the most common type of artificial drainage. Subsurface drainage is used in localized areas but is not a significant basin-wide practice.

There are similarities in the artificial drainage regulations in all three state/provincial jurisdictions. Each approach covers both surface and subsurface drainage. In all three, an assessment of the proposed drainage project on the receiving watercourse and downstream lands is required prior to the issuance of a drainage license. Applicants must demonstrate that there is an adequate outlet downstream available to handle the increased drainage water. This may require the approval of downstream landowners. All three jurisdictions enforce their drainage regulations with fines and/or the closure of the works.

Drainage projects are licensed individually in the state and provinces. The primary focus of licensing is to minimize the potential for impacts on landowners in the immediate area as well as impacts on the basin and its environment. This approach assumes that if impacts are effectively mitigated at the local level, then they tend not to be transmitted throughout the basin system. However, there are gaps in watershed-based planning and challenges in assessing cumulative impacts over time. Nor is a landowner in one jurisdiction allowed to file for a drainage constraint against one in another jurisdiction.

There are also important differences in the regulatory approach of the three jurisdictions. In Saskatchewan and Manitoba, the provinces are responsible for drainage regulation and enforcement. North Dakota state law, by contrast, places considerable responsibility on local governments to oversee what is considered a local issue. Consequently, watershed management districts and boards are responsible for drainage permitting and the state government is involved only when impacts extend beyond the local government's jurisdiction.

2. Review of the science

Wetlands are widely regarded as important components of a natural landscape because of their value to local and regional biodiversity and their critical hydrological role. Wetlands can store substantial amounts of melting snow and runoff and then release the water slowly, reducing the impacts on downstream flows. Reducing wetlands through drainage can affect the timing, magnitude, and volume of runoff, increasing the potential for flooding and degrading ecosystems.

Although gradual, incremental changes in the landscape can lead to small changes in wetlands, the accumulation of these small changes over time can permanently alter the wetlands' function.

Draining wetlands, through artificial drainage practices, can send nutrients, such as phosphorus, sediments, and other pollutants downstream. This water eventually reaches rivers and lakes used for drinking water, irrigation, industrial use, recreational activities, and aquatic ecosystems.

3. Quantifying the extent of artificial drainage in the basin

One of the challenges in quantifying the extent of artificial drainage in the Souris River basin is the dramatic hydrological alteration of the prairie pothole region (including agriculture and its evolving practices, extensive land use modifications from urban and rural built infrastructure such as community and industrial development, road and rail transportation networks, etc.), along with the ongoing conversion of wetlands for agricultural production.

The Study concluded that artificial drainage has increased the basin's effective drainage area, although the change is not uniform throughout the basin. The Study was not able to quantify the extent of artificial drainage across the entire Souris River basin due to a lack of complete, comparable data sets (Figure 36). The existing wetland inventories in the three jurisdictions are incomplete, use different classifications and are based on different imagery dates. (For a more complete analysis, please see: HH3: Souris River Basin Artificial Impacts Review)

About 94 percent of the basin is covered by high-resolution wetland inventory data. For the United States part of the basin, a complete wetland inventory exists in the National Wetland Inventory (NWI). In the Canadian part, there are gaps in the Canadian Wetland Inventory (CWI). However, the NWI is based on imagery from the early 1980s and is outdated. The CWI data, by contrast, are much more recent, spanning the 2005 to 2018 period. As a result, there is no common reference period with which to estimate and compare the changes over time (Figure 36).

The NWI also does not classify completely drained wetlands or identify the agricultural drainage feature as does the CWI. Comparing the NWI data with Ducks Unlimited Canada data for three sub-watersheds of the Souris River in North Dakota indicates that the NWI may underestimate the wetland area impacted by drainage by more than 100 percent. The comparison suggests that there are significant areas of wetland drainage in the basin that are impacting the natural hydrographic network and the effective drainage area.[28]

[28] The effective drainage area is the area that excludes marsh and slough areas and other natural storage areas that would prevent runoff from reaching the mainstream in a year of average runoff.

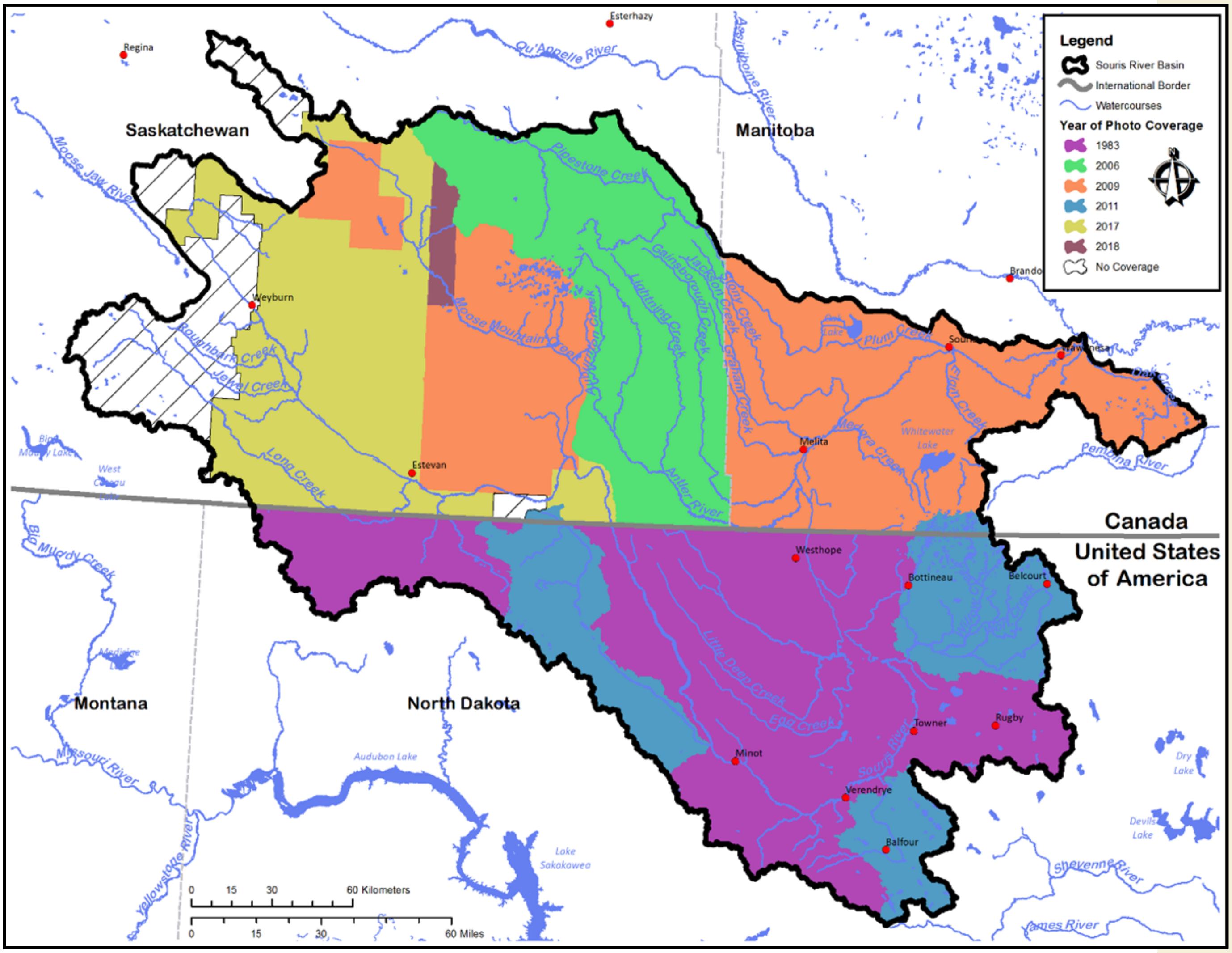

Figure 36 Souris River basin wetland inventory coverage, by year

Figure 37 shows the estimated change in the effective drainage due to artificial drainage based on the available data. The results illustrated in the figure should be considered indicative only, given that some areas are based on imagery that is more than ten years out of date. Overall, it is estimated that artificial drainage has increased the basin's effective drainage area by about 26 percent. The change is not uniform throughout the basin. For example, in Saskatchewan, the headwaters of the Grant Devine watershed and Pipestone Creek show a significant change in the effective drainage area. Two North Dakota watersheds, the Des Lacs River and Willow Creek, indicate significant changes as well. In Manitoba, the areas of the most intensive drainage appear to be in the watersheds of Elgin and Medora Creeks.

Quantifying the extent of artificial drainage in the basin will require a wetland inventory based on digital imagery for a common period and need to include the agricultural drainage features for the entire basin.

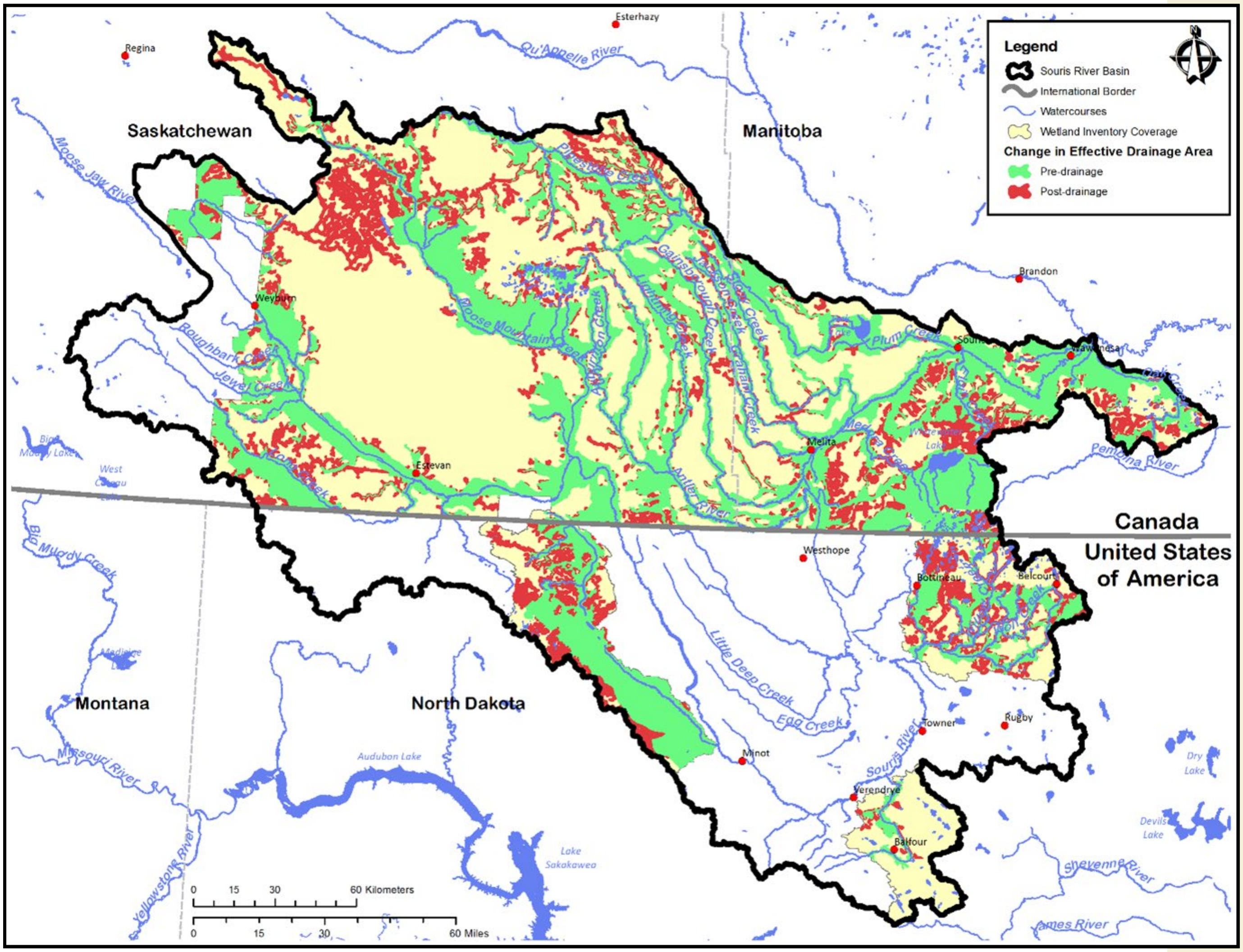

Figure 37 Impacts of drainage: changes in effective drainage area

4. Influence of drainage on transboundary flows

Scientific understanding of the impacts of drainage indicates that artificial drainage in the Souris River basin has the potential to impact both the quality and quantity of water flows in the basin. Given the incomplete wetland inventory data for the basin, the Study investigated the potential impacts by means of a sensitivity analysis.[29]

The analysis focused on the crossing of the Souris River at Sherwood, North Dakota, the location the ISRB uses to make its natural flow apportionment calculations and flood forecasting oversight decisions. Based on the available CWI data, the Study concluded that the effective drainage area at Sherwood has increased by about 35 percent as a result of drainage. Using this as a baseline, a sensitivity analysis was undertaken for "what if" increases in the effective drainage area of 25, 30, 40, 50 and 60 percent.

[29] Sensitivity analysis is a technique that works as a "what if" or simulation analysis under conditions of uncertainty. It determines how different values of an independent variable affect a particular dependent variable under a given set of assumptions.

The sensitivity analysis concluded that:

- In normal (non-flood) years, wetland drainage may result in increased flows at Sherwood. However, in more than 80 percent of the years, the downstream jurisdictions, North Dakota, and Manitoba, will benefit from the additional flow volume, particularly during drought conditions.
- Wetland drainage likely has the greatest impact in the basin in average-to-moderate runoff events and floods. During extreme floods, such as in 2011, wetland drainage has a minor to insignificant impact, as all the wetlands are filling and spilling. However, the increased runoff from artificial drainage could result in more frequent occurrences of a 1:10-year flood. For example, with a 25 percent increase in the effective drainage as a result of artificial drainage, the risk of a 1:10-year flood could increase by more than 10 percent.
- Wetland drainage is potentially deteriorating water quality in the Souris River basin. However, it is not possible to quantify this impact, given the ongoing impacts of other activities on water quality, such as changing land management practices. The Rafferty and Grant Devine Reservoirs may be sequestering significant amounts of the nutrients from upstream watersheds, thus mitigating some of the downstream impacts of wetland drainage in the upper parts of the basin. Updated analysis of water quality trends at the international gaging stations on the Souris River at Sherwood and Westhope, North Dakota, would improve understanding of the impacts of artificial drainage.
- Finally, the Souris River basin continues to experience extensive modifications. Urban and rural development, changing land management practices such as wetland drainage, conservation tilling, brush clearing and grasslands cultivation, as well as construction of road and rail transportation networks have altered natural runoff; some of these changes have contributed to increased runoff and deterioration of water quality in the basin.
- Because human-driven climate change and long-term natural variability in climate also impact streamflow response, it is difficult to predict or define the effect that a change in agricultural drainage or land use/land cover might have on hydrologic response. Streamflow and meteorological monitoring, as well as the implementation of improved climate change and hydrologic modeling are necessary to better understand the relative contributions of climate change versus natural climate variability versus changes to the land surface/drainage on runoff response.

8.2 Apportionment, Water Quality, Aquatic Ecosystem Health

The focus of the 2017 Reference from the Governments of Canada and the United States to the IJC was to investigate and make recommendations regarding improvements to the Operating Plan contained in Annex A of the 1989 Agreement with respect to flooding and water supply risks in the Souris River basin. However, the Reference also directed the IJC's study to consider the implications of any proposed improvements to the Operating Plan on apportionment as well as water quality and aquatic ecosystem health of the Souris River.

8.2.1 APPORTIONMENT

The Study did not formally evaluate the apportionment rules for the Souris River basin as set out in Annex B of the 1989 Agreement. However, a review of apportionment under the Agreement will provide a useful context to one of the alternative Operating Plan measures reviewed in Section 6, the proposed shift in the apportionment period from a 'Calendar Year' to a 'Nov. 1 to Oct. 31' period.

Under the existing rules, Saskatchewan is entitled to 50 percent of the flow which would have occurred in a state of nature at the Sherwood Crossing. An exception to the 50 percent entitlement is made in years when either of the following conditions applies under the "Interim Measures as Modified in 2000":

- annual natural flow volume is greater than 50,000 dam^3 (40,500 acre-feet) at the Sherwood Crossing, and the Lake Darling elevation is greater than 486.095 m (1594.8 ft) on June 1; or,
- annual natural flow volume is greater than 50,000 dam^3 (40,500 acre-feet) at the Sherwood Crossing and the Lake Darling elevation is greater than 485.79 m (1593.8 ft) on June 1 provided that the elevation has not been lower than 485.79 m (1593.8 ft) since the last time Lake Darling had an elevation of 486.095 m (1594.8 ft) on June 1

These conditions allow Saskatchewan to retain 60 percent of natural flow in recognition that a portion of North Dakota share will be in the form of evaporation from Rafferty Reservoir and Grant Devine Reservoir. The lesser amount to North Dakota is in recognition of Saskatchewan's agreement to operate both Rafferty Dam and Alameda Dam (later renamed as Grant Devine) for flood control and for evaporation as the result of the Project.

Apportionment calculations are based on the estimation of natural flow. Natural flow is defined as the quantity of water that would naturally flow in any watercourse had the flow not been affected by human interference or intervention. The natural flow is to be calculated at the Sherwood, North Dakota flow gauging station, close to where the river crosses the Canada-United States international boundary. The site is referred to as the Sherwood Crossing in Annex B of the 1989 Agreement.

Natural flow is calculated as the recorded flow at Souris River near Sherwood station plus water depletions occurring upstream of the station that could have contributed to the recorded flow volumes. Water depletions refer to volumes of water consumed or otherwise removed from the natural flow of the stream. Examples of depletions include water withdrawals for irrigation projects, municipal use, storage in reservoirs and water evaporation losses resulting from storage in reservoirs.

The determination of natural flow is based on standard procedures developed and approved by the International Souris River Board (ISRB). Natural flow apportionment calculations are traditionally provided to the ISRB three times per year to estimate the natural flow occurring in the following three time periods: Jan. 1 - May 31; Jan. 1 – Aug. 31; and Jan. 1 – Dec. 31. The Jan. 1 – May 31 apportionment is conducted to determine if Saskatchewan delivered to North Dakota 50 percent of the first 50,000 dam^3 (40,500 acre-feet) of natural flow that occurred prior to June 1, as required by Annex B.

Image 39 Overland flooding near Towner, North Dakota

The Jan. 1 – Aug. 31 apportionment is conducted to support the ISRB in determining the apportionment balance on or about Oct. 1. Any shortfall that exists as of that date shall be delivered by Saskatchewan prior to Dec. 31. Determining the apportionment balance on or about Oct. 1 provides Saskatchewan with an opportunity to deliver any shortfalls during the fall period to meet the Annex B requirements.

The Jan. 1 - Dec. 31 apportionment is conducted to provide a final annual natural flow apportionment result. This determination of natural flow and the final apportionment balance is provided to the ISRB in February at its winter meeting.

Additional determinations of natural flow may be requested by the ISRB to support operational planning. These additional determinations of natural flow are typically required in low-flow non-flood years.

An evaluation of improvements to the methods or procedures used for the determination of natural flow was beyond the scope of the Study. However, the Study did investigate shifting the period for the determination of entitlements from a Calendar Year to a 'Nov. 1 to Oct. 31' period as one of the core alternative operational plan measures that could be considered.

The Study also made a significant investment in the development of hydrological models for the Souris River basin. These models provide useful insights on the implications of proposed operational changes. They also support the use of performance indicators (PIs) to show the likely effects of various operational measures on a range of water-related interests in the basin.

In addition, the modeling results and PIs also provide information that may be useful to refine the procedures used for the determination of natural flow. Therefore, the Study Board suggests that the ISRB, through its hydrology committee, should review and update the Natural Flow Procedures in the 1989 Agreement; considering the technical studies and modeling done under the Study.

8.2.2 WATER QUALITY

Water quality of the Souris River was identified as an important issue during the Study's public engagement process. In response, the Study developed a series of water quality PIs to help evaluate potential alternative operating measures. The USGS undertook an analysis of the water quality in relation to flow under the guidance of the Study Board. The investigators used a statistical time-series model (R-QWTREND) developed by the USGS for evaluating complex flow-related variability in constituent concentrations. The following water-quality constituents were selected for analysis: chloride; sodium; sulfate; total dissolved solids; total iron; total suspended solids; total nitrogen; total phosphorus; nitrate plus nitrite nitrogen; and dissolved ammonia.

The analysis was conducted for these constituents at three locations in North Dakota: Sherwood, Minot, and Westhope. The R-QWTREND model was used to determine relationships of constituent concentrations to flow, time, and seasonality for the period 1993 to 2018. To address seasonality, each year was partitioned into four seasons.

The R-QWTREND analysis found that variability in concentration for chloride, sodium, sulfate, and total dissolved solids are largely explained by the variability in flow and can be used to evaluate minimum flow thresholds for each season. The variability in other constituents such as total iron, total suspended solids, and nutrients was explained largely by factors such as seasonality. As a result, the implications of minimum flow thresholds were difficult to evaluate.

For reference, the ISRB has a mandate to report yearly on compliance with the established water quality objectives (WQOs) for the two international border crossings near Sherwood and Westhope, North Dakota. Under this mandate, the ISRB has developed a two-year International Water Initiative (IWI) project for evaluating water quality trends for the entire Souris River basin. The ISRB IWI project has run in parallel to the Study. The USGS is leading the effort and will investigate water quality trends for up to 34 sites in the basin, which includes the two binational sites at Sherwood and Westhope. The ISRB IWI project began in the spring of 2020, and has the following objectives:

- perform a comprehensive, integrated, up-to-date water quality trend analysis for selected constituents at sites with sufficient data;
- describe flow-related variability and flow-normalized concentration trends for selected constituents and sites, and statistically describe data from sites with insufficient data for R-QWTREND trend analysis; and,
- evaluate the exceedance rates of the WQOs at the two transboundary locations for the five constituents which consistently have periods of exceeding the WQO and will include the period of record to identify when exceedances began occurring.

The analysis performed under the ISRB IWI project has consolidated water-quality data from various agencies and will provide insight into how processes in the basin affect exceedances of the WQOs at the two binational sites. A database was created and will be maintained to ensure a basin-wide picture of water quality in the Souris River basin.

The water quality analysis performed under the ISRB IWI project could be used to enhance the water quality PIs developed under the Study. The improved water quality PIs will help assess the effectiveness of the operational changes with respect to water quality conditions.

Given the public interest in water quality conditions in the basin, the Study Board concludes that water-quality monitoring should be continued as a basin-wide, long-term activity. It is expected that such an activity would capture a full range of hydrological conditions, changes on the landscape and reservoir operations. The resulting long-term dataset will be critical for evaluating changes in water quality as well as improving knowledge of interconnections between hydrological conditions, landscape changes and reservoir operations on water quality.

8.2.3 AQUATIC ECOSYSTEM HEALTH

As with water quality, aquatic ecosystem health was identified as an important issue in the Reference of the Governments to the IJC and during the Study's public engagement process.

Dissolved oxygen (DO) is a critical indicator of aquatic ecosystem health. Low DO conditions result in fish kills and have negative effects on the health of the aquatic ecosystem. Low DO conditions also can cause constituents such as phosphate, iron, and manganese, which are present in sediments, to become soluble and enter the water column. As a result, it is important to mitigate low DO conditions to reduce the risks of adverse impacts on aquatic ecosystems.

Although the Study did not directly investigate aquatic ecosystem health, it did develop several PIs that provide a measure of the influence that a proposed operational change may have. Like the water quality trends analysis being conducted by the ISRB, the Study recognized that the continuous DO monitoring investigation being conducted by the ISRB as an IWI project will contribute greatly to understanding the processes affecting DO concentrations.

The ISRB DO study began in 2019 and will continue to 2024. Under the project, the USGS has installed continuous DO monitors on the Souris River in North Dakota at Sherwood, Minot and Westhope. These monitors are providing 15-minute, near real-time continuous water quality data on DO, water temperature, and specific conductance levels. The resulting data will be used to improve understanding of DO dynamics and how DO is affected by flow and other factors such as nutrient dynamics, algal growth in the channel, and sediment oxygen demand for different times of the year.

The Study Board concludes that the findings of the continuous DO monitoring study will be useful in improving the aquatic ecosystem health PIs developed under the Study. The improved PIs will help assess the effectiveness of the operational changes with respect to aquatic ecosystem health conditions.

In addition to the improvements in the aquatic ecosystem health PIs developed under the Study, the Study Board believes that the potential for coupling or interconnecting water quantity and quality modelling should be explored. The additional data and knowledge gained from the efforts related to water quality trend analysis and continuous water quality monitoring will offer new insights into the possible interactions between hydrology, climate-driven flow conditions, aquatic ecosystem health and landscape changes.

8.3 Manitoba-based concerns raised by PAG

Throughout the Study's engagement process, Public Advisory Group members from Manitoba raised region-specific concerns related to the Souris River in Manitoba in the river's reach from Westhope (at the North Dakota border) to its discharge in the Assiniboine River near Wawanesa. These concerns were not in the scope of the Study. The items of concern include the following:

1. *Extend the reconstructed hydrology for the Souris River to include the reach from Westhope to Wawanesa, for more complete knowledge of how the river may have been influenced by upstream control structures (reconstructed hydrology would also increase the understanding of contributions into the Manitoba reach, coming from headwaters in the Manitoba and eastern Saskatchewan portions of the Souris River Basin)*

People in the region want a better understanding of the hydrology, the influences of river flow changes historically (with and without flow control structures), including the dams in North Dakota and Saskatchewan and the North Dakota J. Clark Salyer National Wildlife Refuge.

Reconstructed hydrology analysis was conducted by the Study for North Dakota and Saskatchewan, but not in the Manitoba portion of the Souris River basin. To do so would have required additional effort and further analysis of Manitoba/Saskatchewan headwaters and tributaries, and their current and historical influences on contributions into the Souris River. However, these factors did not relate to flow operations of upstream dams on the Souris River, the focus of the 1989 Agreement. The Study analyzed flow changes impacted by upstream structures at Westhope, North Dakota, and correlated benefits and impacts throughout the Manitoba basin using a variety of PIs. Future reconstructed hydrology for the Manitoba reach of the Souris River to its discharge into the Assiniboine River would be useful for a more complete watershed analysis of the basin. Such analysis would improve understanding of how the Souris River is impacted by region-specific influences in the basin (that is, not only the influences from upstream control structures in North Dakota and Saskatchewan).

2. *A better understanding of the United States to Canada apportionment and minimum flow rules established in the current transboundary operating agreement*

The current minimum flow rules are established under the Year 2000 "Appendix A to the Directive to the International Souris River Board for the Interim Measures as Modified for Apportionment of the Souris River." Rules for minimum flows from North Dakota to Manitoba were originally established under the 1959 Interim Measures, referenced in the 1989 Agreement Amendment and Directive dated in 2000 (https://ijc.org/en/srb/who/mandate). During the Study, Manitoba's PAG representatives expressed a desire for a more comprehensive understanding of how upstream structures impact or benefit the minimum flow rules for the Souris River at Westhope into Manitoba, with or without the upstream control structures, including the operations of the J. Clark Salyer National Wildlife Refuge. The concern is whether the operational rules offer sufficient water quantity (flow) into Manitoba. The Study did not analyze the minimum flow rules from North Dakota into Manitoba

3. *A more comprehensive assessment of how the river's water quality in the Manitoba reach may be impacted or benefited by the operations of the Souris River, including structures not in the Study scope (specifically, the J. Clark Salyer National Wildlife Refuge)*

The ISRB conducts water quality analysis at Sherwood and Westhope, North Dakota, and tracks water quality for selected parameters. The interest of Manitoba PAG members is to better understand if the upstream water control structure at the J. Clark Salyer National Wildlife Refuge is influencing water quality in the Souris River reach from Westhope to the Assiniboine River. The concern is whether the operational rules ensure water quality is not worsened from its natural state and that targets are met as the river flows into Manitoba.

8.4 Dam Safety

Even though the topic of Dam Safety was being studied by Saskatchewan in parallel to the development of Plan of Study components, Dam Safety analysis was not originally included in the recommended scope as a task in the work plan for the Study. It should be noted that the usage of the term "Dam Safety" can imply to the public that existing dam integrity issues require immediate attention under current operations but in this system, there is not an imminent threat to the existing dam infrastructure. There are also several other components to Dam Safety analyses including hydrology, hydraulics, and operations guidelines. For this Study, technical questions focused on potential dam operations during extreme rainfall events that can have a magnitude and duration vastly exceeding the 2011 flood.

The July 5, 2017 Reference Letter from Governments to the IJC, and the Sept. 5, 2017, Directive from the IJC to the Study Board, did not include potential dam safety considerations. However, the Study Board did recommend that a dam safety task item be included in the initial work plan (October 2017) with a purpose to evaluate the safety of dam operations given concerns resulting from the 2011 flooding event and updated hydrologic work that was developed by Saskatchewan. The October 2018 revision to the work plan included this task item with a similar task scope.

During the Study, the scope of the dam safety task was questioned by Study participants and the Study Board sought specific guidance from the IJC and governments. In a Dec. 21, 2020 letter from governments, the IJC was advised that issues with respect to dam safety were outside of the scope of the study. In addition, governments stated that they had separately provided direction to the 'designated entities' under the 1989 Agreement to begin technical discussions on understanding the hydrology of the basin that would support further work related to dam safety.

Before the December 2020 guidance was implemented, the Study did consider an alternative that used regulation of flows and reservoir pool levels that in extreme events would reduce overtopping dam risk. Under certain conditions, this alternative could cause flooding that would otherwise not naturally have occurred. The alternative was based on studies completed by Saskatchewan prior to the Plan of Study identifying flow restrictions in Saskatchewan that limited outflows from the Rafferty Reservoir (restricted by spillway capacity) and Grant Devine Reservoir (restricted by a railroad embankment) during extreme events. Examples of these considerations are highlighted in the following paragraphs for which their details may be found in the appropriate technical reports associated with the Study.

During the Study, a detailed modeling tool (HEC-ResSim) was developed that can be used to investigate various operating scenarios that were considered for the overall Study.

Performance Indicators

The Study placed emphasis on the development of performance indicators to more fully understand potential constraints, challenges, and desired outcomes of operational decisions within the basin and to have a method for displaying the effect that a particular operational scenario may have with respect to these performance measures.

A Dam Safety performance indicator was initially derived for Saskatchewan's Rafferty, Grant Devine, and Boundary Reservoirs and Lake Darling Dam in North Dakota. The initial performance indicator was based on evaluation of reservoir pool levels not exceeding the maximum storage limits of the reservoirs. As the Study progressed, variations on criteria and operating concepts were introduced which included potential target flow changes from Annex A and reservoir pool restrictions.

Operating Scenarios and Alternatives

The Study undertook a structured, phased approach to the analysis and evaluation of a broad range of operating scenarios and alternatives. For each of the plan formulation phases, dam safety operations were considered. During Phase 2 of plan formulation, a scenario was discussed based on hydrologic information (extreme storm events) on Rafferty and Grant Devine Reservoirs and potential downstream impacts to include Lake Darling. This study did not look at any other options, but other operational and structural options need to be studied before a plan is selected. For the Study to evaluate the full scope of the Dam Safety task item to a sufficient level of detail, substantial additional time and resources to conduct a thorough analysis of these issues would be required.

The assessment of dam safety alternatives in consideration of dam safety performance indicators was accomplished through Phase 4. Options that included dam safety criteria were identified for further assessment. These options were not considered as operating scenarios after Phase 4 as the task was considered to be outside the scope of the study as per the Dec. 21, 2020 guidance letter from governments.

Subsequently, Phase 5 of the Study did not include any dam safety alternatives but did maintain the performance indicator as an evaluation criterion as noted in the previous section.

Modeling Tool

During Phase 5, a methodology for producing improved results for smaller, less extreme events, such as in 1975 and 1976 flood events, was developed. This improved model constitutes a significant Study contribution providing a valuable a tool that could be used to model operating changes for Rafferty and Grant Devine Reservoirs in Saskatchewan as well as for Lake Darling in North Dakota once the technical discussions on understanding the hydrology of the basin, which would support further work related to dam safety, are concluded.

A description of this modeling tool effort is included in the list of supplementary technical analyses, along with other explorations such as the flood trigger assessment and the yield assessment.

Study Findings and Contributions

The study was not able to significantly advance the discussions on dam safety. Some operational elements were incorporated as an alternative in Phase 4 of the study but were not analyzed or advanced by the time dam safety was removed from the study. A dam-safety performance indicator was carried through as an assessment tool through all phases.

The considerations afforded to the dam-safety performance indicators and operating scenarios did reveal insights into spring and summer operations beyond the existing target flows as defined by Annex A of the 1989 Agreement. For example, the analysis in the early phases of the Study indicated that lowering maximum allowable flows at Sherwood and Minot during spring operations could be achieved without negatively impacting the dam-safety performance indicator in most small-to-moderate flood years. This was further studied under Phase 5 to evaluate how the alternative spring operating rules could be modified to avoid negative dam-safety impacts and ensure flow at Minot does not exceed 14 m^3/s (500 ft^3/s) at the end of May, reducing the frequency of out-of-bank flows downstream.

Several considerations surrounding the implications of various dam-safety operating scenarios were investigated within the Study. These concepts and potential options were not brought to a Study conclusion due to the complexity of the tasks, lack of study resources, and the revised direction by the governments. Some dam-safety elements oriented towards extreme hydrologic events were initially formulated, (pool restrictions, target flow changes, as examples) but the complexity could not be appropriately addressed within the study and accordingly the task item was separated from the ongoing Study work plan.

It should be noted that the study has produced most, if not all of, the tools that will be required to assess the implications of modifying operational rules to accommodate dam-safety criteria. Once the issue of dam safety is satisfactorily resolved, these tools are available to assess and identify a plan that is consistent with the 1989 Agreement and the 1909 Boundary Waters Treaty.

8.5 Adaptive management

Adaptive management is an issue receiving greater attention in water management for all watersheds, including the Souris River basin. The 2017 Reference from the Governments of Canada and the United States to the IJC directed the Souris River Study to assess "possible adaptation strategies to address the potential future variability in water supplies associated with climate change" (Reference Letter item 9).

Objectives of adaptive management

Adaptive management is a structured, iterative approach for improving decisions through long-term monitoring, modeling and evaluation. It ensures that the outcomes of decisions are reviewed and that plans are adjusted, if necessary, as new knowledge becomes available or as conditions change. Fundamentally it is a process that is built on "learning while doing" (IJC, 2012; National Research Council, 2004).

Figure 38 illustrates this process of continuous learning to improve decision making. Core components are the institutional arrangements or governance in which decisions are made, and the need for strong, effective collaboration among the responsible jurisdictions. The process involves an ongoing effort to:

- identify and reduce uncertainties and evaluate options and policies;
- monitor the results of decisions, and incorporate new information to evaluate their performance;
- evaluate water management decisions for consistency with current and updated data, such as:
  - regulations (federal, state, provincial)
  - safety requirements (federal, state, provincial)
  - scientific knowledge (e.g., hydrology, climate change, drainage)
  - Indigenous Nations' interests, knowledge and science, and a recognition of Indigenous Nations as rights[30] holders
  - basin stakeholders' interests, knowledge, and awareness
- identify lessons learned and knowledge gaps to strengthen resilience in the basin
- adjust subsequent management decisions or policies based on the new knowledge as necessary; and,
- complete the feedback loop by reducing uncertainties and applying new knowledge.

[30] Indigenous Nations are recognized as rights and title holders. In Canada, Indigenous Rights are constitutionally enshrined under Section 35 of the Constitution Act, 1982. (See: https://www.rcaanc-cirnac.gc.ca/eng/1100100028574/1529354437231) Canada and the United States often have treaties with Indigenous Nations, although not all Indigenous Nations are signatories to treaties.

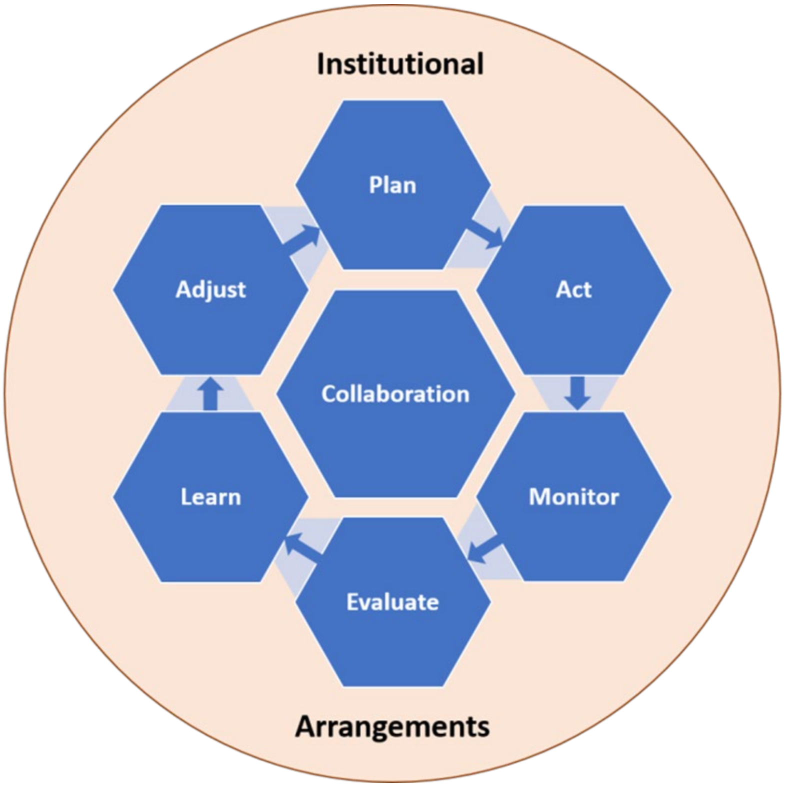

Figure 38 Adaptive management framework (IJC, 2017)

Benefits of adaptive management

Adaptive management is increasingly recognized as having a significant role to play in water management, particularly at the scale of large basins such as the Souris River basin. It can assess the effectiveness of water management efforts considering changing environmental and socioeconomic conditions. This, in turn, can support the ongoing reassessment of models and impacts and the identification of possible changes to operational plans and other resource management decisions. In addition, the process of adaptive management may help decision-makers deal with the uncertainties related to water supplies (e.g., water use availability, flood protection). These uncertainties are affected by natural climate variability and may also be affected by climate change in the basin.

In recent years, the IJC has adopted and promoted adaptive management as a key component of basin-scale water management. For examples[31], the 2006 International Lake Ontario–St Lawrence River Study Report, the 2012 International Upper Great Lakes Study Report, and the 2017 International Rainy-Namakan Rule Curves Study Report all recommended that adaptive management be formally adopted in efforts to manage future water levels and flows in those basins. Adaptive management committees have been established by the IJC to oversee the various stages of the adaptive management

[31] See: Options for Managing Lake Ontario and St. Lawrence River Water Levels and Flows, https://ijc.org/sites/default/files/2018-09/Final%20Report.pdf; Lake Superior Regulation: Addressing Uncertainty in Upper Great Lakes Water Levels, https://www.ijc.org/sites/default/files/Lake_Superior_Regulation_Full_Report.pdf; and Managing Water Levels and Flows in the Rainy River Basin, https://ijc.org/sites/default/files/IRNLRCSB_Final_Report_2017l.pdf.

process in specific transboundary basins, including the Great Lakes-St. Lawrence River Adaptive Management Committee (GLAM) and the Adaptive Management Committee of the International Rainy-Lake of the Woods Watershed Board.

Components of adaptive management processes are currently being practiced in the Souris River basin and have been established in the 1989 Agreement. Some examples include managing flow targets based on forecasting estimates and managing variable drawdown levels of reservoirs based on climate and hydrologic conditions and forecasting estimates. The implementation of one or more of the alternative Operating Plan measures for the Souris River Project evaluated in Section 6 could fit in well with enhancing adaptive management processes. For example, applying adapative mangement principles to extending the winter drawdown to March 1 (Alternative 2) or lowering spring maximum flow levels (Alternative 3) would allow for ongoing monitoring and evaluation of the results and feedback into future decisions to adjust the measures if necessary.

Regardless of the alternative Operating Plan measures that may be adopted to improve operations currently established under the 1989 Agreement, there will continue to be a need in the basin for ongoing communication, monitoring, modeling and research to: assess risk, address uncertainties and changing conditions, and identify appropriate adaptive actions.

Challenges and Opportunities

There are several important challenges to introducing a strengthened process of adaptive management in the Souris River basin.

1. ***The nature of the 1989 Agreement***

A key issue is the nature of the 1989 Agreement. In other boundary waters governed by the 1909 Treaty, international boards established under the IJC are responsible for managing water levels and flows through IJC orders of approval issued in the past by the IJC. In these situations, it is within the IJC's purview to conduct reviews of the orders governing these boards, and to make decisions on if and how those orders should be updated based on new scientific and socioeconomic knowledge. However, the 1989 Agreement covering the Souris River basin is not an instrument of the IJC, but rather an international agreement between the United States and Canada. Article V paragraph 3 of the Agreement states that:

> *"The Parties shall jointly review the Operating Plan at five-year intervals, or as mutually agreed, in an effort to maximize the provision of flood control and water supply benefits that can be provided consistent with the terms of this Agreement."*

However, there is no indication within the text of the 1989 Agreement as to how the Parties should launch such a review, how it should be funded, or who should conduct the review. Lacking any trigger or mechanism to execute a review of the order, the five-year review clause under Article V has never been exercised. Indeed, it took nearly 30 years and a record basin-wide flooding event in 2011 for the 1989 Agreement to be reviewed in this current Study. The Study Board identifies specific adaptive management concepts around this issue to ensure the ISRB can move forward in a coherent way and that all agencies who now have state-of the-art tools at their disposal can maintain and build on these efforts over the near and long term.

Moving forward, if adaptive management is to be formally enhanced for the Souris River basin – with its commitment to continuous monitoring and periodic review of the performance of the operations -- then it will need to have some foundation in an updated Agreement between the two countries.

2. ***Funding***

A second challenge is that as an ongoing process integrated into a broader planning and management regime, adaptive management needs secure funding. Often, funding to address significant water management issues is a response to extreme events such as droughts or floods. Such studies are funded and carried out for a certain number of months or years, and when completed, their funding ends. Adaptive management, by its nature, is ongoing and requires a continuous funding stream (IJC, 2017).

3. ***Multi-party involvement with dedicated ISRB Adaptive Management Resources***

A third important challenge to strengthening adaptive management is that large international watersheds are managed by *multiple agencies* in different jurisdictions. Each agency has authority and funding to address specific components. Each has its own set of federal and state or provincial laws and regulations. Efforts to organize the broader, ongoing coordinated approach of adaptive management must recognize and accommodate these distinct and legitimate interests. Water management agencies, in cooperation with the IJC, must also be willing to commit core human resources to ongoing needs dedicated to adaptive management issues and initiatives; this requires prioritized time commitments. Clear roles should be established for federal (U.S. and Canada), state and provincial agencies. Sources of funding will be required and need to be identified (e.g., potentially through IJC's International Watersheds Initiative program).

Moving forward

There appear to be opportunities for building on several of the Study's initiatives and findings and incorporating an adaptive management approach for managing water levels and flows in the Souris River basin within the context of the 1989 Agreement.

1. **Clarifying the 1989 Agreement**

The Study Board concludes that Article V of the 1989 Agreement stipulating a periodic review of the Operating Plan should be retained, as it provides a clear and predictable opportunity or focus for ongoing learning and improvement. However, the Study Board also concludes that the Governments of Canada and the United States could strengthen the role of adaptive management in the basin by clarifying in the Agreement the organization or organizations responsible for conducting the tasks associated with successful adaptive management -- such as monitoring data, reviewing the science, evaluating the operations, and testing and suggesting future modifications to the Operating Plan. In addition, as agency regulations, and institutional/operational realities may change in time, there is no clearly defined path forward in determining how to deal with such changes and their possible impacts on the 1989 Agreement. Formalizing the review process using adaptive management principles would be beneficial to guide all parties affected by the 1989 Agreement.

The Study Board also suggests that the review period set out in the 1989 Agreement should be extended from an original 5-year cycle to a 7-to-10-year cycle and not longer than 15 years to be consistent with IJC practices but be a more structured and formalized priority. The scientific and financial investments during the current study have produced information that was not available when the original agreement was developed, and these tools need to be retained and used in the future. Key elements from the study are now available with modeling and data infrastructure of the Souris River including:

- Reconstructed hydrology for most of the basin except Manitoba,
- HEC-ResSim
- HEC-RAS
- Stochastically Modeled Sequences of Hydrologic Response
- MESH
- Workflow: Production of Climate-Changed Hydrology, and
- Other modeling and forecasting systems

A culture of continuous evaluation and improvement of these model systems needs to be established. Examples of some continuous improvement leading to better knowledge and decision-making for the Souris River flow operations could include:

- Using an index such as Standardized Precipitation-Evapotranspiration Index (SPEI) to assess basin antecedent conditions guiding decisions on winter drawdown variations (or determining other options or improved indices over SPEI, should they become available as scientific advancements are developed in the future);
- Augmenting forecasting procedures for Spring Freshet and rainfall events as new tools are developed to better understand hydrologic inputs;
- Improving the evaporation estimates pertaining to the basin reservoirs for apportionment and accounting of river flow as scientific knowledge increases; and,
- Incorporating new understanding of water quality, drainage, natural climate variability, human-driven climate change, ecosystems, land use development and infrastructure changes (including water infrastructure), etc.

Undertaking continuous improvements and facilitating reviews on a 7-to-10-year basis require planning and targeted resources. The investigations conducted for such formalized reviews may be comparable in scope to some components of the technical analysis completed under the Souris River Study and would build on the newly developed Study models. Reviews would allow for improved understanding of important trends in operations, climate variability and land use changes as they emerge. Adaptive management studies and formalized reviews would build on, and enhance the existing data, models and evaluation tools developed and used in the current Study.

The Study Board suggests that the IJC and the ISRB should consider possible options for consideration by governments on adaptive management governance and activities. This would include considerations related to preparing for formalized periodic reviews for an appropriate timeframe, but no later than the proposed maximum 15-year interval. As an example, the IJC and ISRB may want to designate an existing committee or create an adaptive management sub-committee for this purpose.

Finally, the Study Board suggests that the Agreement stipulates the development, approval, and review of Reservoir Regulation Manuals (see Section 4 – Review of the 1989 Operating Plan). Under the existing Agreement, the Reservoir Regulation Manuals require the approval of the Governments of Canada and the United States. These manuals could be further broadened to provide a mechanism that allows specific changes to be made to dam operations that are clearly defined and identified under an ongoing adaptive management process (e.g., under an "Operational Guidelines" document that defines a set of criteria for operations such as the rule curves established in Rainy-Namakan operations). The operational flexibility needed for improvements guided by new information may possibly be achieved if established "Operational Guidelines" were reviewed and updated at regular intervals (for example, every five years). The mechanism to achieve this is not yet clear but may be possible if some acceptable defined conditions could be established in the Agreement, perhaps with revisions only requiring the approval of the ISRB (akin to the Rainy-Namakan Reference and rule curves example presented above).

The Souris River System is operated by three separate agencies (WSA, USACE, USFWS) who are responsible for operating the dams in accordance with Annex A of the 1989 Agreement, and to comply with their own legal requirements. As new information becomes available (e.g., new design requirements or standards, flood-plain management regulations, infrastructure changes, drainage regulations, etc.) it is possible that the implementation of the Operating Plan outlined in the Agreement may have conflicting challenges (e.g., jurisdictional mandates or legal requirements may differ). It is essential that any inconsistencies that emerge in this regard be raised quickly, transparently and brought to the attention of governments with recommendations for resolution in an as expedient a manner as possible. The Study Board recommends that operating agencies be directed to bring any information that could impact the operation of the Agreement to the IJC (through the ISRB) as soon as they are made aware of them. The ISRB and the IJC would review the information and make recommendations to governments within a specified timeframe on how the issues might be addressed.

2. ***Strengthening the role of performance indicators (PIs); Indigenous Science***

The development of PIs was of particular benefit to the study, as they represented a collection of expert knowledge linking the operation of the Souris River basin to the impacts to areas of concern for agencies and other interests. These PIs were developed through significant efforts involving engagement, collaborative investigation, and numerical modeling to produce the deterministic mathematical links between impacts such as flooding, water availability, fish habitat, and recreation with dam operations.

Evaluation tools such as these PIs are key tools in an adaptive management process for the basin. If they are maintained and kept current, they represent the essential and reproducible evaluation toolset for the process of continuous learning and improvement. Therefore, having made this initial investment in PIs for the Study, it is in the interest of all parties to maintain the relevance of PIs and to expand their scope to bridge knowledge gaps that were unable to be addressed during this Study.

Given the Study's time and resource limitations, some classes of PIs were not investigated or did not adequately capture the natural processes (e.g., biological, chemical, and physical processes, dissolved oxygen and/or more comprehensive suite of water quality characteristics in the river; water flow and quality impacts of land use practices including drainage and complex interactions between land, riparian zones, groundwater systems and the river). Such detailed scientific analysis was not used in the evaluations of alternative Operating Plan measures. For example, the water quality and ecosystem health PIs did not yield the strong relationships with operational activities to make a useful contribution to the Study's analysis. As new knowledge of land use activities and on natural processes becomes available, this information could be included in hydrologic models and possibly influence adaptive management decisions.

Of special note is the potential for improved engagement with Indigenous Nations in the basin on future water management challenges. The relationships initiated under the Study with Indigenous Nations were highly worthwhile but were developed too late in the Study process to allow for the time required to develop mathematical PIs of interest to many of the Nations. The Study was successful in working with only one Nation to develop PIs that were fully incorporated into the Study's numerical modeling work. Other Nations have expressed concern that they were unable to contribute in the same way and have asked for assurances that there will be future opportunities to collaborate in this regard. An adaptive management process can allow for this continued collaboration to proceed and be of real value following the Study. Furthermore, beyond the use of PIs, adaptive management processes should seek to incorporate ongoing observations and inputs not just from western science, but also from ***Indigenous Knowledge***[32] and ***Indigenous Science***.

To address these concerns and promote the strengthening of adaptive management approaches in the basin, the Study Board recommends that the PI products be retained and enhanced into the future by the operating agencies (USACE, USFWS, WSA) under the leadership and direction of the ISRB. The ISRB should be charged with regularly reviewing, improving and updating the PIs, with support from the IJC, either through dedicated adaptive management activities or through the International Watershed Initiative (IWI) Program.

3. *Establishing an adaptive management committee for the Souris River basin*

The Study Board recommends that the IJC and governments work with the ISRB to consider options for moving forward with adaptive management in the basin under the Agreement. For example, an adaptive management committee or another responsible body could be established under the ISRB in a manner similar to the previously established IJC committees noted above.

Successful implementation of an adaptive management strategy requires a commitment to:

- setting priorities;
- engaging with all interests in the basin, including Indigenous Nations;
- maintaining operational models and data;
- monitoring the implementation of plans;

[32] Indigenous Knowledge relates to understandings, skills and philosophies of Indigenous societies with long histories of interaction with their natural surroundings (See: http://www.unesco.org/new/en/natural-sciences/priority-areas/links/related-information/what-is-local-and-indigenous-knowledge); Indigenous Science is often linked with traditional ecological knowledge (See: https://onlinelibrary.wiley.com/doi/abs/10.1002/1098-237X(200101)85:1%3C6::AID-SCE3%3E3.0.CO;2-R)

- assessing performance and incorporating new science as it becomes available; and,
- ensuring the dam operators and other key interests have the information they need to adjust their plans as needed.

This effort requires a commitment of resources to effectively manage and execute the full scope of adaptive management tasks. It also requires a designated group to be accountable for the process.

9 Study Board Findings and Recommendations

Section 9 presents the major findings and recommendations of the International Souris River Study Board (Study Board).

The Study Board acknowledges that the governance mechanism of the 1989 Agreement differs in both countries. Canada has designated the Province of Saskatchewan as the Canadian entity for the construction, operation, and maintenance of the improvements mentioned in the Agreement, whereas in the United States, these responsibilities have been designated to federal agencies – the U.S. Army Corps of Engineers and the U.S. Fish and Wildlife Service. It must also be noted that the ISRB has an oversight responsibility and function, under the purview of the IJC which includes providing the IJC and the designated entities, under the 1989 Agreement, recommendations on how flood operations and coordination activities could be improved. Keeping this in mind, under the ISRSB's analysis, the Study team has grouped its analyses under a series of five themes, outlining its findings and recommendations. **It is important to understand that some of these findings and recommendations may result in changes to the 1989 Agreement. The Parties to the Agreement (i.e., the governments) will need to determine a resolution framework for these recommendations**.

9.1 The challenge of flood control and water supply in the Souris River basin

For more than 80 years, Canada and the United States have worked together through the International Joint Commission (IJC) to manage the transboundary waters of the Souris River for the benefit of a range of interests, including communities, agriculture, industry, recreation, and ecosystems. Today, the waters of the Souris River are extensively managed for flood control and water supply by dams, diversion canals and other water resource infrastructure. Major reservoirs include the Boundary, Rafferty and Grant Devine in Saskatchewan, and Lake Darling in North Dakota.

The current Operating Plan for the basin has been in place since 1989, part of the *1989 International Agreement between the Government of Canada and the Government of the United States of America for Water Supply and Flood Control in the Souris River Basin* (the 1989 Agreement). That Agreement requires a periodic review of the plan to improve the provision of flood control and water supply benefits.

The climate and topography of the Souris River basin presents complex challenges to providing both flood control and water supply benefits to the community residents, farmers and ranchers and other interests in the basin. Long, cold winters tend to retain snowfall until the spring melt. As well, much of the basin is part of the prairie pothole region, characterized by shallow potholes or kettle lakes. Together, these factors can contribute to highly variable flows in the basin, from day to day and from year to year, and make it highly vulnerable to the impacts of extreme weather conditions.

In 2011, the Souris River basin experienced an unprecedented flood, far exceeding the scale of any other flood event in the more than 100 years for which records are available. Extremely wet conditions in the preceding fall, combined with an above average snowmelt and heavy spring and early summer rainfall resulted in long-duration flooding from spring through summer, that significantly affected homeowners, businesses, and properties throughout the basin. Water management and control structures were severely tested as never before.

The 2011 flood focused renewed attention on the existing Operating Plan under the 1989 Agreement and led to calls for additional flood protection measures to be considered.

This Study is a direct response of the Governments of Canada and the United States to the 2011 extreme flooding event. Following extensive discussions with interests in the region, the IJC submitted to the two federal governments a Plan of Study to address the challenges of flood protection and water supply in the basin. In 2017, the governments issued a Reference for the IJC to undertake a study to evaluate and make recommendations regarding:

- the Operating Plan contained in Annex A to the 1989 Agreement; and,
- how the provision of flood control and water supply benefits in the basin might be maximized

The Study Board sought to address these objectives by means of a comprehensive, cooperative, and scientifically rigorous approach. Using extensive modeling supported by a broad participatory approach to planning and evaluation, the Study Board developed and evaluated numerous alternative Operating Plan measures under a wide range of climate and water supply conditions. It tested, refined, and re-evaluated these alternatives, until it was able to focus in on a small number of alternative measures that had potential to improve flood control and water supply benefits in the basin. It also evaluated these alternatives against the performance of the existing 1989 Operating Plan.

Finally, the Study Board addressed several important emerging water management issues in the basin, including future climate conditions and the role of adaptive management.

Over the course of its work, the Study Board directly engaged the many interests in the basin, through the Public Advisory Group (PAG) and the Resource and Agency Advisory Group (RAAG). The Study Board also met with Tribes, First Nations, and the Métis Nation throughout the basin. With the support of the PAG, RAAG, and Indigenous Nations, the Study Board developed and implemented numerous engagement and outreach activities to ensure that all interests in the basin were aware of the Study; they contributed their knowledge and expertise representing their interests, views and concerns of the basin, and were encouraged to share the Study progress and findings with others in their own networks.

The analyses, findings and recommendations of the Study are the products of this broadly-based cooperative effort across the Souris River basin.

9.2 Key findings and recommendations

Based on the results of the analyses described in this report, the Study Board presents the following findings and recommendations, grouped under five key themes:

- improving Annex A of the 1989 Agreement;
- strengthening water supply and flood control benefits;
- improving data collection and management;
- addressing other important water management challenges in the basin; and,
- building on the Study's engagement and outreach.

9.2.1 REVIEWING THE 1989 AGREEMENT

Finding 1(a): 1989 Agreement Language review for Annex A

The Study Board completed its review of the language of the 1989 Agreement. The Study Board agreed on an updated 2020 plain language document to strengthen the language for clarity and improved understanding. Six items were unresolved in the review. Improved plain language of the agreement is useful to guide the IJC and the jurisdictions responsible for operating the structures in the river system.

Therefore, the Study Board recommends that:

> The IJC support the plain language revisions and clarifications to the 1989 Annex A recommended by the Study Board (revised language will need legal review and an implementation plan).
>
> The IJC consider advising the governments on the six issues that need guidance, direction, and legal analysis by the Parties to the Agreement.

Finding 1(b): Performance of the 1989 Operating Plan

The Study Board concluded that, overall, the 1989 Operating Plan has performed well in providing water supply and flood control benefits.

The addition of Grant Devine Lake, Rafferty Reservoir, Boundary Reservoir, and Lake Darling to the Souris River basin (i.e., the Souris River System) provided flood protection for the spring snowmelt in 2011 but does not provide enough flood storage for protection from runoff similar in magnitude to the summer 2011 basin-wide rainfall runoff events. However, the reservoirs do provide significant to modest flood protection from the Estevan, Saskatchewan reach to as far downstream as Westhope, North Dakota, and into Manitoba for floods similar in magnitude to the major floods experienced in 1969 and 1976.

In addition to the direct benefits to flood control and water supply, the presence of the Souris River Project reservoirs, as modeled under the baseline simulation, also resulted in benefits and impacts to secondary effects on environmental resources, socio-economic components, historic and cultural sites, water quality and recreation.

The existing plan under the 1989 Agreement works well in relation to water supply and flood control. There are no major operational changes that will result in significant improvements in both water supply and flood control benefits across the basin.

The Study Board recommends that:

> The modeling systems developed by the Study and used to evaluate flow scenarios (including the effects and performance of the 1989 Agreement), continue to be used and updated to evaluate operational performance.

9.2.2 STRENGTHENING WATER SUPPLY AND FLOOD CONTROL BENEFITS

Finding 2: Alternative measures for consideration of improvements to the 1989 Agreement

The hydrological research by the Study supports the conclusion that the 1989 Agreement is effective in achieving its intended objectives of flood protection and water supply benefits. Based on the modeling that was completed, only marginal benefits to water supply and flood protection could be identified. This is due to the constraints of the basin's natural characteristics and the river system's existing water infrastructure.

The Study team has documented through extensive analyses, the merits and effectiveness of the 1989 Agreement, in providing flood protection and water supply, within the constraints of the natural systems and human-built water infrastructure systems of the Souris River. While the 1989 Agreement is functioning well, options for improvements exist, but will result in a need to balance performance trade-offs.

Based on its evaluation of the alternatives, the Study Board made the following key findings:

Alternative Measure 1:

Winter Drawdown Targets – Options 1 and 2

The analysis of **Alternative Measure 1** showed that:

- Antecedent soil moisture conditions can be used for operational decisions on winter drawdown target elevations, adjusting for Dry, Normal or Wet basin conditions, with trade-offs to the amount of water stored in reservoirs
- Depending on the option selected, benefits could be accrued to water supply or to river water quality
- Reservoir storage would still require flood risk management

Alternative Measure 2:

Winter Drawdown Extension to March 1

The analysis of **Alternative Measure 2** showed that:

- Extending the reservoir drawdown target date from Feb. 1 to March 1 draws water down from the reservoirs over a longer winter period, improving river water quality and aquatic habit

Alternative Measure 3:

Lower Spring Maximum Flow Limits

The analysis of **Alternative Measure 3** showed that:

- Lowering of the spring maximum flow limits reduces flood risk of agricultural lands downstream of Minot with a trade-off of storing water at higher levels in the reservoirs
- This approach reduces flood risk for small to moderate flood events (peak flows of approximately 57-85 m^3/s (2,000-3,000 ft^3/s) at Minot, North Dakota)
- The trade-off is that storage used for these smaller floods may not be available should a larger flood event occur (i.e., increased risks could occur)

Alternative Measure 4:

Summer Operations - Options 1 and 2

The analysis of **Alternative Measure 4** showed that:

- Establishing a more robust summer operation plan that provides clearer operator guidance in managing summer floods
- Both options use reservoir storage and require careful management to reduce reservoir impacts and manage risk related to the passage of higher flood events should they occur

Alternative Measure 5:

Apportionment Year Shift to a Water Year (November to October)

The analysis of **Alternative Measure 5** showed that:

- Changing apportionment rules to be calculated from November to October ensures winter releases of water from Canadian reservoirs supporting flood risk management are credited to Canada as apportionment to the United States; this would result in more gradual releasing of flood water and assist in water supply storage and management in Canada

- The volume of apportioned water is not changed. However, the trade-off in changing the apportionment rules to a Water Year from a Calendar Year (January to December) results in a shift of timing for the apportioned water delivered to the United States, and slightly decreases the storage at Lake Darling in the United States

Therefore, the Study Board recommends that:

The following suite of alternative measures be considered for incremental or marginal improvements to the 1989 Agreement:

1. M**odify the Winter Drawdown Elevation Targets** to build greater flexibility into reservoir operations by varying reservoir elevation targets according to antecedent moisture conditions in the basin
2. **Extend the Winter Drawdown Date** from Feb. 1 to March 1 to provide additional river flow for improved environmental benefits during February
3. **Lower the Spring Maximum Flow Limits** to reduce flood peaks and agricultural flood risk during small to moderate floods in riverine reaches in North Dakota (i.e., floods under 57-85 m^3/s or 2,000 to 3,000 ft^3/s)
4. **Establish a Summer Operating Plan** to provide more guidance to reservoir operators to better manage summer reservoir operations under all conditions
5. **Shift the Apportionment rule calculations to a Water Year** (November to October) from the current Calendar Year (January to December) to ensure flood protection releases in November and December are credited towards apportionment.

Selecting the best options will need to consider the full suite of alternative measures, options within the measures, and seasonal sequencing, culminating in choices to replace or remain within established 1989 rules. Careful analysis of trade-offs is required by the Governments of Canada and the United States to find the best and most balanced options for Canada, the United States, Saskatchewan, North Dakota, Manitoba, and the citizens in the basin, including Indigenous Nations, and diverse stakeholders who have vested interests in the Souris River basin.

9.2.3 IMPROVING DATA COLLECTION AND MANAGEMENT

Finding 3: Precipitation gauges

The Study Board identified that gaps in precipitation gauging exist, affecting the meteorological data and risk analysis, which could impair data analysis and decision making for flow management.

Therefore, the Study Board recommends that:

> The IJC, through the International Souris River Board, engage with all the appropriate agencies, to report regularly on any efforts to reduce identified gaps in precipitation gauging stations within the Souris River watershed.
>
> The IJC work with the International Souris River Board to determine an appropriate reporting interval.

Finding 4: Streamflow metering gauges

The Study Board identified gaps in flow gauging (also found in previous studies). These gaps impair analysis of river flow data and risk analysis, which could impair flow management decisions.

Therefore, the Study Board recommends that:

> The IJC, through the International Souris River Board, engage with all the appropriate agencies, to report regularly on any efforts to reduce identified gaps in streamflow gauging stations within the Souris River Watershed.
>
> The IJC work with the International Souris River Board to determine an appropriate reporting interval.

Finding 5: Collection of additional hydrologic data

The Study Board identified gaps in key hydrological data and data collection in the Souris River basin. These include gaps in:

- monitoring snow survey data for flood forecasting and water supply management;
- soil moisture data that affect knowledge of antecedent conditions affecting hydrology; and,
- low-flow and drought monitoring tools for water supply decision support, including methods and datasets to better estimate evapotranspiration data for reservoirs and throughout the basin.

In addition, there is a need for improved hydrologic models targeted to the Souris River prairie topography, blowing snow, frozen ground conditions and artificial drainage conditions within the basin.

Each of these gaps and needs influence effective decision making for flood protection and water supply management.

Therefore, the Study Board recommends that:

> The IJC, through the International Souris River Board, engage with the appropriate agencies, to prioritize and report regularly on any efforts to reduce identified gaps in other hydrologic data within the Souris River Watershed.
>
> The IJC work with the International Souris River Board to determine an appropriate reporting interval.

Finding 6: Better dissemination of hydrologic data

Better dissemination of hydrologic data is necessary to incorporate real-time meteorological and hydrological data for the Souris River basin. Reinvigorating the IJC website would allow for improved awareness of actual basin conditions by the public and other users of the IJC website and promote better flood protection and water supply awareness to serve as an advance warning system to guide mitigation measures, as well as to improve public awareness of flow operations management.

Therefore, the Study Board recommends that:

> The IJC, through the International Souris River Board, develop better methods to disseminate all hydrologic data (including flood forecasting, water flows, and flow operations) in the Souris River Watershed, and that these efforts be reported on regularly.

Finding 7: LiDAR and bathymetry for reservoirs

Area-capacity curves are used to understand the volume of water stored in reservoirs. Data gaps need to be filled to develop more accurate area-capacity curves for Rafferty and Grant Devine Reservoirs. Gathering this data will improve flood forecasting, water supply and operational flow management of these reservoirs.

Therefore, the Study Board recommends that:

> The IJC work with the Saskatchewan Water Security Agency (through the International Souris River Board) to provide updates on identifying and filling in data gaps in the Rafferty and Grant Devine area-capacity curves (for example, using LiDAR or bathymetry) for developing improved hydraulic models.

9.2.4 ADDRESSING OTHER WATER MANAGEMENT CHALLENGES IN THE BASIN

Finding 8: Artificial drainage

Artificial drainage is practiced throughout the basin. Insufficient scientific data exist to fully understand its potential impacts on water supply, water quality and apportionment for flow management. The public and many stakeholders have expressed concerns about artificial drainage risks and impacts. Regulations and legal requirements are continually being reviewed as scientific understanding of artificial drainage increases. The IJC and the Souris River basin resource agencies and the public need to be aware of the current knowledge and legal requirements of artificial drainage and its potential impacts on operations management of the Souris River.

It is recognized that artificial drainage may have linkages to IJC's mandate through apportionment. Furthermore, there are also public concerns on drainage impacts to water quality, water quantity and wetlands.

Therefore, the Study Board recommends that:

> The International Souris River Board share scientific understanding of Souris River artificial drainage every two years, to advance evolving expert and public knowledge of the impacts, as well as the associated legal and regulatory requirements.

Finding 9: Adaptive management

Adaptive management approaches have been established in the 1989 Agreement (e.g., adjusting flows and reservoir levels to address climate and hydrologic variability). Building on several of the Study's initiatives and findings, there are opportunities to strengthen adaptive management approaches for managing water levels and flows in the Souris River basin within the context of the Agreement. Furthermore, adaptive management approaches would seek to continually adapt to new knowledge, new science, and changing basin conditions for improved operations and decision making.

Therefore, the Study Board recommends that:

> The IJC (and, where necessary, the Parties to the Agreement) consider strengthening adaptive management approaches in managing water levels and flows of the Souris River, with the understanding that any changes to the 1989 Agreement will require government to government consensus. Strengthening adaptive management may include, among other things:
>
> - clarifying roles and responsibilities for conducting adaptive management tasks (e.g., determine if the ISRB, a new adaptive management committee, or a different governance structure is best suited to assume adaptive management roles; support roles of operating and designated agencies participating in adaptive management, etc.);

- extending but formalizing the period of review of the Operating Plan from five years to potentially up to 15 years (a better period for adapting to new knowledge); and,
- clarifying the roles and responsibilities of the IJC and the International Souris River Board in adaptive management studies and periodic reviews.

Adaptive management should consider the on-going role of performance indicators and how they may be a useful tool in guiding new knowledge, studies, and decisions. Adaptive management should consider the role of Indigenous Nations and Indigenous Science, and how this knowledge can be incorporated and strengthened under the leadership of the ISRB. The ISRB should be responsible for reviewing and updating the PIs developed in the Study and collaborating with Indigenous Nations to develop performance indicators that reflect their interests.

Adaptive management will require dedicated resources from many agencies. The IJC and governments will need to work with the ISRB to consider options for establishing adaptive management governance processes and activities.

Moving forward, if adaptive management is to be formally enhanced for the Souris River basin – with its commitment to continuous monitoring and periodic review of the performance of the operations -- then it will need to have some foundation in an updated Agreement between the two countries.

9.2.5 BUILDING ON THE STUDY'S ENGAGEMENT AND OUTREACH

Finding 10: Continued engagement with the Public Advisory Group and the Resource and Agency Advisory Group

The Study Board has undertaken extensive public and resource agency engagement over the course of the Study. There are now increased interests and expectations for future engagement beyond the Study, and for an ongoing dialogue between these groups and the IJC in the future.

Therefore, the Study Board recommends that:

The IJC and International Souris River Board consider continued engagement with the Study's Public Advisory Group and Resource and Agency Advisory Group.

Finding 11: Engagement with Indigenous Nations

The Study Board sought input from Indigenous Nations with current and ancestral interests in the Souris River basin. The increased awareness from Indigenous Nations has led to an interest in continued engagement beyond the Study, through an Indigenous Advisory Group and Indigenous representation on the International Souris River Board.

Therefore, the Study Board recommends that:

> The IJC continue to engage with Indigenous Nations. Indigenous Nations expressed interest in forming an Indigenous Advisory Group and participating as Board Members on the International Souris River Board.

9.3 Summary of recommendations

The Study Board recommends that:

1. Reviewing the 1989 Agreement

a. 1989 Agreement Language review for Annex A

> The IJC support the plain language revisions and clarifications to the 1989 Annex A recommended by the Study Board (revised language will need legal review and an implementation plan).
>
> The IJC consider advising the governments on the six issues that need guidance, direction, and legal analysis by the Parties to the Agreement.

b. Performance of the 1989 Operating Plan

> The modeling systems developed by the Study and used to evaluate flow scenarios (including the performance of the 1989 Agreement), continue to be used and updated to evaluate operational performance.

2. Strengthening flood control and water supply benefits

> The following suite of alternative measures be considered for incremental or marginal improvements to the 1989 Agreement:
>
> 1. **Modify the Winter Drawdown Elevation Targets** to build greater flexibility into reservoir operations by varying reservoir elevation targets according to antecedent moisture conditions in the basin
> 2. **Extend the Winter Drawdown Date** from February 1st to March 1st to provide additional river flow for improved environmental benefits during February

3. **Lower the Spring Maximum Flow Limits** to reduce flood peaks and agricultural flood risk during small to moderate floods in riverine reaches in North Dakota (i.e., floods under 57-85 m^3/s or 2,000 to 3,000 ft^3/s)
4. **Establish a Summer Operating Plan** to provide more guidance to reservoir operators to better manage summer reservoir operations under all conditions
5. **Shift the Apportionment rule calculations to a Water Year (November to October)** from the current Calendar Year (January to December) to ensure flood protection releases in November and December are credited towards apportionment

Selecting the best options will need to consider the full suite of alternative measures, options within the measures, and seasonal sequencing, culminating in choices to replace or remain within established 1989 rules. Careful analysis of trade-offs is required by the Governments of Canada and the United States to find the best and most balanced options for Canada, the United States, Saskatchewan, North Dakota, Manitoba, and the citizens in the basin, including Indigenous Nations, and diverse stakeholders who have vested interests in the Souris River basin.

3. Precipitation gauges

The IJC, through the International Souris River Board, engage with all the appropriate agencies, to report regularly on any efforts to reduce identified gaps in precipitation gauging stations within the Souris River watershed.

The IJC work with the International Souris River Board to determine an appropriate reporting interval.

4. Streamflow metering gauges

The IJC, through the International Souris River Board, engage with all the appropriate agencies, to report regularly on any efforts to reduce identified gaps in streamflow gauging stations within the Souris River Watershed.

The IJC work with the International Souris River Board to determine an appropriate reporting interval.

5. Collection of additional hydrologic data

> The IJC, through the International Souris River Board, engage with the appropriate agencies, to prioritize and report regularly on any efforts to reduce identified gaps in other hydrologic data within the Souris River Watershed.
>
> The IJC work with the International Souris River Board to determine an appropriate reporting interval.

6. Better dissemination of hydrologic data

> The IJC, through the International Souris River Board, develop better methods to disseminate all hydrologic data (including flood forecasting, water flows, and flow operations) in the Souris River watershed, and that these efforts be reported on regularly.

7. LiDAR and bathymetry for reservoirs

> The IJC work with the Saskatchewan Water Security Agency (through the International Souris River Board) to provide updates on identifying and filling in data gaps in the Rafferty and Grant Devine area-capacity curves (for example, using LiDAR or bathymetry) for developing improved hydraulic models.

8. Artificial drainage impacts review

> The International Souris River Board share scientific understanding of Souris River artificial drainage every two years, to advance evolving expert and public knowledge of the impacts, as well as the associated legal and regulatory requirements.

9. Adaptive management

The IJC (and, where necessary, the Parties to the Agreement) consider strengthening adaptive management approaches in managing water levels and flows of the Souris River, with the understanding that any changes to the 1989 Agreement will require government to government consensus. Strengthening adaptive management may include, among other things:

- clarifying roles and responsibilities for conducting adaptive management tasks (e.g., determine if the ISRB, a new adaptive management committee, or a different governance structure is best suited to assume adaptive management roles; support roles of operating and designated agencies participating in adaptive management, etc.);
- extending but formalizing the period of review of the Operating Plan from five years to potentially up to 15 years (a better period for adapting to new knowledge); and,
- clarifying the roles and responsibilities of the IJC and the International Souris River Board in adaptive management studies and periodic reviews.

Adaptive management should consider the ongoing role of performance indicators and how they may be a useful tool in guiding new knowledge, studies, and decisions. Adaptive management should consider the role of Indigenous Nations and Indigenous Science in the development of PIs for the Souris River, and how this knowledge can be incorporated and strengthened under the leadership of the International Souris River Board. The ISRB should be responsible for reviewing and updating the PIs developed in the Study and collaborating with Indigenous Nations to develop performance indicators that reflect their interests.

Adaptive management will require dedicated resources from many agencies. The IJC and governments will need to work with the ISRB to consider options for establishing adaptive management governance processes and activities.

Moving forward, if adaptive management is to be formally enhanced for the Souris River basin – with its commitment to continuous monitoring and periodic review of the performance of the operations -- then it will need to have some foundation in an updated Agreement between the two countries.

10. Continued engagement with the Public Advisory Group and the Resource and Agency Advisory Group

> The IJC and International Souris River Board consider continued engagement with the Study's Public Advisory Group and Resource and Agency Advisory Group.

11. Engagement with Indigenous Nations

> The IJC continue to engage with Indigenous Nations. Indigenous Nations expressed interest in forming an Indigenous Advisory Group and participating as Board Members on the International Souris River Board.

References

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Glossary

The following is a list of key technical terms used in the main report.

1:100-YEAR FLOOD: - A flooding event that has a 1 percent chance of occurring every year and a 39.5 percent chance of occurring at least once over a period of 50 years, and a 63.4 percent chance of occurring at least once over a period of 100 years.

1:10-YEAR FLOOD – A flooding event that has a 10 percent chance of occurring every year and a 99.5 percent chance of occurring at least once over a period of 50 years.

1989 AGREEMENT (*1989 International Agreement between the Government of Canada and the Government of the United States of America for Water Supply and Flood Control in the Souris River Basin*) – A comprehensive framework for jointly managing the waters of the Souris River basin. The broad purposes of the Agreement are to provide water supply to Canada and flood control to the United States. It provides a set of objectives, operating guidelines and responsibilities, and review mechanisms regarding management of the major water control structures and apportionment of flows in the basin.

1989 OPERATING PLAN (See Annex A of the 1989 AGREEMENT)

ADAPTIVE MANAGEMENT – A planning process that can provide a structured, iterative approach for improving actions through long-term monitoring, modeling and assessment. Through adaptive management, decisions can be reviewed, adjusted, and revised as new information and knowledge becomes available or as conditions change.

ALTERNATIVES – In the context of the Study, alternatives are a change or series of changes to how the basin's reservoir system is operated – that is, the levels of reservoirs and the timing of releases affecting flows, or a physical change to one of more of the reservoirs.

ANNEX A – Part of the 1989 Agreement between Canada and the United States that provides the plan for the operations of the four main reservoirs for flood control and water supply. It includes data on the physical characteristics of the reservoirs, prescribes rules for flood and non-flood operations, and sets out procedures for communications and the exchange of information among the responsible agencies. Also known as the **1989 Operating Plan**.

ANNEX B – Part of the 1989 Agreement that outlines the water apportionment agreement between Canada and the United States.

APPORTIONMENT – For the purposes of the ISRSB study, apportionment refers to the determination of the division of water (i.e., water sharing) between Canada and the United States based on the 1989 Agreement and the 1959 Interim Measures as amended in 2000.

BATHYMETRY – Measurement and charting of water depths, channel configurations and cross-sections to describe the channel's width, depth, geometry, and alignment.

BOUNDARY WATERS TREATY OF 1909 – The agreement between the United States and Canada that established principles and mechanisms for the resolution of disputes related to boundary waters shared by the two countries. The International Joint Commission was created as a result of this treaty.

CLIMATE – The prevalent weather conditions of a given region (temperature, precipitation, wind speed, atmospheric pressure, etc.) observed throughout the year and averaged over a number of years.

CLIMATE CHANGE – Long-term significant change in the expected patterns of average weather of a specific region over an appropriately significant period as a result of changes in atmospheric conditions and/or oceanic conditions.

CLIMATE VARIABILITY – Naturally occurring climate phenomenon reflecting the interaction between the ocean and the atmosphere for a specified period.

CONTROL STRUCTURES – Hydraulic structures (dams, spillways, canals, and channel improvements) built to control outflows and levels of a river or rover system.

DIRECTIVE – An IJC instruction to a new or existing Study Board specifying the study's terms of reference, including tasks and responsibilities.

ECOSYSTEM – A biological community in interaction with its physical environment and including the transfer and circulation of matter and energy.

EFFECTIVE DRAINAGE AREA – The area that excludes marsh and slough areas and other natural storage areas that would prevent runoff from reaching the mainstream in a year of average runoff.

ENSO (El Niño Southern Oscillation) – The term given to the phenomena of irregular changes in air and sea temperatures over the eastern Pacific Ocean that can last several months. Changes, whether to cooler or warmer than normal, can influence the jet stream and weather patterns over North America.

ENVIRONMENT – Air, land, or water; plant and animal life including humans; and the social, economic, cultural, physical, biological, and other conditions that may act on an organism or community to influence its development or existence.

HABITAT – The particular environment or place where a plant or an animal naturally lives and grows.

HYDRAULICS – Study of the mechanical properties of liquids, including energy transmission and the effects of flow of water.

HYDROLOGY –Study of the properties of water, its distribution and circulation on and below the earth's surface and in the atmosphere.

INTERESTS – In the context of the Study, groups, systems, or activities served by water levels and flows of the Souris River basin, such as: domestic, municipal, and industrial water use; riparian landowners; ecosystems; and cultural/archeological interests. (Note: this is a different term as used in the 1909 Boundary Waters Treaty's use of "Interests")

INTERNATIONAL JOINT COMMISSION (IJC) – International independent agency formed in 1909 by the United States and Canada under the *Boundary Waters Treaty* to prevent and resolve boundary waters disputes between the two countries. The IJC makes decisions on applications for projects such as dams in boundary waters, issues Orders of Approval and regulates the operations of many of those projects.

LiDAR – A method for collecting data using laser beams, similar to sonar or radar. LiDAR is an acronym for "Light Detection and Ranging."

PERFORMANCE INDICATOR – A tool for measuring or comparing impacts of different water levels and flows in the Souris River basin on various interests.

PLAN FORMULATION METHOD – A method involving a multi-objective, multi-stakeholder evaluation procedure used to evaluate factors in determining whether a revised Operating Plan performs better than an existing plan.

REACH – A segment of a river, typically referring to a segment with uniform physiographic and/or hydraulic features.

RIPARIAN – Relating to or found along a shoreline.

RIPARIANS – Persons residing on the banks of a body of water. Typically associated with private owners of shoreline property.

STATE OF NATURE – For the purposes of the Study, the term refers to a hypothetical basin configuration where it assumed that the structures that limit or regulate flow out of Souris River basin waters do not exist. This allows for the modeling of flows in a pre-dam condition – a best estimate of the system under natural conditions.

STUDY – the study established by the Governments of Canada and the United States per the July 5, 2017 Reference letter regarding the tasks to be undertaken by the International Joint Commission as assigned to the International Souris River Study Board

STUDY BOARD – The formal International Souris River Study Board members

STUDY TEAM – the Study Board and the technical pool of staff providing major contributions to the Study

STOCHASTIC HYDROLOGY– Randomly-generated runoff sequences using existing hydrologic data, generated over many iterations, to reflect a greater understanding of the spectrum of hydrologic variability.

TARGET FLOW – The instantaneous flow at a given location that should not be exceeded during a given flood event as a result of releases from a reservoir or reservoirs.

WATER SUPPLY – Water reaching a basin as a direct result of precipitation, minus evaporation from land and lake surfaces.

WETLANDS – An area characterized by wet soil and high biologically productivity, providing an important habitat for waterfowl, amphibians, reptiles, and mammals.

Appendices

1. 1989 International Agreement
2. Reference Letters from the Governments

   a. Reference Letter from the Government of Canada

   b. Reference Letter from the Government of the United States
3. Directive from the International Joint Commission to the International Souris River Study Board
4. Study Organization and Contributors

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5. **Summaries of Study Technical Team Reports**
   https://ijc.org/en/srsb/appendix-5-summary-description-technical-task-teams-and-reports-0

6. **Summary of Application of Performance Indicators in the Evaluation of Alternative Operating Plan Measures**
   https://ijc.org/en/srsb/appendix-6-summary-application-performance-indicators-evaluation-alternative-operating-plan

7. **Measurement Units Conversion Factors**

Metric System – United States Customary System Units

(With abbreviations)

Length

1 millimeter (mm) = 0.0394 inch (in)
1 in = 25.4 mm
1 centimeter (cm) = .3937 in
1 in = 2.54 cm
1 meter (m) = 3.2808 feet (ft)
1 ft = 0.3048 m
1 kilometer (km) = 0.6214 mile (mi)
1 mi = 1.6093 km

Area

1 square kilometer (km2) = 0.3861 square mile (mi^2)
1 mi2 = 2.59 km2
1 hectare (ha) = 2.47 acres
1 acre = 0.405 ha

Volume

1 acre-foot = 1.23 dam^3 (decameters^3)
1 dam^3 = 1,000 m^3

Flow rate

1 cubic meter a second (m^3/s) = 35.315 cubic ft a second (ft^3/s) 1 ft^3/s = 0.02832 m^3/s