International Souris River Study Board

Review and Update of the 2013 Hydrometeorological Data Network Improvement Report

International Souris River Study Board Task DW3

December 21, 2018

Executive Summary

In February, 2013, a group of federal, provincial, and state agency partners from the United States and Canada met in St. Paul, MN, to assess the current hydrometeorological data networks within the Souris River basin in Saskatchewan, North Dakota, and Manitoba. The workshop resulted from action items identified after record flooding in 2011 caused considerable damage within the basin, including catastrophic flooding in Minot, ND.

The purpose of the workshop was to assess the current data collection and dissemination networks to better support existing and anticipated future needs with respect to emergency preparedness, river forecasting, and reservoir regulation for flood risk reduction. In addition, the adequacy of existing dissemination methods was discussed, and participants created a prioritized list of recommended locations for new precipitation and streamflow gages within the Souris River Basin.

The International Souris River Study Board (ISRSB) has been tasked with reviewing the 2013 Hydromet Improvement Workshop report as part of Plan of Study Task DW3, assessing which priorities and recommendations identified within the 2013 report have been implemented, and which priorities are still valid. The objective of the current report is to identify remaining gaps and to make recommendations for improvements that will help to facilitate water resource management decision-making within the basin.

The most important items that have been identified by the ISRSB as remaining priorities include:

1. The addition of precipitation stations in data-sparse areas that would provide high-quality year-round observational data. While the number of stations in the hydrometric network has increased since 2013, there has not been an increase in the number of stations that provide consistent, quality observations year-round. The current study has identified priority areas where additional precipitation stations would significantly aid and improve modeling and forecasting within the basin.

2. A lack of real-time stream gage data in areas that are critical for the estimation of flow coming from Saskatchewan into North Dakota. A large ungaged area downstream of the Canadian Reservoirs and upstream of the stream gage near the Sherwood Crossing contributes to forecast uncertainty, and additional stream gage data in this area would increase confidence in forecasts and lead-time for regulators upstream of Minot.

In addition to these priorities, this report will also detail the current state of the hydrometric network and provided a summary of the changes and remaining priorities since 2013. It should be noted that even with the implementation of the recommended

improvements, inherent challenges to forecasting and reservoir regulation strategy will remain. Modeling and forecasting challenges due to climatic variability in the region, and the limitations of current modeling processes to produce accurate streamflow simulations that represent the complex runoff processes in the prairie pothole landscape are likely to persist.

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Background

In February 2013, a workshop was held to review the state of the hydrometeorological data network in the Souris River Basin. Figure 1 shows the total precipitation gage network (available in 2013 and 2018), while Figure 2 illustrates the data that were accessible and reliable for forecasting and modeling at the National Weather Service's North Central River Forecast Center (NCRFC) in 2013.

Figure 3 shows a map of the Souris stream gage network, with real-time and discontinued sites, and proposed locations for new stream gages that were identified at the 2013 workshop.

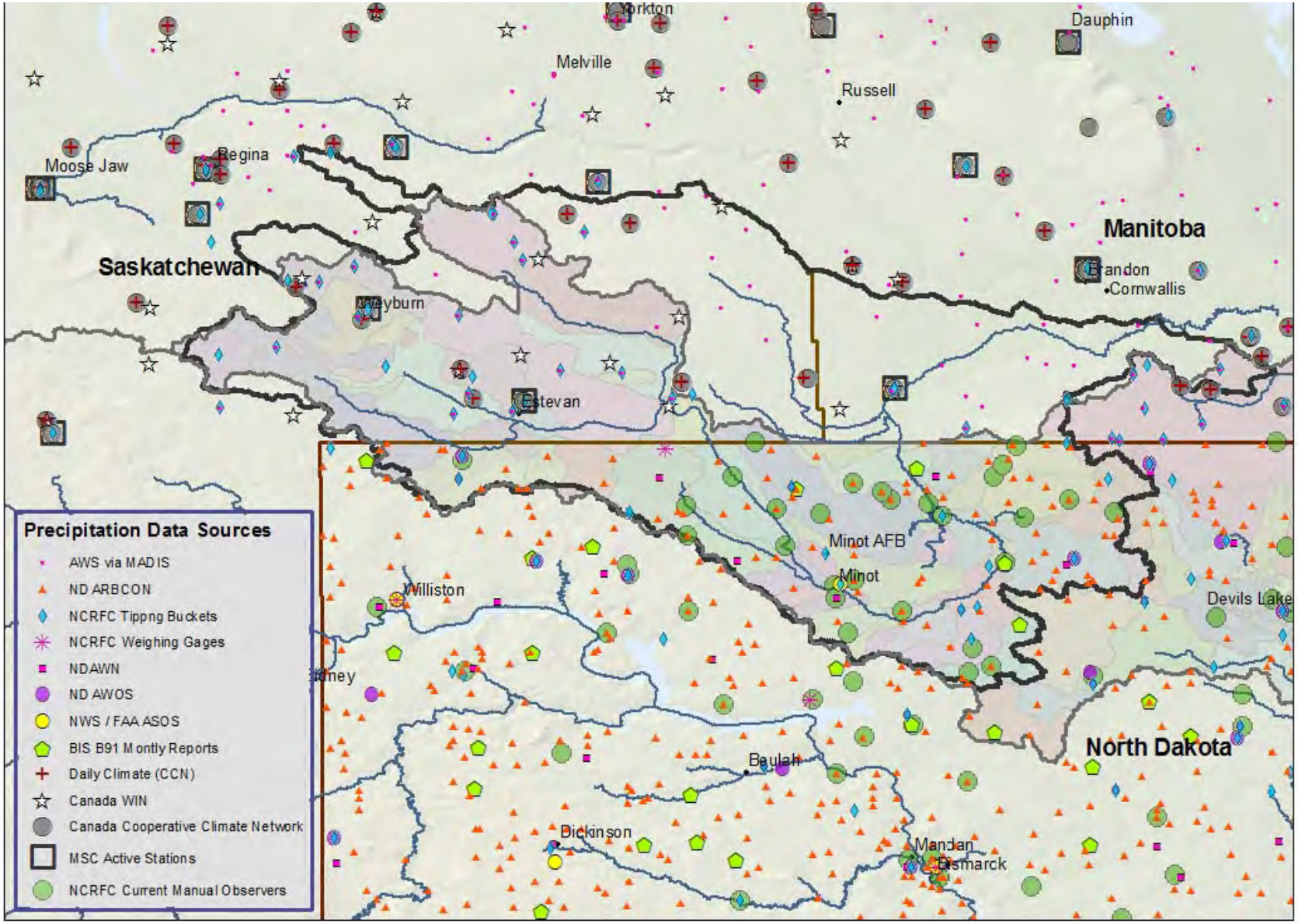

Figure 1: Shows all potential sources of precipitation data 2013-2018 (source NCRFC)

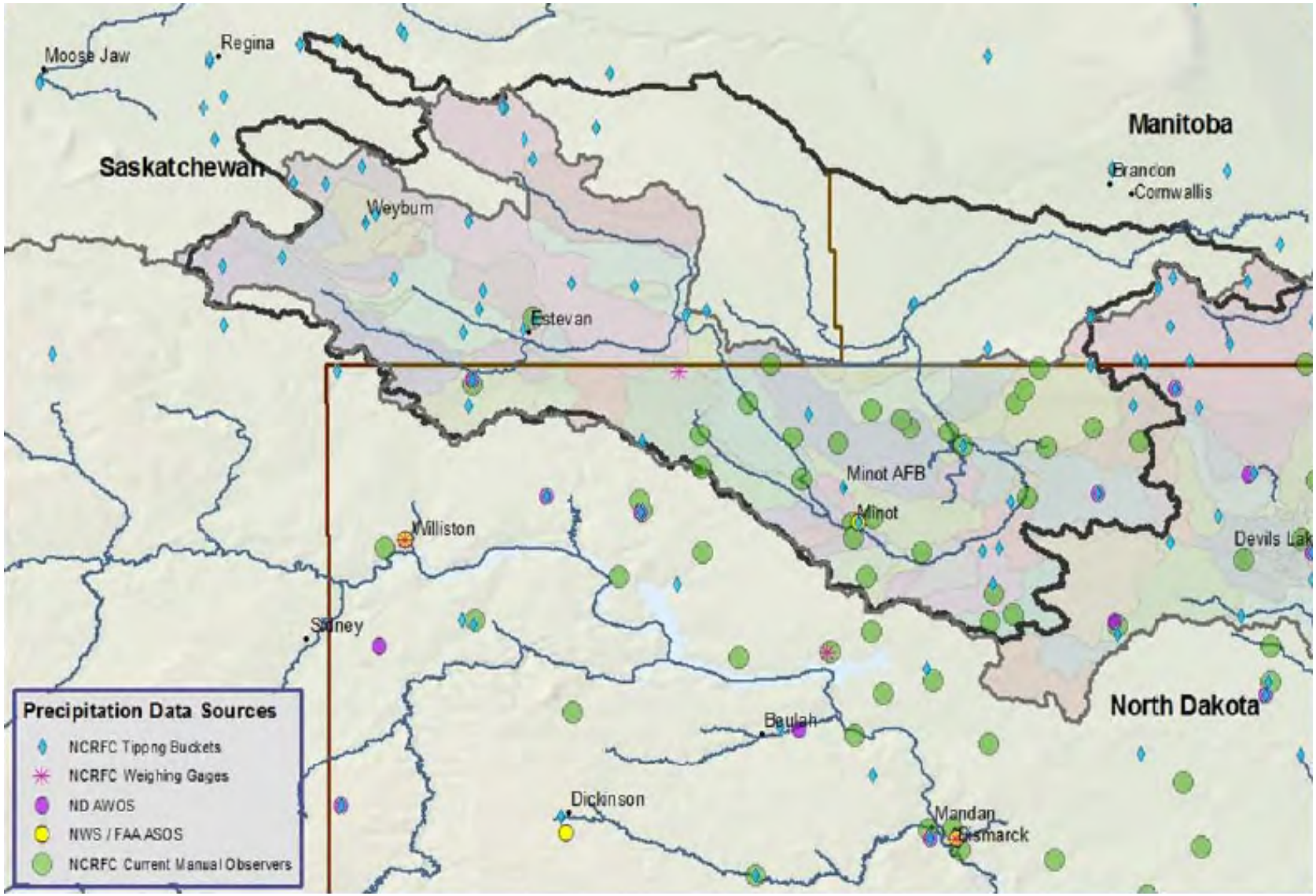

Figure 2: NCRFC 2013 total precipitation network with accessible precipitation data for modeling and forecasting source: (U.S. Army Corps of Engineers St. Paul District, 2013a)

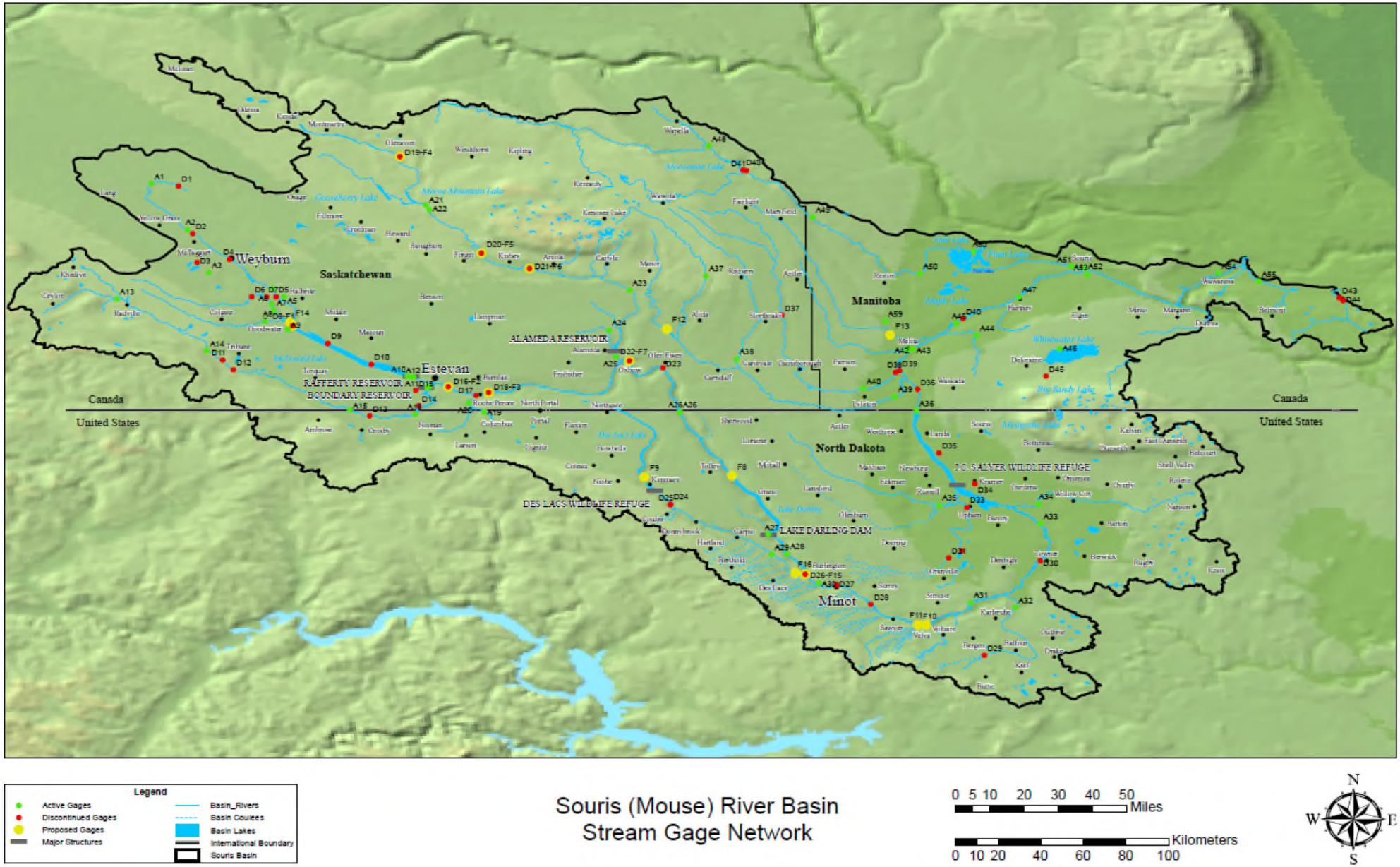

Figure 3: Souris River Stream Gage network showing current, discontinued and proposed stream gages ***Source:*** (U.S. Army Corps of Engineers St. Paul District, 2013a)

The workshop included participants from the St. Paul District United States Army Corps of Engineers (USACE), United States Fish and Wildlife Service (USFWS), Water Security Agency of Saskatchewan (WSA), North Dakota State Water Commission (NDSWC), United States Geological Survey (USGS), National Weather Service North Central River Forecast Center (NCRFC), Manitoba Infrastructure and Transportation (MIT), and representatives from the International Joint Commission (IJC) and the International Souris River Board (ISRB). The workshop's goal was to assess the hydrometeorological network and the dissemination of data within the basin, and come up with recommendations for improvements. These priorities and potential action items can be found in the Souris River Basin Hydrometeorological Data Network Improvement Workshop Report (U.S. Army Corps of Engineers St. Paul District, 2013e) and are summarized below:

- Improve the real-time precipitation network by consolidating all the different networks (NDAWN, WIN, ARB, NWS, ECCC, et al) and improve access to that data in real-time for all agency partners.
- Develop a coordination and implementation plan for placement and upgrading of stream gages and precipitation stations.
- Inventory existing data sets and models to streamline the information and sharing of data and metadata.
- Develop a MOU for data sharing between Canada and US (all the different agencies) to improve access to historical and real-time data.
- Create an agency only repository/website with a GIS-like map that includes both published and unpublished data, including river and precipitation data.
- Explore collaboration opportunities using FEWS (NWS), CWMS (USACE) and MIT modeling platforms.
- Expand ISRB's Flow Forecasting Liaison Committee (FFLC) or create another committee with support through the ISRB to tackle some of these issues. Have one single coordination group and define/refine interagency collaboration processes.

The top 4 priority recommendations for streamflow and precipitation gages from the 2013 Hydromet Improvement Workshop were:

1. Reactivating a discontinued streamflow gage on the Souris River near Oxbow, SK, downstream of the confluence of Moose Mountain Creek and the Souris River. This would capture a large portion of the ungaged local flow downstream of the SK reservoirs and upstream of the streamflow gage at the Sherwood, ND crossing.

2. Additional precipitation stations in the Coulee Region (defined as the areas downstream of Kenmare to Burlington on the Des Lacs River right bank and from Burlington and Minot to southwest of Velva on the Souris River right bank), because the coulees respond fast to precipitation and impact forecasting (Figure 7, Area 1)

3. Additional precipitation stations north of McGregor, ND due to lack of radar coverage in the area that impacts forecasting. (Figure 7, Area 2)

4. Reactivating a discontinued streamflow gage on the Souris River near Estevan, streamflow gage, located immediately downstream of the Rafferty and Boundary reservoirs)

2018 Update: Goals and Action Items

Many of the prioritized goals and potential action items from the 2013 workshop have been completed or are in progress. The consolidation of the precipitation network has been ongoing, and most of the real-time observational data are ingested and processed by the NWS/NCRFC, who makes gridded and mean areal precipitation (MAP) and temperature (MAT) estimates available to agency partners via secure ftp.

The NWS and WSA have signed a MOU that allows access to Weather Innovation's Saskatchewan Crop Insurance Corporation (WIN-SCIC) precipitation network in SK; however, in the United States the data is only for use in the NCRFC river models, and the proprietary nature of the data restricts the NCRFC from sharing the raw data externally. The sharing of products generated from the raw data is permitted provided the raw data cannot be disseminated from the product. More effort is required to broaden the accessibility of the data to all agency partners, including Environment Climate Change Canada (ECCC). However, this will likely come with additional costs.

Additionally, while the consolidation and access to additional precipitation networks has improved data quantity, the increase in the number of reporting sites has not led to a significant increase in data quality and availability for forecasting and modeling purposes (Figures 4 and 5). Figure 5 illustrates the data available consistently after NCRFC analysis based on daily QC processes, and shows that there are still gaps in areal coverage. This is of concern, as it places limits on the available input needed for the river models that are used to produce forecasts and inform reservoir operations. Reliability of the data is dependent on the type of precipitation station and the consistency of the manual observations. ARB, ECCC, NDAWN, CoCoRaHS networks all show fewer stations available after the NCRFC QC process is completed. And there is still a significant degradation of the network in the winter vs. the summer (Figure 6). The lack of quality data and holes in the areal coverage increase the modeling and forecast uncertainty.

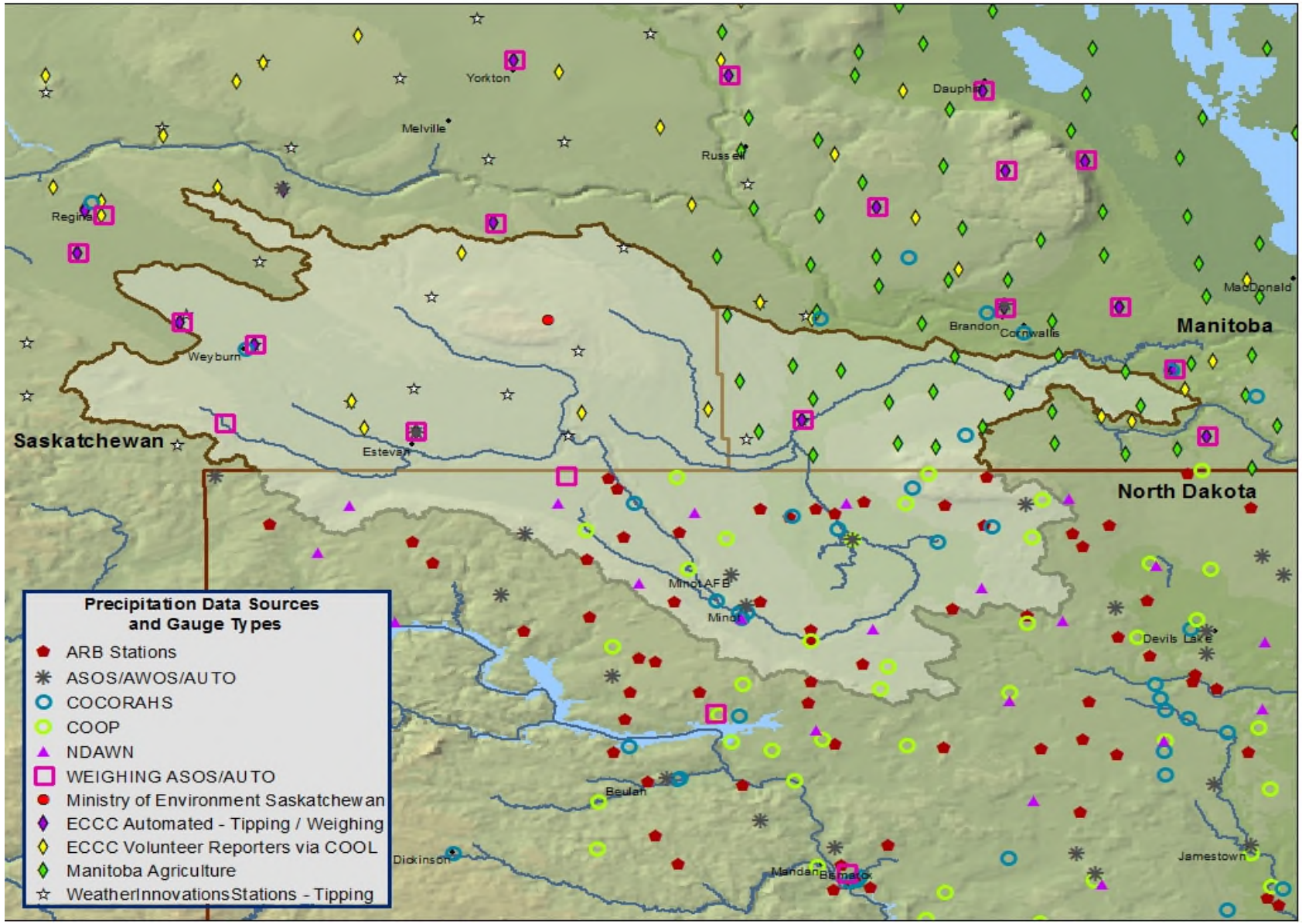

Figure 4: NCRFC 2018 Potential Summer Precipitation Network

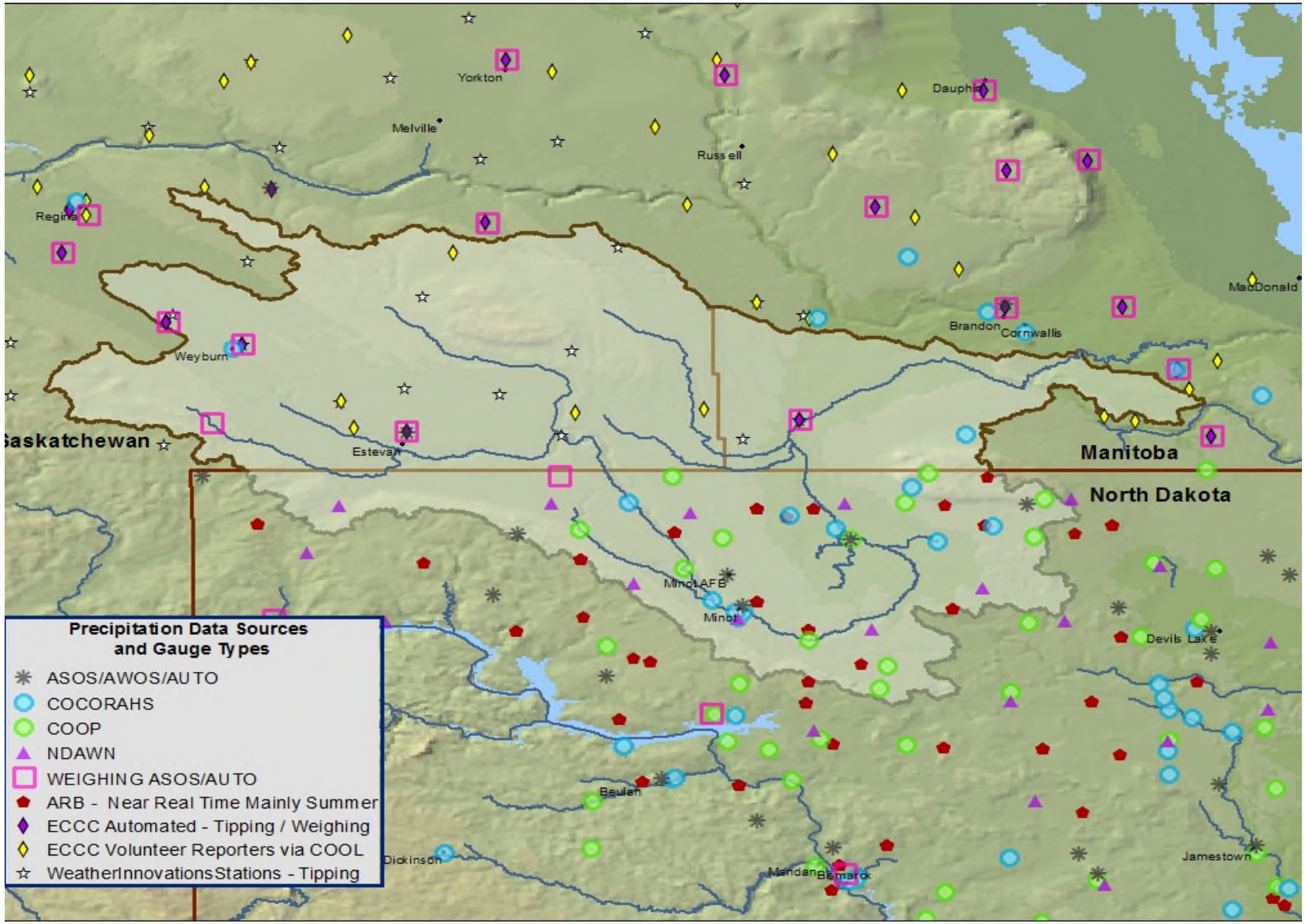

Figure 5: NCRFC 2018 Summer Precipitation Network with reliable data that is useable for river forecasting (based on NCRFC daily quality control and analysis)

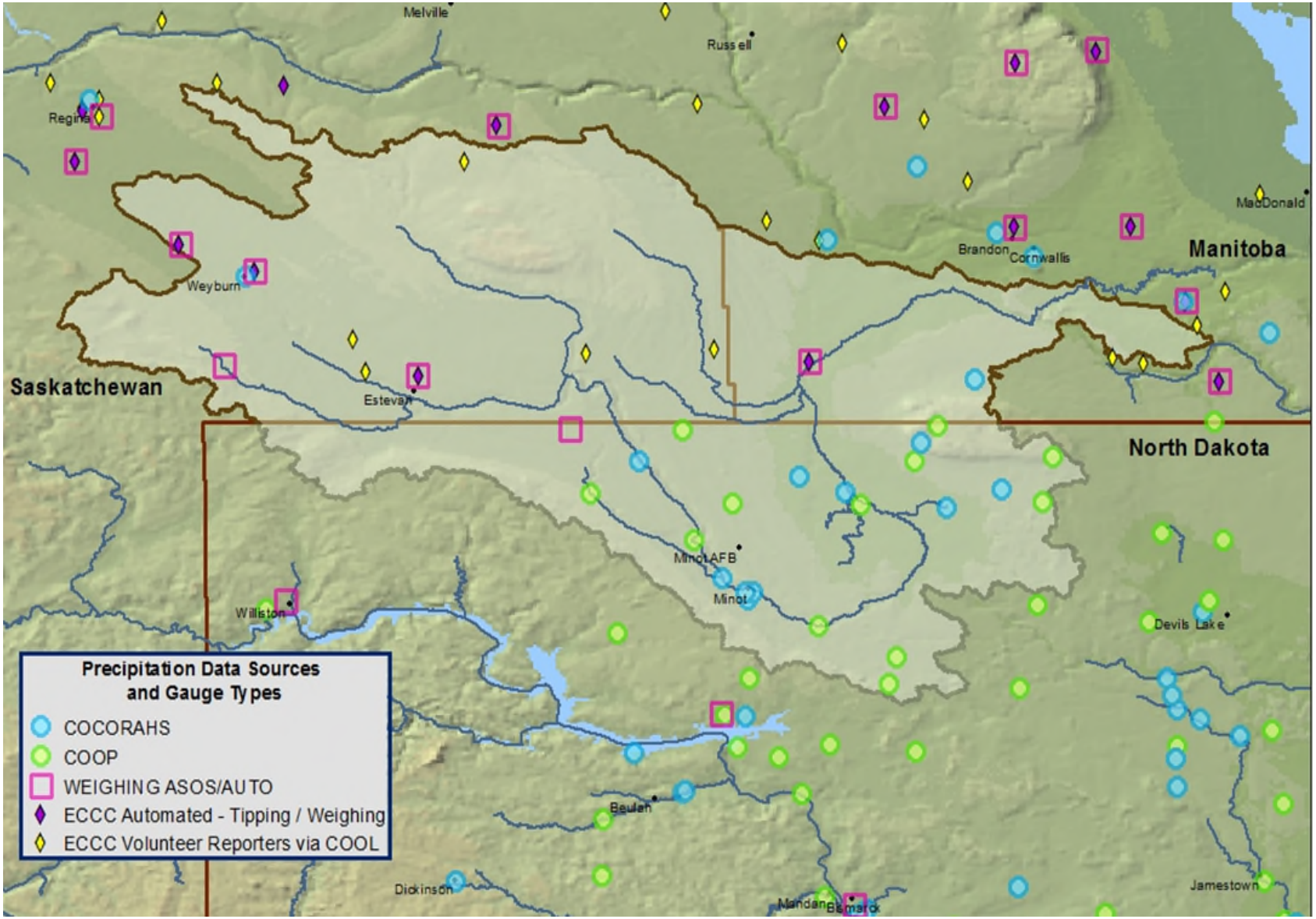

Figure 6: NCRFC Meteorological network useable for forecasting in the winter

Some of the stream gage locations that were identified as priorities in the 2013 study have been implemented as rapid deployment gages by the USGS and NDSWC during times of high water since 2013 (Des Lacs River, Baden and Burlington; Souris downstream of Lake Darling and at Logan; Salyer NWR east of Upham). The availability of the rapid deployment gages has mitigated some of the operational uncertainty during times of flooding, but the limited number of gages can still be problematic when flooding is widespread or an intense rainfall event causes flooding that progresses more rapidly than gages can be deployed. The transmitters used in the rapid deployment gages will be supported until 2026. After 2026 the rapid deployment gages will require upgrades to faster transmitters to remain in service.

2018 Update: Model Data and Dissemination

Improvements have been made to the availability of modeling data and data exchange. USACE completed the Regional and Reconstructed Hydrology of the Souris River and that data set is currently being used as a frame of reference to evaluate reservoir operations as part of the review of Annex A (U.S. Army Corps of Engineers St. Paul District, 2013c). This data set is important, as it provides a baseline, comprehensive flow dataset for the Souris River Basin, to be used in model development and calibration efforts.

Similarly, the USGS has completed a stochastic modeling study using tree ring data going back 700+ years, which allowed the examination of seasonal precipitation patterns and climatic variation (Kolars, Vecchia, & Ryberg, 2015). This information was used to develop a model for simulating future streamflow to determine the probabilities of future floods or droughts. This information is also available as input for modeling and study efforts.

HEC-RAS and HEC-ResSim models are nearing completion as part of the Plan of Study (PoS), to provide a consistent reservoir modeling platform and routing methodology throughout the basin.

Other sources of modeling data, dissemination methods, and model output have been inventoried and are summarized in more detail in Appendix A. Much of the model data has been aggregated and is disseminated by the NCRFC via the web or secure ftp, including soil moisture states, observed and forecast precipitation and temperature data, snow water equivalent data, and model output data for reservoir inflows that are used by WSA, USACE and MIT. Systematic observations of soil moisture are largely not available, expensive and simply not representative at a point scale. Soil moisture indexed-derived products based on data assimilation systems and passive satellite microwave observations, are being developed in both the United States and Canada

through the MSC and NOAA. As they become more mature, forecasting teams will make full use of these systems. Estimating lake or reservoir evaporation is difficult because evaporation pans have proven to be poorly correlated with actual evapotranspiration and lake evaporation. Although sophisticated research methods exist to measure evapotranspiration and lake evaporation, no systematic methods are available to compute ET and evaporation except using models based on standard meteorological variables.

The multiagency use of the NWSchat tool has facilitated a more timely exchange of data, including field observations, changes to reservoir outflows, and access to USGS streamflow measurements. This has greatly improved communications and processing of information critical to forecasting since the 2013 Hydromet Improvement Workshop report was written.

The ISRB's Flow Forecasting Liaison Committee (FFLC) was identified as a resource to address some of the issues from the 2011 post-flood and 2013 Hydromet Improvement Workshop reports. The FFLC was tasked by the ISRB to document WSA and NCRFC spring runoff forecast procedures, and to develop a communications plan that addressed and incorporated the items identified in the 2011 and 2013 reports. The procedures also extended the spring runoff processes to include summer rainfall events and were approved by the ISRB in 2016.

2018 Update: Remaining Gaps

A coordinated plan for placement and upgrading of the stream gages and precipitation stations has yet to be developed, and will be included in the list of recommendations at the end of this report.

The majority of areas that were high priority for additional precipitation stations have not seen a notable increase in data. The addition of WIN-SCIC data for use by the NCRFC and WSA helps to cover some gaps, however not all agencies have access to the data, including ECCC. Figure 7 illustrates the areas where additional high-quality, year-round precipitation stations are recommended (numbered by priority and identified in Table 1). The additional access of this data by ECCC would help to improve the Canadian Precipitation Analysis (CaPa).

WSA is addressing the three data gaps in Saskatchewan by installing all-season precipitation gages (OTT Pluvio^2 L 200) at the hydrometric gaging stations they operate at Long Creek near Maxim (Area 3 on Figure 7), Souris River near Beechard (Area 5 on Figure 7), and Moose Mountain Creek downstream of Moose Mountain Lake (Area 4 on Figure 7). This data will be available to forecasting agencies in near real-time using the

GOES DCP. The Long Creek precipitation gage was installed in 2013 and the other two will be installed in 2019.

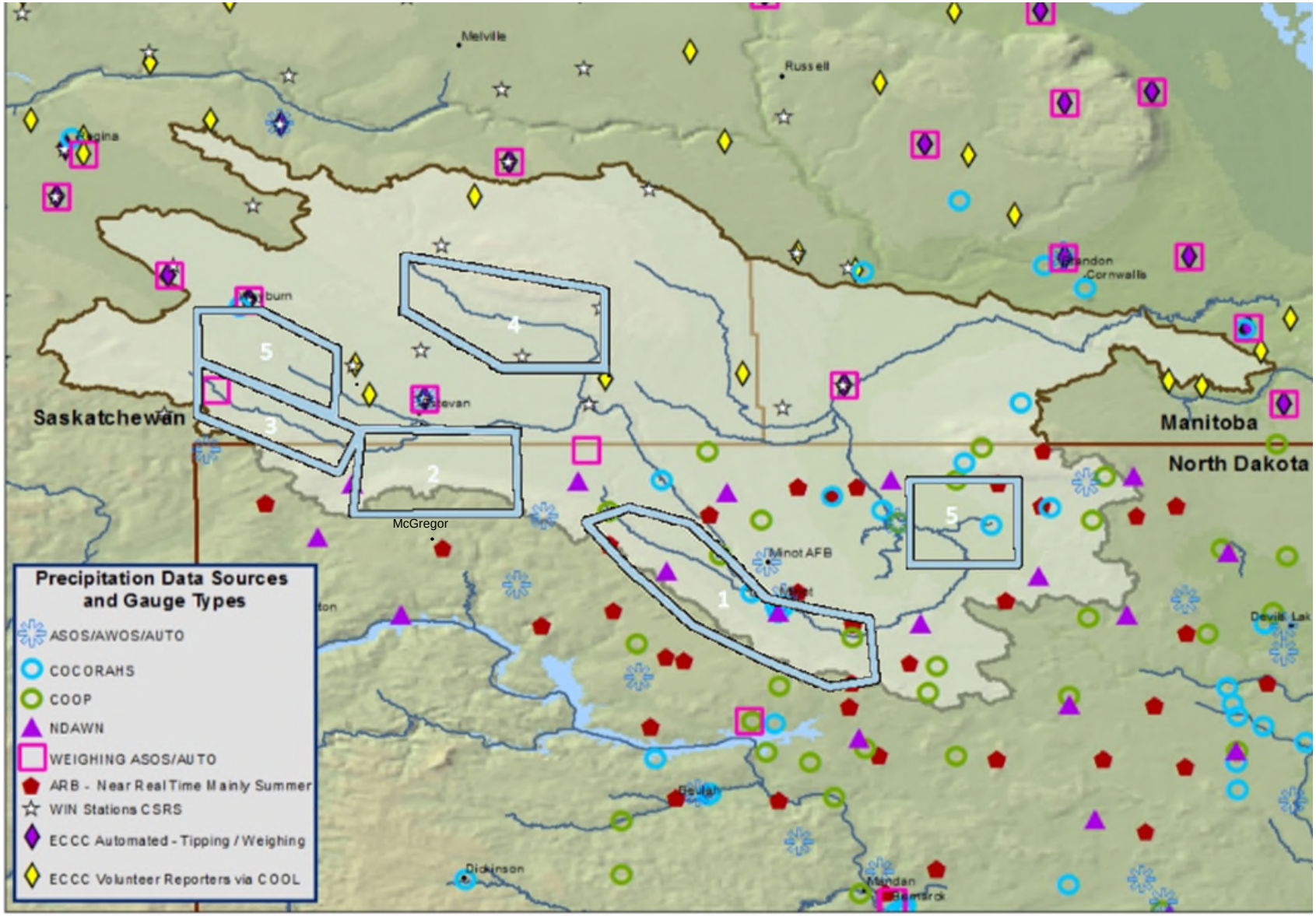

Figure 7: NCRFC 2018 reliable summer network with prioritized areas for additional data

Table 1: Proposed real-time precipitation gages in priority order from 2013 Workshop

Priority	Gage Location	Rationale
1	Coulee Region (defined as the areas downstream of Kenmare to Burlington on the Des Lacs River right bank and from Burlington and Minot to southwest of Velva on the Souris River right bank)	The coulees are flashy in response to precipitation and impact forecasting and regulation
2	North of McGregor, ND	Lack of radar
3	Tribune/Hoffer/Goodwater (Long Creek)	Lack of radar and important tributaries to Rafferty reservoir
4	Arcola area	Lack of data
5	Tied - Innes/Neptune/Weyburn (Rafferty)	Lack of data
5	Tied– South of Bottineau	Lack of data

Figure 8 shows the current stream gage locations, and the proposed gages that are based on the 2013 Hydromet Improvement Workshop priorities. Some changes in priorities have been identified by the current PoS working group, and will be discussed in the recommendations section of this report.

Figure 8: Hydrological gages that are real time and recommendations for additional gages Sources: (USGS, 2018) (Environment and Climate Change Canada, 2018) (U.S. Army Corps of Engineers St. Paul District, 2013b)

Snow water equivalent estimates continue to contribute a great deal of uncertainty to forecasts and reservoir operations, especially given the quality of the winter precipitation network and the challenges associated with radar coverage year-round. Snow water equivalent estimates that are provided by the National Water Center--Chanhassen gamma survey flights (formerly known as NOHRSC) have proven to be some of the most reliable data in the winter for forecasting spring inflow volumes. This data provides better areal coverage than point source estimates and the accumulated multisensor precipitation estimates that are maintained in the NCRFC hydrologic forecast model. Budgetary and resource constraints are currently putting the accessibility of this data at risk. Other snowpack observation data sets are outlined in Appendix A, Table 5.

Much of the effort since 2013 has been focused on flood mitigation and flood forecasting improvements. To date little focus on water-supply and low flow processes has occurred. However, the same data networks and processes that support flood forecasting can be used for low-flow coordination. The FFLC's documented forecast process and communications plan can be adapted for low-flow conditions, but forecasting and operations planning for water supply in drought years needs to be further examined and better understood. Some of the PoS tasks are beginning to address this topic, but more focus on communicating forecast uncertainty and processes specifically tailored to low-flow and drought conditions are needed for effective water supply management.

Plan of Study task HH10 is examining forecast history since 2010, in order to assess forecast quality. There may be some conclusions once this task is completed that will allow a better understanding and incorporation of forecast uncertainty in to future processes and products.

While there is not yet an agency-only access point with a GIS-like map that contains unpublished and published river and precipitation data, there has been progress in SharePoint tools and the creation of a repository for managing Plan of Study information, which includes documentation of many of the issues of interest in this report. There is also published streamflow data available on the ISRB website.

Additionally, the limitations of stream flow modeling processes are likely to persist in the near-term. Models currently in development, such as the National Weather Service's National Water Model (NWM), are years away from being fully functional for use in forecasting and face the same data gaps and uncertainty in forcing inputs as the current hydrologic models in use at the NWS, USACE, WSA, MIT, and ECCC. Climatic variability and complexity of runoff process in the prairie pothole region are limitations that can only be partially mitigated. Studies that address forecast uncertainty and climate change impacts are underway and can help to drive modeling improvements.

Recommendations

Recommendations that are specific to addressing the issues previously identified and that remain priorities in 2018 include:

1. The addition of precipitation stations in data-sparse areas that would provide high-quality year-round observational data, especially in the Coulee Region and North of McGregor, ND. These areas are identified and prioritized in Figure 7 and Table 1. Cost estimates for implementing and maintaining a new precipitation station are included in Table 2.

2. Additional stream gages with real-time data, especially the Souris River near Oxbow, which is located downstream of the confluence of Moose Mountain Creek and the Souris River, and downstream of Grant Devine and Rafferty reservoirs. A large ungaged area downstream of the Canadian reservoirs and upstream of the gage near the Sherwood Crossing contributes to forecast uncertainty, and additional stream gage data in this area would increase confidence in forecasts and lead-time for regulators upstream of Minot. Cost estimates for implementing and maintaining a new stream gaging station are included in Table 3.

Table 2: Cost Estimates of Implementing Precipitation Gage Recommendations

	Initial Cost	Operation and Maintenance cost*
Canada (CDN)	$8,000	$6,000-$10,000/yr
United States (USD)	$6,000	$6,000-$10,000/yr

*Maintenance cost estimates include the cost of replacing the equipment, as it is required.

Canadian estimates are based on adding all-season precipitation gages to sites with stream gages. Costs would be higher if a logger and telemetry were required to establish a new site.

Table 3: Cost Estimates of Implementing Stream Gage Recommendations

	Initial Cost	Operation and Maintenance cost*
Canada (CDN)	$15,000	$15,000-$17,000 /yr
United States (USD)	$10,000	$20,000-22,000 /yr

*Operation and maintenance cost estimates include the cost of replacing the equipment, as it is required

Other stream gage recommendations that remain priorities in 2018 are listed in Table 4.

Table 4: Proposed real-time stream gages in priority order from 2013 Workshop

Priority	Gage Location	Purpose	Importance
1	Souris River near Oxbow	flood forecasting, water supply & appropriations	Captures local area downstream of Rafferty and Grant Devine reservoirs and increases lead time for inflows in to Lake Darling
2	Souris River near Estevan	flood forecasting, water supply & appropriations	No longer a priority in 2018
3	Rafferty Reservoir – water level gage	reservoir regulation, flood forecasting, water supply	Inflow to Rafferty; useful to minimize wind impacts on levels
4	Souris River Upstream of Lake Darling at Hwy 5	reservoir regulation	No longer a priority in 2018
5	Tied – Jackson Creek near Broomhill	flood forecasting, modeling	Spatial Distribution of real time data available, Tributary
5	Tied– Bonnes Coulee near Velva	flood forecasting	Major Coulee
6	Auburnton Creek near Auburton	flood forecasting, modeling	Spatial Distribution of real time data available, Tributary
7	Des Lacs River at the NWR outlet	flood forecasting, modeling	Outflow from Refuge and upper Des Lacs basin; rapid deployment gage has been used

Challenges to Implementation

The installation and operation of the recommended new stream gaging stations will face unique funding challenges in the U.S. portion of the Souris Basin, due to the funding model used to fund stream gages. Since 1889, the USGS has operated a multipurpose stream gage network supported primarily by other U.S. Federal, State, and local agencies. Streamflow data from these stations are used for planning and decisions related to agriculture, industry, urban water supplies, navigation, riverine and riparian habitat, water appropriation, and flood forecasting. Many partners contribute funding for the operation of gaging stations to collaboratively achieve U.S. Federal mission goals and individual goals of the funding agencies. Thus, adding some or all recommended stream gages will require collaboration and funding from several U.S. Federal, State, or local agencies. With current funding pressures and budget cuts that have impacted the stream gage and other water resource programs, funding new stream gages will likely be difficult.

In Canada, the situation is similar to the United States, with the network operation cost shared between the Federal and Provincial Governments. In general, monitoring related to apportionment is a federal responsibility and monitoring to support operations is a provincial responsibility. Since the sites proposed in Canada would be primarily of interest to the provinces and are located in Saskatchewan, it would fall on WSA to install, operate, and maintain the proposed sites, or add the costs to the cost share agreement with ECCC. Manitoba faces the same situation.

Other Recommendations and Potential Action Items

The following recommendations are supplementary to the previous recommendations and have been identified by various study team members as important considerations. They have been included in this report to ensure that they are documented.

- Continue to address data dissemination issues with NDAWN, WIN-SCIC and other Mesonets and continue the discussion between ECCC and the Weather INnovations (WIN) network to make precipitation data publicly accessible, and for use in the generation of the Canadian Precipitation Analysis. Broadening the access to private observation networks would improve modeling efforts and decision support across the basin.

- Add a hydrometric gage on a lower tributary to Long Creek between the Western Crossing and Noonan gages. WSA would benefit from the hydrological data received before Boundary Reservoir, as flow from Long Creek can impact Boundary Reservoir quickly.

- A comprehensive snow survey program should be developed and maintained for the basin. This information is currently collected by ad-hoc in-situ snow surveys and through flown gamma surveys. There is no one place to collect, archive, and access this data. A one-stop repository for all hydrometric data would help.

- The feasibility of a soil moisture observing program should also be considered.

- Low-flow and drought monitoring tools and processes for water supply decision support should be developed, including methods and datasets to support better estimation of evapotranspiration (ET) in river and reservoir modeling.

- Examine the potential for satellite re-analysis products depicting soil-moisture and ice conditions to provide additional valuable data for forecasting and decision support.

- Data accessibility and data harmonization continue to be challenging. Examine the value of various data assimilation products that blend observations and model output.

- Pursue studies and model improvements to incorporate better understanding of the runoff processes that are unique to the prairie pothole region, including fill and spill, frozen ground, and artificial drainage network impacts.

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Appendix A: Data Dissemination Tables

Table 5: NWS Current State Inputs for Souris River Modeling

Data Type	Source	Dissemination Method (Ingest)	Comment
Observed Temperatures (point)	Gridded Objective Analysis (MSAS) ASOS/AWOS automated network	SBN/Internal network	
Forecast Temperatures (gridded)	WFO forecast (Day1-7): meteorological model output (Day 8-15) Day 15-30 CFSv2	Internal	
Observed Precipitation (point and gridded)	Radar, Satellite, COOP, CoCoRaHS, COE/USGS, WeatherFarm "AWS", ECCC, WSA "WIN", NDAWN, ARB	Internal (Radar, Satellite, COOP); LDM/DCP (COE/USGS); CoCoRaHS, WeatherFarm LDM via MADIS, NWS CR LDM, web scraping	COOP data processed at 12Z; ECCC data manually accessed via web
Forecast Precipitation (gridded)	WPC, WFO and NBM as appropriate	Internal	Updates available every 6 hours
Snowpack Observations (point & gridded)	COOP, NWC Chanhassen (modeled and flight line surveys), COE, WSA Surveys, NDSWC	Internal (COOP, NWS); email (WSA survey, NDSWC, COE)	
Observed River Stages/Pool Elevations	USGS, COE, FWS, ECCC, WSA	DCP (Internal); Manual readings (phone)	
Ratings	USGS, COE, ECCC	Internal, web, email	Given access to EC WSC ratings online. We would like to automate this collection process.
Stage/Flow Measurements	USGS, ECCC	NWSchat, web, email	Daily email from EC WSC containing measurements and other gage issues for SK and MB. We would like to automate this collection process.
Reservoir Operations	WSA, COE, FWS	Canadian dams via email; Lake Darling via NWSchat or email; JClark Salyer and Des Lacs Kenmare we initiate call to FWS	In other areas, we receive data via LDM

Table 6: NWS Current State Outputs for Souris River Modeling

Data Type/Product	Dissemination Method	Comment
Observed Temperatures (point)	NCRFC push to LDM	RTMA for CWSMs
Forecast Temperatures (gridded)	NCRFC push to LDM	RTMA for CWSMs
Observed Precipitation (gridded & calculated)	NCRFC push to WFOs, Web, LDM	2X daily
Forecast Precipitation (gridded)	NCRFC push to WFOs, Web, LDM	2X daily
Flood Stage Forecasts	NCRFC push to WFOs, Web	as needed
Flow Forecasts	NCRFC push to Web, LDM	daily
Probabilistic Forecasts	NCRFC push to WFOs, Web	monthly
Reservoir Inflow Forecasts	NCRFC email	special products
Manual Gage data	WFO push to Web	
Weather/Flood Watches & Warnings	WFO push to Web	

Appendix B: Explanation of Terms and Networks

North Dakota Atmospheric Resource Board Cooperative Observer Network (ARBCON): ARBCON is a volunteer run network that records rainfall and hail occurrences. Reports are sent in daily and some observers report snowfall. (North Dakota Atmospheric Resource Board, n.d.)

Automated Surface Observing System (ASOS): The ASOS program is a joint effort of the National Weather Service (NWS), the Federal Aviation Administration (FAA), and the Department of Defense (DOD). The ASOS systems serves as the nation's primary surface weather observing network. ASOS is designed to support weather forecast activities and aviation operations and, at the same time, support the needs of the meteorological, hydrological, and climatological research communities (National Weather Services, n.d.).

AWOS: Automated Weather Observing System (AWOS) units are operated and controlled by the Federal Aviation Administration. These systems are among the oldest automated weather stations and predate ASOS. They generally report at 20-minute intervals and do not report special observations for rapidly changing weather conditions (National Center for Environmental Inforamtion , n.d.).

BIS B91: NWS Bismarck Weather Forecast Office monthly observer reports

Canadian Cooperative Climate Network (CCN): The former name for the volunteer climate network run by ECCC.

Community Collaborative Rain, Hail, Snow Network (CoCoRaHS): CoCoRaHS is a volunteer network of civilian precipitation observers located throughout the United States and Canada. Volunteers collect and send data daily to a central data system at www.cocorahs.org. (Community Collaborative Rain, Hail & Snow Network , n.d.)

COOL: Cooperative Observations On-Line website where ECCC volunteers upload climate data.

CSRS: Canadian Spatial Reference System.

Corps Water Management System (CWMS): The Corps Water Management System (CWMS) is the automated information system used by the U.S. Army Corps of Engineers (USACE) to support its water control management mission (U.S. Army Corps of Engineers (USACE), (n.d. e)).

Delft-Flood Early Warning System (FEWS): The Delft-Flood Early Warning System is a river forecasting infrastructure software (Deltares).

GOES Data Collection Platform (DCP): The Geostationary Operational Environmental Satellite Data Collection System (GOES DCS) provides environmental data from remote data collection sites to Federal, state, and local agencies that are responsible for monitoring the environment and Earth's resources (NOAA-National Environmnetal Satellite, Data and Information Services (NESDIS), 2016).

Hydrological Engineering Center's-River Analysis System (HEC-RAS): HEC-RAS is a software that allows the user to perform one-dimensional steady flow, one and two-dimensional unsteady flow calculations, sediment transport/mobile bed computations, and water temperature/water quality modeling (U.S. Army Corps of Engineers, (n.d. d)).

Hydrological Engineering Center's-Reservoir System Simulation (HEC-ResSim): The Reservoir System Simulation (HEC-ResSim) software developed by the U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center is used to model reservoir operations at one or more reservoirs for a variety of operational goals and constraints (U.S. Army Corps of Engineers, (n.d. f)).

Manitoba Agriculture Network: Also referred to as Rain Watch, The Ministry of Agriculture Food and Rural Development (MAFRD) runs a precipitation network in the province of Manitoba. The data is uploaded to a website (https://www.gov.mb.ca/agriculture/weather/rain-watch.html) near real time from the individual stations.

MesoNet: A Mesonet is a network of automated environmental monitoring stations.

Met Office Integrated Data Archive System (MIDAS): Met Office Integrated Data Archive System

North Dakota Agricultural Weather Network (NDAWN): This network reports precipitation, air temp and wind speeds. The data from the NDAWN network is automated and received every 5 min by wireless modem. The data is quality checked before it is uploaded as historical data. (North Dakota State University)

NWS/FAA ASOS: National Weather Service and Federal Aviation Agency Automated Sensor Observing System

NWS COOP data: National Weather Service Cooperative Observer network. Observing network for reporting weather data; daily observations are provided by observers and are archived at the National Climatic Data Center (NCDC). NWS COOP station reports become part of the NCDC official climate record.

NWSChat: NWSChat is an Instant Messaging program utilized by NWS operational personnel to share critical warning decision expertise and other types of significant

weather information essential to the NWS's mission of saving lives and property (NWSChat Administration Team).

Saskatchewan Ministry of Environment: Network operated by the Saskatchewan Ministry of Environment, primarily for wildfire management purposes.

Weather INnovations Consulting LP (WIN): Weather INnovations Consulting LP (WIN) collects, analyses and warehouses weather data from a large network that covers most of Western Canada, including several sites within the Souris Basin. They have historical data, and monthly and daily climate normal (Weather INonations, n.d.).