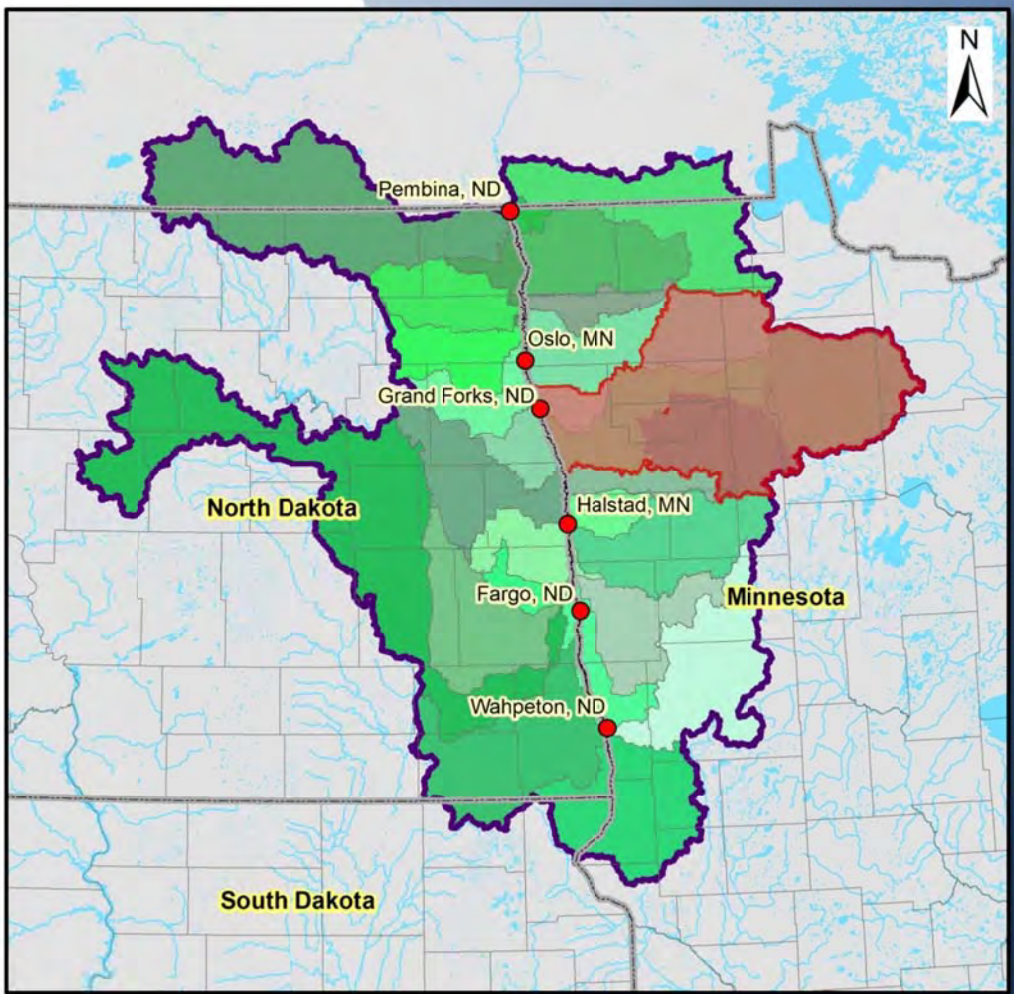
Red Lake Watershed
Expanded Distributed Detention Strategy



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RED LAKE WATERSHED
EXPANDED DISTRIBUTED DETENTION STRATEGY

Prepared on behalf of:

Red Lake Watershed District
Red River Watershed Management Board

November 21, 2013

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I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Minnesota.

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Date: November 21, 2013

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EXECUTIVE SUMMARY

The Red River Watershed Management Board (RRWMB) is funding the development of a comprehensive plan for expanded distributed detention strategies for watershed districts within the Minnesota portion of Red River Basin. In an effort to reduce peak flows along the Red River of the North (Red River) mainstem by 20% during a flooding event similar to the 1997 flood, each tributary has been provided with both peak flow and volume reduction goals as set forth in the Red River Basin Commission's (RRBC) Long Term Flood Solutions (LTFS) Basin Wide Flood Flow Reduction Strategy Report [Reference 3]. The goals set forth for the Red Lake Watershed District (RLWD) are 35% peak flow reduction and 13% volume reduction at the USGS Gage on the Red Lake River at Crookston, and 12% peak flow reduction and 10% volume reduction in ungagged areas [Reference 2].

The Red Lake Watershed District (RLWD) contains 25 existing runoff detention facilities, listed in **Table 1**. In this study it is assumed that the Upper and Lower Red Lakes are sufficiently large that additional impoundments in this area will not affect peak flows on the Red Lake River. Some of the existing facilities are intended for wildlife habitat or water supply, but also have a secondary flood management effect. Three of these impoundments were constructed after the 1997 spring flood event and contribute toward meeting the peak flow and volume reduction goals. Additional proposed impoundment sites were identified in this study to complete the flood reduction goals. These proposed impoundments were sited considering guidelines established by the RRWMB. Under these guidelines, a proposed impoundment should store at least three to four inches of drainage area runoff within the gated storage (the impoundment storage below the primary spillway) and an additional one to two inches of runoff as ungated storage (the storage above the primary spillway and below the emergency spillway) across a minimum drainage area of twenty square miles. In addition, the guidelines calls for proposed sites which would limit permit complexity and eliminate or reduce impacts to existing structures.

The HEC-HMS models developed for the United States Army Corps of Engineers (USACE) in 2012 as part of the Red River of the North Basin-Wide Modeling Approach project [Reference 6] have been utilized to simulate the detention sites throughout the RLWD. A digital elevation model (DEM), created from the hydrologically conditioned LiDAR data included with the USACE models, was manipulated to simulate embankments, culverts, and cutoff ditches for each proposed site. ESRI ArcGIS™ tools were then employed to determine drainage areas and storage curves for each proposed site. Pre-1997 conditions were developed based on the existing impoundments developed prior to Spring 1997 along with delineated drainage areas representing post-1997 and proposed sites. The Post-1997 and Proposed Sites conditions were then added to the HEC-HMS model to determine the effect that each site would have towards the peak flow reduction goals. Both the Pre-1997 conditions and the Post-1997 and Proposed Sites conditions were analyzed using the Red River Basin Standardized Melt Progression Event in the HEC-HMS models [Reference 1], representing snowmelt similar to the 1997 flood event.

In total, 58 off-channel and tributary proposed sites were identified providing an approximate total of 254,600 acre-feet of storage, or 4.3 inches regulating 1,098 square miles of the RLWD's approximate 6,030 square mile drainage area. Due to the limited availability of uninhibited land containing topography which is conducive to detention, the peak flow reduction goal of 35% at Crookston was not met using only proposed off-channel and tributary sites. Therefore eight proposed on-channel mainstem sites were also simulated to achieve the peak flow and volume reduction goals. The combination of all Post-1997 and proposed sites simulated provides a projected total of 429,778 acre-feet of storage, or 2.4 inches regulating 3,409 square miles.

1 INTRODUCTION

1.1 RED RIVER BASIN BACKGROUND

The Red River Basin covers approximately 49,000 square miles of drainage area over portions of South Dakota, North Dakota, Minnesota, and the Canadian province of Manitoba. The basin was formed by prehistoric Lake Agassiz, which covered the existing basin area and extended north of the Hudson Bay. The bottom of the lake bed is extremely flat, until reaching the beach ridges which slope upwards to higher elevations. The Red River of the North sits at the bottom of this lake bed. Due to the flat topography, overbank flooding of the Red River and its tributaries can cover large areas of land, and has historically caused extensive property damage throughout the basin. Flood mitigation efforts throughout the basin have included both structural and non-structural measures, including construction of levee and floodwall systems, bypass channels, and flood impoundment pools, as well as ice jam mitigation techniques such as cutting and scoring river ice to facilitate breakup.

The basin has been divided into separate governing jurisdictions of Watershed Districts in Minnesota, Water Resource Districts in North Dakota, and various governing bodies within Manitoba. In an effort to help each of these districts work together to mitigate flooding across the region, several organizations have been formed. These organizations include the Red River Basin Commission (RRBC) which has board members from each state/province in the basin, the Red River Watershed Management Board (RRWMB) in Minnesota, and the Red River Joint Water Resource District in North Dakota. In recent years these organizations have placed a focus on strategies which reduce flows on the Red River by altering the hydrology of its contributing watersheds. An initial goal of 20% peak flow reduction along the Red River mainstem was set by the RRBC because it would have reduced the Red River elevations of the 1997 spring flood in Grand Forks to a level that the levees existing at that time would have been able to withstand. To set goals for individual watershed districts, the RRBC developed a Red River mainstem model using Mike 11 software. The model was calibrated to simulate the 1997 spring flood and hydrologic inputs included the measured flows from the main tributaries and derived flows from ungaged tributary areas. The model was then used to determine specific peak flow reductions needed along the main tributaries as well as several ungaged areas to reach the reduction goal of 20% along the Red River. These reductions ranged from 0 to 50%, and averaged about 35%. The specific results are provided with the RRBC's Long Term Flood Solutions (LTFS) Basin Wide Flood Flow Reduction Strategy report [Reference 3].

To more accurately determine the level of effort that will be required to meet the flow reduction goals, multiple HEC-HMS hydrologic models have been developed to simulate runoff within the tributaries of the Red River [Reference 6]. Standardized procedures were employed through the use of hydrologically conditioned LiDAR and ArcGIS software to create each model such that there are now consistently developed HEC-HMS models that simulate runoff throughout the majority of the Red River Basin. The development of these models was funded by the USACE along with the cities of Fargo, ND and Moorhead, MN. These models are the basis for this study to simulate potential flood mitigation projects throughout the basin and help determine both local and regional benefits.

1.2 RED LAKE WATERSHED DISTRICT BACKGROUND

The Red Lake Watershed District (RLWD) is located in the central portion of the Red River Basin within the State of Minnesota, as shown in **Figure 1**. The RLWD consists of approximately 6,030 square miles in total, 300 square miles of which are within the Grand Marais subwatershed and 5,730 contributing to the Red Lake River. The drainage area contributing to the Red Lake River at the USGS Gage in Crookston is approximately 5,340 square miles.

Due to the large size of the RLWD, the watershed is described as six separate subwatersheds. A map of the RWLD showing each of the six subwatersheds is provided in **Figure 2**. The subwatershed presented here are:

- The Upper and Lower Red Lake
- Thief River
- Clearwater River
- Lower Red Lake River
- Grand Marais
- Direct drainage to the Red River

The easternmost subwatershed is primarily forested and drains to Upper and Lower Red Lake. A large portion of this area falls within the boundary of the Red Lake Indian Reservation and is primarily controlled by the Red Lake Band of Ojibwe. The outflow from this subwatershed is regulated by Red Lake Dam and flows into the Lower Red Lake River. The storage capability of the Upper and Lower Red Lake allows for a regulation of releases to limit downstream flooding from this subwatershed. It is assumed that further proposed impoundment locations within this subwatershed would not change operations of the Red Lake Dam. Proposed impoundment sites in this study are located in the other subwatersheds.

The northernmost subwatershed drains to the Thief River. This area is dominated by gradual slopes and contains a variety of land uses including forests, wetlands, and agriculture. A large area within the Thief River subwatershed is dedicated to wildlife and habitat management within the Thief Lake Wildlife Management Area (WMA) and Aggasiz National Wildlife Refuge. While existing impoundments in these areas are intended and operated for habitat purposes, the system of impoundments also has secondary flood management benefits. Thief River flows into the Lower Red Lake River at Thief River Falls.

The south-central subwatershed drains to the Clearwater River and consists primarily of rolling hills with land uses ranging form agriculture to residential. This subwatershed has a relatively high amount of natural storage and non-contributing drainage area. Clearwater River flows into the Lower Red Lake River at Red Lake Falls.

The final three subwatersheds are in the central and western portions of the RLWD. The Upper and Lower Red Lake River, Thief River, and Clearwater subwatersheds drain to the Lower Red Lake River, and the Grand Marais Creek subwatershed drains to the Grand Marais Creek, which flows directly to the Red Lake River. Both of these subwatersheds contain gradual slopes and are primarily utilized for agricultural purposes. The remaining subwatershed consists of limited area draining directly to the Red River.

1.3 SCOPE AND PURPOSE

As described above, the Red River Basin is prone to flooding which has historically resulted in significant damages along both the main stem of the Red River and throughout its tributaries. Methods such as diversions and levees could be used throughout the Red River Basin to protect individual communities; however, these strategies only pass flood-flows on to downstream areas and communities. As discussed above, the RRBC has put forth a basin wide plan within the Basin Wide Flood Flow Reduction Strategy which calls for a reduction in peak flows throughout the entire Red River Basin. The goals set for RLWD include a 35% peak flow reduction and 13% volume reduction at the USGS gage in Crookston and a 12% peak flow reduction and 10% volume reduction in the Red Lake River ungagged area during a flood event similar to the 1997 flood [Reference 2].

The method to be utilized for the RLWD Expanded Distributed Detention Strategy is detention. The entirety of the RLWD, excluding the Upper and Lower Red Lake area, was reviewed to identify areas where runoff could be stored. Determination of these areas included a review of LiDAR data, RLWD water management planning documents [Reference 7], use of the International Water Institute's (IWI) Project Planning Tool (PPT), and guidelines set forth by the RRWMB. The RRWMB project guidelines includes consideration of permit complexity, gated storage of 3 to 4-inches of drainage area runoff, and control of drainage areas greater than 20 square miles.

The identified sites were added to the HEC-HMS model of the RLWD created through the US Army Corps of Engineers Red River Hydrologic Modeling Study [Reference 6]. The model was run with the synthetic hydrology developed as part of the RRBC Standardized Melt Progression Analysis [Reference 1]. This event utilizes the 100-year runoff depths described in the NRCS's Technical Release No. 60 publication [Reference 4]. The model was then run to estimate the peak flow and volume reductions resulting from implementation of existing Post-1997 impoundments and proposed identified sites.

2 FLOOD WATER DETENTION LOCATION SELECTION

2.1 EXISTING FLOOD WATER DETENTION LOCATIONS

There are multiple flood water impoundments currently existing within the RLWD which provide approximately 240,000 acre-feet of total modeled storage capacity. A summary of the available storage and site characteristics of these impoundments is provided in **Table 1**. The impoundments constructed after the 1997 spring flood event are the Parnell, Euclid East, and Brandt Impoundments, each of which reside within the Grand Marais subwatershed. These existing Post-1997 impoundments provide approximately 4,350 acre-feet of gated storage and 5,000 acre-feet of ungated storage. The Parnell Impoundment can affect peak flows at the Crookston Gage, as Red Lake River drainage area contributes to this impoundment when a gate on Judicial Ditch 60 is closed. As each of these impoundments was constructed after the 1997 flood event they are included in the RLWD's effort towards meeting the LTFS Basinwide Flow Reduction Strategy goals.

Many of the sites developed prior to 1997 are not owned and operated by the RLWD. For some of these sites there is little or no available data which could be used to determine gated and ungated storage capacity. Therefore actual gated and ungated storage for many of the existing detention areas within the RLWD is unknown. Stage-storage curves have been utilized for each existing site based on available data including engineer's reports and project summary data provided by the RLWD where available. For sites with little or no available design and operating data, LiDAR-derived stage storage curves were developed and outlet spillway information was assumed based on LiDAR data and aerial imagery.

The storage contained within the Upper and Lower Red Lakes has not been considered in the reported existing storage capacity number nor has it been considered throughout this report. The Upper and Lower Red Lake is operated by the USACE, and the dam operating manual has been consulted to determine operating characteristics. Based on the operating manual and historical discharge data, a continuous discharge of 250 cfs has been assumed to discharge from the lakes throughout the entirety of the simulated event.

2.2 INTERNATIONAL WATER INSTITUTE – PROJECT PLANNING TOOL

The IWI's Project Planning Tool (PPT) has been designed to help identify potential locations for flood damage reduction projects and to streamline the project planning and permitting process. The tool has several features which include GIS layers that utilize LiDAR data to reveal areas where floodwaters could be stored based on existing depressions and roads. In addition to existing topographical features, the tool also provides layers which reveal potential storage capacity in areas if existing roads were to be raised, thus simulating embankments which could be created to detain runoff throughout the watershed. Each of these layers was used to identify target locations within the RWLD where implementation of detention projects may be possible. In additional to aiding in locating potential flood storage locations, the tool's Permit Complexity layer was utilized to highlight areas within the RLWD where environmental features, such as wetlands, could potentially create obstacles in the implementation of detention locations. These areas were avoided to the extent possible.

2.3 SELECTION CRITERIA

Potential detention sites were selected based on the guidelines set fourth by the RRWMB of providing gated storage for three to four inches of drainage area runoff for a minimum drainage area of 20 square miles. As described above, the IWI PPT was used to provide target areas within the RLWD where this goal could be met. Net impact on the reduction of peak flows to the Red Lake River at Crookston was also largely considered, as specific areas within the watershed contribute differently to the peak flow at the Crookston gage. Areas close to the Crookston gage may contribute to the Red Lake River prior to the river peak flow occurring. Termed the "early" zone, potential impoundment sites here may have limited or possibly detrimental effects in reducing river peak flows. Areas far from the Crookston gage, the "late" zone, may have a long travel time such that peak runoff from these areas is unlikely to occur at the same time as the river peak at Crookston. Impoundments here would not be effective in reducing river peak flows. Areas within the optimal "middle" zone could vary in effectiveness, dependent on existing and natural storage and timing of the snowmelt. Although all areas were looked at for potential detention sites, the areas in the "middle" zone were targeted more heavily as they will likely have the largest impact on reducing peak flows and thus become the most cost effective options. To determine these zones, the USACE developed models were simulated multiple times, each time with a different subbasin area removed. The peak flow change at the Crookston gage was scaled based on the drainage area that was removed. The results of this analysis are provided in **Figure 8**, and specific areas that were determined to be highly effective per square mile of drainage area retained were noted.

Both permit complexity and constructability were also considered in the site selection process. Areas with sensitive environmental characteristics, such as wetlands, and/or multiple man-made structures, such as homes or farm-yards, were avoided to the extent possible, and where possible conceptual embankments were created such that land near structures could be utilized for flood water detention while not impacting the immediate area of the structure. Due to the limited availability of land which does not contain structures currently existing throughout the RLWD, several of the sites selected do not meet the guidelines to contain three to four inches of runoff with a minimum drainage area of twenty square miles. Sites with smaller drainage areas and/or storage capacities were also selected in an effort to reach the overall peak flow reduction goal for the 100-year 10-day runoff event.

Sites previously identified by the RLWD were also reviewed. Potential embankments, outlet locations, and diversion ditches were refined as necessary to provide the maximum amount of storage capacity and drainage area for each site. Also, four sites contributing to areas downstream of the Crookston gate have also been identified. These sites, along with the Brandt, Euclid East, and Parnell Impoundments, would contribute to the peak flow reduction goal for RLWD ungagged areas.

2.4 SUMMARY OF SELECTED LOCATIONS

In total, 58 proposed off-channel and tributary detention sites and 8 proposed on-channel main stem detention sites have been identified throughout the RLWD. The sites provide a combined storage capacity of approximately 429,780 acre feet, amounting to 2.4 inches of gated storage over a regulated drainage area of 3,410 square miles. Although many of these sites fall within the selection guidelines, a number of them may be slightly outside of the guidelines. Sites slightly outside of the guidelines were considered due to the limited amount of available land within the RLWD. The simulation of the Post-1997 sites and 58 proposed off-channel and tributary sites resulted in a peak flow reduction of 18.1% at the Crookston gage for the 100-year 10-day runoff event. Due to the need to reach a peak flow reduction of 35% at the Crookston gage, an additional eight on-channel mainstem proposed sites were simulated within the Thief River, the Clearwater River, and the Lower Red Lake River subwatersheds. Although these later sites would likely be difficult to permit, they were necessary to reach the peak flow reduction goal of 35% at Crookston. **Figure 3** shows the regulated drainage areas of the existing and proposed impoundments.

3 HYDROLOGIC ANALYSIS

Hydrologic analysis of potential detention sites used modeling products developed by the U.S. Army Corps of Engineers [Reference 6]. The Red Lake River Watershed is modeled as separate and linked models. The Upper and Lower Red Lakes covers 1,920 square miles of contributing drainage area. Releases from Red Lake Dam are assumed to operate as in 1997, with approximate flows limited to 250 cfs. The remaining modeled watersheds are the Thief River (with a contributing drainage area of 1,070 square miles), Clearwater (contributing drainage area of 1,360 square miles) and Lower Red Lake River (contributing drainage area of 1,380 square miles). Part of the Red Lake River watershed drains directly to the Red River. This portion also includes the Grand Marais watershed.

3.1 MODIFICATIONS TO EXISTING CONDITIONS

Detail was added to the existing baseline HEC-HMS model at the locations of the proposed impoundments described in Section 2. Model parameters were derived in a consistent manner as was used for USACE model development [Reference 6]. The drainage area to each potential impoundment location was determined using the hydrologically conditioned LiDAR elevation data. Loss rates were assessed upstream of each potential dam location using the USACE 24-hour baseline curve number data. The time of concentrations and watershed Clark unit hydrograph storage coefficients were assessed using the previously determined calibration adjustments and Minnesota DNR Travel Time GIS script [Reference 6]. Reach routing was adjusted based on the location of the potential dam site. Existing impoundments that were present before 1997 (Pre-1997 sites) were retained in the existing conditions model.

3.2 DEVELOPMENT OF PROPOSED CONDITIONS

Existing post-1997 sites and proposed sites were added to the proposed conditions model. The embankments, drainage ditches, and tie-in ditches for each proposed sites were hydrologically conditioned into the LiDAR elevation data and used to determine the specific drainage areas to each potential impoundment. Within the drainage area, the top of dam elevation was used to identify the impoundment flood footprint and associated storage capacity. The top of gated storage was assumed to be two feet below the top of dam for off-channel potential impoundments and five feet below the top of dam for on-channel sites. **Table 2** provides the calculated drainage area, gated, and ungated storage volumes for each proposed site.

For simplicity, all flood water detention locations were assumed to operate with a full drawdown, or dry, initial condition. Locations where runoff is proposed to be diverted from natural water courses were assumed to allow a base flow within those systems before excess runoff was diverted out of the channel and into the impoundment locations. Runoff diverted from legal ditches and intermittent watercourses was assumed to collect all runoff reaching the cut-off channel diverted into the impoundment location. When the diverted runoff volume exceeded the available gated storage within the impoundment, additional runoff was allowed to outflow from the site and continue downstream. This same “fill and spill” methodology was assumed for the analysis of proposed detention locations.

3.3 RED RIVER BASIN STANDARDIZED MELT PROGRESSION EVENT

To more accurately simulate a synthetic spring melt condition within the US portion of the Red River Basin, the Red River Basin Commission completed an analysis in early 2013 [Reference 1]. This analysis utilized temperature data at observation locations throughout the Red River Basin to estimate when snowmelt conditions generally occur during a typical spring. The results of this virtual thaw progression are illustrated in **Figure 4**. This timing analysis was applied to a 100-year 10-day runoff scenario depth illustrated in **Figure 5**. Based on the 100-year 10-day runoff scenario shown in **Figure 5**, equivalent rainfall depths for the 100-year 10-day runoff were developed using the composite 24-hour NRCS curve number for the portion of the Red River Basin upstream of Halstad, MN. This composite 24-hour curve number was found to be approximately 73. The resultant equivalent rainfall depths are illustrated in **Figure 6**. This equivalent rainfall depth was then applied using the Minnesota Principal Spillway Temporal Rainfall Distribution, as defined in the Minnesota Hydrology Guide. This temporal distribution is illustrated in **Figure 7**. Start time for the rainfall was set by the Virtual Thaw Progression (**Figure 4**) at each respective location. This information was developed in a manner to allow application via the gridded precipitation meteorological option within HEC-HMS. Gridded precipitation allows for each subbasin to depict a unique temporal distribution and total depth depending on its geographic orientation in relation to the Standardized Melt Progression. The resultant Red River Basin Standardized Melt Progression Event was utilized to determine volume and peak flow reduction criteria based on the Long Term Flood Solutions recommendations. For further information regarding the Red River Basin Standardized Melt Progression Event, refer to the Red River Basin Standardized Melt Progression Event Analysis Report completed by the Red River Basin Commission, April 2013 [Reference 1].

4 RESULTS

4.1 RED LAKE WATERSHED DISTRICT SUMMARY

The RRBC's LTFS Basinwide Flow Reduction Strategy report [Reference 2] calls for a peak flow reduction of 35% and a runoff volume reduction of 13% on the Red Lake River at Crookston during a 100-year 10-day event similar in nature to the 1997 flood. In addition, the report also has set a goal of 12% peak flow reduction and 10% volume reduction for the Red Lake River ungagged areas. The Thief River, Clearwater, Lower Red Lake River, Grand Marais, and direct drainages to the Red River of the RLWD were reviewed for proposed detention locations. The Upper and Lower Red Lakes subwatershd, due to its being controlled by the Red Lake dam, was not included in this study.

The identified proposed off-channel and tributary detention locations along with the post-1997 sites resulted in a peak flow reduction of 18.1% and a runoff volume reduction of 11.4% at the USGS Gage on the Red Lake River at Crookston when compared with pre-1997 conditions. Due to the lack of off-channel and tributary sites available within the RLWD which meet the site selection guidelines, eight mainstem on-channel proposed sites were further identified. The addition of these sites resulted in a peak flow reduction of 35.0% and a runoff volume reduction of 26.3% at the USGS Gage on the Red Lake River at Crookston when compared with pre-1997 conditions. The hydrograph comparing pre-1997 conditions, post-1997 sites with proposed off-channel and tributary sites conditions, and proposed conditions including mainstem on-channel sites is provided in **Figure 9**. Additional hydrographs providing model results at the outlets of both the Thief River and Clearwater River are provided in **Figures 10** and **11**. Specific performance statistics for each identified location during the 100-year, 10-day Red River Basin Standardized Melt Progression Event are provided in **Table 3**. The performance statistics show the volume stored using gated impoundment storage and percent reductions in peak inflows and volumes at the outlet of each impoundment. Additionally, runoff volume and peak flow reductions at various locations within the RLWD are presented in **Tables 4** and **5**.

4.2 RECOMMENDATIONS

The proposed detention locations identified as part of this effort present one possible scenario to reach the runoff volume and peak flow reduction goals for the RLWD as specified in the RRBC's LTFS Basinwide Flow Reduction Strategy. It is anticipated that the RLWD will use the results of this analysis to assist in reducing peak flows along the Red River main stem while also pursuing projects that maximize local benefit within the RLWD.

REFERENCES

1. Red River Basin Commission, *Red River Basin Standardized Melt Progression Event Analysis,* April 10, 2013.

2. Red River Basin Commission, *LTFS Basinwide Flow Reduction Strategy,* January 20, 2010.
   Available on-line at:
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3. Red River Basin Commission, Long Term Flood Solutions for the Red River Basin, September 2011.

4. U.S. Department of Agriculture, Natural Resources Conservation Service, *Earth Dams and Reservoirs*, Technical Release No. 60, July 2005.

5. U.S. Department of Agriculture, Natural Resources Conservation Service, *Hydrology Guide for Minnesota.*

6. Fargo-Moorhead Metro Basin-Wide Modeling Approach – Hydrologic Modeling, *HEC-HMS Model Development for Various Tributaries below the Red River of the North at Halstad, MN*, October 15, 2012.

7. Red Lake Watershed District, *10-Year Comprehensive Plan*, May 2006.

Tables

Table 1
Existing Conditions Flood Water Detention Location Statistics

Site Name	Drainage Area [Mi^2]	Total Modeled Volume [ac-ft] (Runoff [in]) (source: USACE HMS models)
Impoundment Locations Constructed Before the 1997 Spring Flood Event		
Thief Lake	178.6 Mi^2	51,797 Ac-ft *(5.4")*
Agassiz National Wildlife Refuge (consists of multiple impoundments)	255.3 Mi^2	82,280 Ac-ft *(6.0")*
Lost River Impoundment	28.4 Mi^2	10,523 Ac-ft *(6.9")*
Pine Lake Outlet	38.9 Mi^2	1,546 Ac-ft *(0.7")*
Schirrick Dam	108.8 Mi^2	5,059 Ac-ft *(0.9")*
Moose River North Pool	40.8 Mi^2	12,000 Ac-ft *(5.5")*
Moose River South Pool	79.1 Mi^2	23,672 Ac-ft *(5.6")*
Elm Lake-Farmes Pool Impoundment	33.8 Mi^2	8,958 Ac-ft *(5.0")*
Good Lake	38.8 Mi^2	15,661 Ac-ft *(7.6")*
Kee-Wah-Sah	36.2 Mi^2	3,985 Ac-ft *(2.1")*
Hill River	85.1 Mi^2	659 Ac-ft *(0.1")*
Little Pine WMA	6.1 Mi^2	57 Ac-ft *(0.2")*
Clearwater Lake	149.8 Mi^2	3,676 Ac-ft *(0.5")*
Spike Lake WMA	13.6 Mi^2	36 Ac-ft *(<0.1")*
Big Swamp	35.1 Mi^2	2 Ac-ft *(<0.1")*
Maple Lake	32.0 Mi^2	7,216 Ac-ft *(4.2")*
Seeger Dam	6.7 Mi^2	184 Ac-ft *(0.5")*
Goose Lake	15.3 Mi^2	2,603 Ac-ft *(3.2")*
Baird Beyer Dam	8.1 Mi^2	409 Ac-ft *(0.9")*
BR6	4.4 Mi^2	365 Ac-ft *(1.5")*
Louisville Parnell	2.1 Mi^2	225 Ac-ft *(2.0")*
Parnell TWP FSE	2.8 Mi^2	616 Ac-ft *(4.2")*
Subtotal (Before 1997)	1,199.8 Mi^2	231,529 Ac-ft *(3.6")*
Impoundment Locations Constructed After the 1997 Spring Flood Event		
Parnell Impoundment	16.2 Mi^2	3,129 Ac-ft *(3.6")*
Euclid East Impoundment	17.1 Mi^2	1,878 Ac-ft *(2.1")*
Brandt Impoundment	22.9 Mi^2	3,641 Ac-ft *(3.0")*
Subtotal (After 1997)	56.2 Mi^2	8,648 Ac-ft *(3.4")*
Total (Current Conditions)	1,256.0 Mi^2	240,177 Ac-ft *(3.6")*

Notes:

Upper and Lower Red Lake is not included in this study. It is assumed that proposed impoundments upstream of this lake will have negligible impacts on downstream Red Lake River peak flows.

Total Modeled Volume represents the modeled peak storage resulting from the Red River Basin Standardized Melt Progression Event run in HEC-HMS prior to implementation of proposed sites. Total available storage may be larger than total modeled volume at certain sites.

Table 2
Proposed Conditions Flood Water Detention Location Statistics

Site Name	Drainage Area	Gated Volume Ac-ft (inches runoff)	Ungated Volume Ac-ft (inches runoff)	Total Volume Ac-ft (inches runoff)
Identified Off-Channel and Tributary Proposed Detention Locations				
TR-1	5.6 Mi^2	1,150 Ac-ft *(3.9")*	1,370 Ac-ft *(4.6")*	2,520 Ac-ft *(8.4")*
TR-2	95.3 Mi^2	2,880 Ac-ft *(0.6")*	1,805 Ac-ft *(0.4")*	4,685 Ac-ft *(0.9")*
TR-3	9.9 Mi^2	650 Ac-ft *(1.2")*	625 Ac-ft *(1.2")*	1,275 Ac-ft *(2.4")*
TR-4	16.4 Mi^2	2,045 Ac-ft *(2.3")*	1,755Ac-ft *(2.0")*	3,800 Ac-ft *(4.3")*
TR-5	33.3 Mi^2	1,440 Ac-ft *(0.8")*	1,525 Ac-ft *(0.9")*	2,965 Ac-ft *(1.7")*
TR-6	52.9 Mi^2	1,585 Ac-ft *(0.6")*	3,195 Ac-ft *(1.1")*	4,780 Ac-ft *(1.7")*
TR-7	26.7 Mi^2	1,785 Ac-ft *(1.3")*	2,170 Ac-ft *(1.5")*	3,955 Ac-ft (2.8")
TR-8	102.9 Mi^2	2,485 Ac-ft *(0.5")*	2,075 Ac-ft *(0.4")*	4,560 Ac-ft *(0.8")*
TR-9	113.6 Mi^2	3,005 Ac-ft *(0.5")*	2,830 Ac-ft *(0.5")*	5,835 Ac-ft *(1.0")*
TR-10	126.3 Mi^2	50 Ac-ft *(<0.1")*	785 Ac-ft *(0.1")*	835 Ac-ft *(0.1")*
TR-11	168.3 Mi^2	120 Ac-ft *(<0.1")*	1,610 Ac-ft *(0.2")*	1,730 Ac-ft *(0.2")*
TR-12	23.8 Mi^2	695 Ac-ft *(0.5")*	1,885 Ac-ft *(1.5")*	2,580 Ac-ft *(2.0")*
TR-13	56.5 Mi^2	550 Ac-ft *(0.2")*	1,020 Ac-ft *(0.3")*	1,570 Ac-ft *(0.5")*
CR-1	26.9 Mi^2	7,595 Ac-ft *(5.3")*	1,420 Ac-ft *(1.0")*	9,015 Ac-ft *(6.3")*
CR-2	99.3 Mi^2	5,590 Ac-ft *(1.1")*	3,190 Ac-ft *(0.6")*	8,780 Ac-ft *(1.7")*
CR-3	103.0 Mi^2	2,430 Ac-ft *(0.4")*	580 Ac-ft *(0.1")*	3,010 Ac-ft *(0.5")*
*CR-4	6.5 Mi^2	2,260 Ac-ft *(6.5")*	850 Ac-ft *(2.5")*	3,110 Ac-ft *(9.0")*
CR-5	127.3 Mi^2	2,000 Ac-ft *(0.3")*	910 Ac-ft *(0.1")*	2,910 Ac-ft *(0.4")*
*CR-6	7.7 Mi^2	12,220 Ac-ft *(29.8")*	710 Ac-ft *(1.7")*	12,930 Ac-ft *(31.5")*

Table 2
Proposed Conditions Flood Water Detention Location Statistics

Site Name	Drainage Area	Gated Volume Ac-ft (inches runoff)	Ungated Volume Ac-ft (inches runoff)	Total Volume Ac-ft (inches runoff)
*CR-7	13.7 Mi^2	2,305 Ac-ft *(3.2")*	1,195 Ac-ft *(1.6")*	3,500 Ac-ft *(4.8")*
*CR-8	9.4 Mi^2	1,390 Ac-ft *(2.8")*	535 Ac-ft *(1.1")*	1,925 Ac-ft *(3.8")*
*CR-9	13.1 Mi^2	1,560 Ac-ft *(2.2")*	1,130 Ac-ft *(1.6")*	2,690 Ac-ft *(3.9")*
CR-10	3.9 Mi^2	880 Ac-ft *(4.2")*	1,110 Ac-ft *(5.3")*	1,990 Ac-ft *(9.6")*
CR-11	9.2 Mi^2	745 Ac-ft *(1.5")*	1,820 Ac-ft *(3.7")*	2,565 Ac-ft *(5.2")*
CR-12	4.0 Mi^2	600 Ac-ft *(2.8")*	1,030 Ac-ft *(4.8")*	1,630 Ac-ft *(7.6")*
*CR-13	6.2 Mi^2	2,270 Ac-ft *(6.9")*	4,100 Ac-ft *(12.4")*	6,370 Ac-ft *(19.3")*
CR-14	10.0 Mi^2	3,440 Ac-ft *(6.5")*	3,060 Ac-ft *(5.7")*	6,500 Ac-ft *(12.2")*
CR-15	92.8 Mi^2	4,905 Ac-ft *(1.0")*	2,605 Ac-ft *(0.5")*	7,510 Ac-ft *(1.5")*
CR-16	121.0 Mi^2	6,790 Ac-ft *(1.1")*	2,760 Ac-ft *(0.4")*	9,550 Ac-ft *(1.5")*
*CR-17	15.7 Mi^2	545 Ac-ft *(0.7")*	445 Ac-ft *(0.5")*	990 Ac-ft *(1.2")*
*CR-18	11.7 Mi^2	1,820 Ac-ft *(2.9")*	2,960 Ac-ft *(4.7")*	4,780 Ac-ft *(7.7")*
*CR-19	28.0 Mi^2	7,720 Ac-ft *(5.2")*	1,280 Ac-ft *(0.9")*	9,000 Ac-ft *(6.0")*
*CR-20	11.6 Mi^2	230 Ac-ft *(0.4")*	290 Ac-ft *(0.5")*	520 Ac-ft *(0.8")*
*CR-21	15.1 Mi^2	770 Ac-ft	1,480 Ac-ft *(1.8")*	2,250 Ac-ft *(2.8")*
*CR-22	5.1 Mi^2	1,950 Ac-ft *(7.2")*	3,750 Ac-ft *(13.8")*	5,700 Ac-ft *(21.0")*
CR-23	7.3 Mi^2	2,110 Ac-ft *(5.4")*	1,650 Ac-ft *(4.2")*	3,760 Ac-ft *(9.7")*
CR-24	48.1 Mi^2	340 Ac-ft *(0.1")*	1,025 Ac-ft *(0.4")*	1,365 Ac-ft *(0.5")*
CR-25	28.4 Mi^2	5,250 Ac-ft *(3.5")*	1,135 Ac-ft *(0.7")*	6,385 Ac-ft *(4.2")*
*CR-26	6.3 Mi^2	2,195 Ac-ft *(6.5")*	955 Ac-ft *(2.8")*	3,150 Ac-ft *(9.4")*

Table 2
Proposed Conditions Flood Water Detention Location Statistics

Site Name	Drainage Area	Gated Volume Ac-ft (inches runoff)	Ungated Volume Ac-ft (inches runoff)	Total Volume Ac-ft (inches runoff)
*CR-27	56.5 Mi^2	5,005 Ac-ft *(1.7")*	1,995 Ac-ft *(0.7")*	7,000 Ac-ft *(2.3")*
CR-28	55.1 Mi^2	8,390 Ac-ft *(2.9")*	3,240 Ac-ft *(1.1")*	11,630 Ac-ft *(4.0")*
CR-29	100.6 Mi^2	2,480 Ac-ft *(0.5")*	975 Ac-ft *(0.2")*	3,455 Ac-ft *(0.6")*
CR-30	199.6 Mi^2	520 Ac-ft *(<0.1")*	850 Ac-ft *(0.1")*	1,370 Ac-ft *(0.1")*
URLR-1	12.4 Mi^2	4,590 Ac-ft *(6.9")*	6,190 Ac-ft *(9.4")*	10,780 Ac-ft *(16.3")*
URLR-2	10.0 Mi^2	2,255 Ac-ft *(4.2")*	1,830 Ac-ft *(3.4")*	4,085 Ac-ft *(7.7")*
URLR-3	10.5 Mi^2	2,130 Ac-ft *(3.8")*	1,590 Ac-ft *(2.8")*	3,720 Ac-ft *(6.6")*
URLR-4	5.2 Mi^2	820 Ac-ft *(3.0")*	1,835 Ac-ft *(6.6")*	2,655 Ac-ft *(9.6")*
LRLR-1	2.5 Mi^2	950 Ac-ft *(7.1")*	1,395 Ac-ft *(10.5")*	2,345 Ac-ft *(17.6")*
*LRLR-2	12.2 Mi^2	3,560 Ac-ft *(5.5")*	1,340 Ac-ft *(2.1")*	4,900 Ac-ft *(7.5")*
*LRLR-3	14.4 Mi^2	1,940 Ac-ft *(2.5")*	1,170 Ac-ft *(1.5")*	3,110 Ac-ft *(4.0")*
*LRLR-4	7.4 Mi^2	1,920Ac-ft *(4.9")*	1,790 Ac-ft *(4.5")*	3,710 Ac-ft *(9.4")*
*LRLR-5	24.5 Mi^2	5,090 Ac-ft *(3.9")*	1,470 Ac-ft *(1.1")*	6,560 Ac-ft *(5.0")*
LRLR-6	11.9 Mi^2	2,590 Ac-ft *(4.1")*	560 Ac-ft *(0.9")*	3,150 Ac-ft *(5.0")*
*LRLR-7	23.1 Mi^2	6,690 Ac-ft *(5.4")*	800 Ac-ft *(0.6")*	7,490 Ac-ft *(6.1")*
*LRLR-8 (Ungaged)	5.7 Mi^2	1,760 Ac-ft *(5.8")*	680 Ac-ft *(2.2")*	2,440 Ac-ft *(8.0")*
*LRLR-9 (Ungaged)	3.5 Mi^2	1,170 Ac-ft *(6.3")*	800 Ac-ft *(4.3")*	1,970 Ac-ft *(10.6")*
LRLR-10 (Ungaged)	41.8 Mi^2	6,365 Ac-ft *(2.9")*	2,260 Ac-ft *(1.0")*	8,625 Ac-ft *(3.9")*
LRLR-11 (Ungaged)	21.9 Mi^2	1,280 Ac-ft *(1.1")*	1,350 Ac-ft *(1.2")*	2,630 Ac-ft *(2.3")*
Subtotal *(Proposed Off-channel and Tributary Sites)*	1,097.9 Mi^2	157,855 Ac-ft *(2.7")*	96,745 Ac-ft *(1.7")*	254,600 Ac-ft *(4.3")*

Table 2
Proposed Conditions Flood Water Detention Location Statistics

Site Name	Drainage Area	Gated Volume Ac-ft (inches runoff)	Ungated Volume Ac-ft (inches runoff)	Total Volume Ac-ft (inches runoff)
Identified On-Channel Main Stem Proposed Detention Locations				
TR Mainstem 1 (Marshal Co. Ditch 20)	79.4 Mi^2	12,790 Ac-ft *(3.0")*	1,360 Ac-ft *(0.3")*	14,150 Ac-ft *(3.3")*
TR Mainstem 2 (Pennington Co. J 18)	51.6 Mi^2	2,665 Ac-ft *(1.0")*	3,350 Ac-ft *(1.2")*	6,015 Ac-ft *(2.2")*
TR Mainstem 3 (Marshal Co. Ditch 20)	215.4 Mi^2	23,760 Ac-ft *(2.1")*	4,235 Ac-ft *(0.4")*	27,995 Ac-ft *(2.4")*
CR Mainstem 1 (Clearwater River)	174.3 Mi^2	23,125 Ac-ft *(2.5")*	19,715 Ac-ft *(2.1")*	42,840 Ac-ft *(4.6")*
CR Mainstem 2 (Clearwater River)	1,288.3 Mi^2	16,670 Ac-ft *(0.2")*	960 Ac-ft *(<0.1")*	17,630 Ac-ft *(0.3")*
CR Mainstem 3 (Clearwater River)	1,103.5 Mi^2	18,645 Ac-ft *(0.3")*	2,045 Ac-ft *(<0.1")*	20,690 Ac-ft *(0.4")*
LRLR Mainstem 1 (Red Lake River)	1,683.4 Mi^2	9,610 Ac-ft *(0.1")*	350 Ac-ft *(<0.1")*	9,960 Ac-ft *(0.1")*
LRLR Mainstem 2 (Red Lake River)	3,254.9 Mi^2	26,330 Ac-ft *(0.2")*	920 Ac-ft *(<0.1")*	27,250 Ac-ft *(0.2")*
Subtotal *(Proposed On-Channel Sites)*	3,254.9 Mi^2	133,595 Ac-ft *(0.8")*	32,935 Ac-ft *(0.2")*	166,530 Ac-ft *(1.0")*
Subtotal *(All Proposed Sites)*	3,361.1 Mi^2	291,450 Ac-ft *(1.6")*	129,680 Ac-ft *(0.7")*	421,130 Ac-ft *(2.3")*
Subtotal *(All Proposed Sites and Existing Post-1997 Sites)*	3,409.5 Mi^2	**	**	429,778 Ac-ft *(2.4")*
Total *(All Existing and Proposed Sites)*	3,416.1 Mi^2	**	**	661,307 Ac-ft *(3.6")*

Notes:

*=More storage is available than what has been utilized due to limited drainage area.

**=Actual gated and ungated storage for all existing detention areas within the RLWD is unknown. Total storage values have been modeled for each existing site based on available data including engineer's reports, project summary data provided by the RLWD, and LiDAR derived stage storage curves for sites not controlled by the RLWD.

Upper and Lower Red Lake is not included in this study. It is assumed that proposed impoundments upstream of this lake will have negligible impacts on downstream Red Lake River peak flows.

Volume is tabulated volume 35 days after start of snowmelt.

Table 3
Flood Water Detention Location Performance Statistics (Proposed Conditions)
Red River Basin Standardized Melt Progression Event

Site Name	Year Implemented	Modeled Drainage Area	Peak Inflow	Peak Outflow	Peak Flow Reduction	Inflow Volume	Outflow Volume	Volume Reduction
Impoundment Locations Constructed Before the 1997 Spring Flood Event								
Thief Lake	1931	219.4 Mi^2	4,204 cfs	1,862 cfs	55.7%	72,182 Ac-ft *(6.2")*	60,879 Ac-ft *(5.2")*	15.7%
*Agassiz National Wildlife Refuge	1937	334.4 Mi^2	n/a	n/a	n/a	n/a	n/a	n/a
Lost River Impoundment	1978	28.4 Mi^2	766 cfs	560 cfs	26.9%	15,310 Ac-ft *(10.1")*	14,522 Ac-ft *(9.6")*	5.1%
Pine Lake Outlet	1980	45.0 Mi^2	241 cfs	192 cfs	20.3%	5,815 Ac-ft *(2.4")*	5,414 Ac-ft *(2.3")*	6.9%
Schirrick Dam	1985	108.8 Mi^2	2,804 cfs	2,759 cfs	1.6%	28,713 Ac-ft *(4.9")*	24,783 Ac-ft *(4.3")*	13.7%
Moose River North Pool	1988	40.8 Mi^2	1,321 cfs	1,105 cfs	16.4%	15,230 Ac-ft *(7.0")*	8,030 Ac-ft *(3.7")*	47.3%
Moose River South Pool	1988	79.1 Mi^2	853 cfs	341 cfs	60.1%	27,228 Ac-ft *(6.5")*	7,704 Ac-ft *(1.8")*	71.7%
Elm Lake-Farmes Pool Impoundment	1991	62.2 Mi^2	666 cfs	576 cfs	13.5%	19,770 Ac-ft *(6.0")*	19,159 Ac-ft *(5.8")*	3.1%
Good Lake	1996	38.8 Mi^2	999 cfs	125 cfs	87.5 %	15,551 Ac-ft *(7.5")*	5,735 Ac-ft *(2.8")*	63.1%
Kee-Wah-Sah	Pre-1997	36.2 Mi^2	295 cfs	188 cfs	36.3%	10,767 Ac-ft *(5.6")*	7,518 Ac-ft *(3.9")*	30.2%
Hill River	Pre-1997	Hill River replaced by CR-2, see results below						
Little Pine WMA	Pre-1997	Little Pine WMA replaced by CR-26, see results below						
Clearwater Lake	Pre-1997	149.8 Mi^2	1,223 cfs	1,177 cfs	3.8%	38,721 Ac-ft *(4.8")*	37,458 Ac-ft *(4.7")*	3.3%
Spike Lake WMA	Pre-1997	13.6 Mi^2	128 cfs	128 cfs	0.1%	4,221 Ac-ft *(5.8")*	4,217 Ac-ft *(5.8")*	0.1%
Big Swamp	Pre-1997	35.1 Mi^2	243 cfs	243 cfs	0.0%	9,225 Ac-ft *(4.9")*	9,225 Ac-ft *(4.9")*	0.0%
Maple Lake	Pre-1997	32.0 Mi^2	994 cfs	69 cfs	93.1%	8,155 Ac-ft *(4.8")*	3,870 Ac-ft *(2.3")*	52.5%
Seeger Dam	Pre-1997	6.7 Mi^2	317 cfs	240 cfs	24.3%	2,322 Ac-ft *(6.5")*	2,322 Ac-ft *(6.5")*	0.0%
Goose Lake	Pre-1997	15.3 Mi^2	421 cfs	195 cfs	53.7%	4,731 Ac-ft *(5.8")*	3,993 Ac-ft *(4.9")*	15.6%
Baird Beyer Dam	Pre-1997	23.4 Mi^2	291 cfs	291 cfs	0.0%	6,092 Ac-ft *(4.9")*	6,077 Ac-ft *(4.9")*	0.2%
BR6	Pre-1997	4.4 Mi^2	161 cfs	108 cfs	32.9%	1,317 Ac-ft *(5.6")*	1,264 Ac-ft *(5.4")*	4.0%

Table 3
Flood Water Detention Location Performance Statistics (Proposed Conditions)
Red River Basin Standardized Melt Progression Event

Site Name	Year Implemented	Modeled Drainage Area	Peak Inflow	Peak Outflow	Peak Flow Reduction	Inflow Volume	Outflow Volume	Volume Reduction
Louisville Parnell	Pre-1997	1.1 Mi^2	125 cfs	45 cfs	64.0%	659 Ac-ft *(11.2")*	659 Ac-ft *(11.2")*	0.0%
Parnell TWP FSE	Pre-1997	25.2 Mi^2	433 cfs	431 cfs	0.5%	4,357 Ac-ft *(3.2")*	3,910 Ac-ft *(2.9")*	10.3%
Impoundment Locations Constructed After the 1997 Spring Flood Event								
Parnell Impoundment	1999	23.0 Mi^2	741 cfs	400 cfs	46.0%	6,521 Ac-ft *(5.3")*	3,521 Ac-ft *(2.9")*	46.0%
Euclid East Impoundment	2007	17.1 Mi^2	256 cfs	46 cfs	82.0%	2,097 Ac-ft *(2.3")*	219 Ac-ft *(0.2")*	89.6%
Brandt Impoundment	2008	22.9 Mi^2	1,033 cfs	300 cfs	71.0%	7,733 Ac-ft *(6.3")*	4,607 Ac-ft *(3.8")*	40.4%
Identified Proposed Off-Channel and Tributary Detention Locations								
TR-1	Proposed	5.6 Mi^2	312 cfs	123 cfs	60.7%	1,879 Ac-ft *(6.3")*	742 Ac-ft *(2.5")*	60.5%
TR-2	Proposed	95.3 Mi^2	476 cfs	396 cfs	16.9%	14,817 Ac-ft *(2.9")*	11,823 Ac-ft *(2.3")*	20.2%
TR-3	Proposed	9.9 Mi^2	205 cfs	159 cfs	22.3%	3,131 Ac-ft *(5.9")*	2,493 Ac-ft *(4.7")*	20.4%
TR-4	Proposed	16.4 Mi^2	347 cfs	217 cfs	37.4%	6,649 Ac-ft *(7.6")*	4,725 Ac-ft *(5.4")*	28.9%
TR-5	Proposed	33.3 Mi^2	963 cfs	775 cfs	19.5%	12,208 Ac-ft *(6.9")*	10,916 Ac-ft *(6.1")*	10.6%
TR-6	Proposed	52.9 Mi^2	1,237 cfs	1,177 cfs	4.9%	17,733 Ac-ft *(6.3")*	17,730 Ac-ft *(6.3")*	0.0%
TR-7	Proposed	26.7 Mi^2	614 cfs	556 cfs	9.5%	10,402 Ac-ft *(7.3")*	10,399 Ac-ft *(7.3")*	0.0%
TR-8	Proposed	102.9 Mi^2	2,260 cfs	2,167 cfs	4.1%	37,284 Ac-ft *(6.8")*	35,187 Ac-ft *(6.4")*	5.6%
TR-9	Proposed	113.6 Mi^2	2,530 cfs	2,368 cfs	6.4%	41,073 Ac-ft *(6.8")*	39,090 Ac-ft *(6.5")*	4.8%
TR-10	Proposed	126.3 Mi^2	299 cfs	299 cfs	0.0%	3,168 Ac-ft *(0.5")*	3,121 Ac-ft *(0.5")*	1.5%
TR-11	Proposed	168.3 Mi^2	3,513 cfs	3,512 cfs	0.0%	60,583 Ac-ft *(6.7")*	60,462 Ac-ft *(6.7")*	0.2%
TR-12	Proposed	23.8 Mi^2	399 cfs	369 cfs	7.7%	7,855 Ac-ft *(6.2%)*	7,246 Ac-ft *(5.7%)*	7.8%
TR-13	Proposed	56.5 Mi^2	1,109 cfs	1,109 cfs	0.0%	19,572 Ac-ft *(6.5")*	19,026 Ac-ft *(6.3")*	2.8%
CR-1	Proposed	26.9 Mi^2	326 cfs	58 cfs	82.1%	8,367 Ac-ft *(5.8")*	778 Ac-ft *(0.5")*	90.7%
CR-2	Proposed	99.3 Mi^2	1,055 cfs	770 cfs	27.0%	21,178 Ac-ft *(4.0")*	17,845 Ac-ft *(3.4")*	15.7%
CR-3	Proposed	103.0 Mi^2	810 cfs	728 cfs	10.1%	18,863 Ac-ft *(3.4")*	17,227 Ac-ft *(3.1")*	8.7%

Table 3
Flood Water Detention Location Performance Statistics (Proposed Conditions)
Red River Basin Standardized Melt Progression Event

Site Name	Year Implemented	Modeled Drainage Area	Peak Inflow	Peak Outflow	Peak Flow Reduction	Inflow Volume	Outflow Volume	Volume Reduction
CR-4	Proposed	6.5 Mi^2	194 cfs	0 cfs	100.0%	2,260 Ac-ft *(6.5")*	0 Ac-ft *(0.0")*	100.0%
CR-5	Proposed	127.3 Mi^2	973 cfs	972 cfs	0.1%	22,500 Ac-ft *(3.3")*	21,027 Ac-ft *(3.1")*	6.5%
CR-6	Proposed	7.7 Mi^2	104 cfs	0 cfs	100.0%	1,223 Ac-ft *(3.0")*	0 Ac-ft *(0.0")*	100.0%
CR-7	Proposed	13.7 Mi^2	353 cfs	224 cfs	36.6%	4,141 Ac-ft *(5.7")*	1,835 Ac-ft *(2.5")*	55.7%
CR-8	Proposed	9.4 Mi^2	101 cfs	0 cfs	100.0%	1,388 Ac-ft *(2.8")*	0 Ac-ft *(0.0")*	100.0%
CR-9	Proposed	13.1 Mi^2	184 cfs	0 cfs	100.0%	1,560 Ac-ft *(2.2")*	0 Ac-ft *(0.0")*	100.0%
CR-10	Proposed	3.9 Mi^2	103 cfs	40 cfs	61.2%	1,545 Ac-ft *(7.4")*	388 Ac-ft *(1.9")*	74.9%
CR-11	Proposed	9.2 Mi^2	257 cfs	240 cfs	6.5%	2,962 Ac-ft *(6.0")*	2,242 Ac-ft *(4.6")*	24.3%
CR-12	Proposed	4.0 Mi^2	81 cfs	29 cfs	64.8%	810 Ac-ft *(3.8")*	216 Ac-ft *(1.0")*	73.3%
CR-13	Proposed	6.2 Mi^2	197 cfs	104 cfs	47.3%	2,271 Ac-ft *(6.9")*	1,712 Ac-ft *(5.2")*	24.6%
CR-14	Proposed	10.0 Mi^2	278 cfs	0 cfs	100.0%	3,442 Ac-ft *(6.5")*	0 Ac-ft *(0.0")*	100.0%
CR-15	Proposed	92.8 Mi^2	868 cfs	523 cfs	39.8%	16,207 Ac-ft *(3.3")*	11,931 Ac-ft *(2.4")*	26.4%
CR-16	Proposed	121.0 Mi^2	933 cfs	677 cfs	27.4%	19,783 Ac-ft *(3.1")*	16,677 Ac-ft *(2.6")*	15.7%
CR-17	Proposed	15.7 Mi^2	179 cfs	154 cfs	14.0%	5,205 Ac-ft *(6.2")*	4,661 Ac-ft *(5.6")*	10.5%
CR-18	Proposed	11.7 Mi^2	231 cfs	200 cfs	13.7%	3,533 Ac-ft *(5.7")*	3,229 Ac-ft *(5.2")*	8.6%
CR-19	Proposed	28.0 Mi^2	164 cfs	0 cfs	100.0%	5,341 Ac-ft *(3.6")*	0 Ac-ft *(0.0")*	100.0%
CR-20	Proposed	11.6 Mi^2	59 cfs	48 cfs	19.1%	564 Ac-ft *(0.9")*	333 Ac-ft *(0.5")*	41.0%
CR-21	Proposed	15.1 Mi^2	101 cfs	0 cfs	100.0%	772 Ac-ft *(1.0")*	0 Ac-ft *(0.0")*	100.0%
CR-22	Proposed	5.1 Mi^2	151 cfs	0 cfs	100.0%	1,951 Ac-ft *(7.2")*	0 Ac-ft *(0.0")*	100.0%
CR-23	Proposed	7.3 Mi^2	217 cfs	40 cfs	81.4%	2,302 Ac-ft *(5.9")*	200 Ac-ft *(0.5")*	91.3%
CR-24	Proposed	48.1 Mi^2	1,163 cfs	1,163 cfs	0.0%	14,349 Ac-ft *(5.6")*	14,031 Ac-ft *(5.5")*	2.2%
CR-25	Proposed	28.4 Mi^2	198 cfs	98 cfs	50.5%	7,260 Ac-ft *(4.8")*	1,970 Ac-ft *(1.3")*	72.9%

Table 3
Flood Water Detention Location Performance Statistics (Proposed Conditions)
Red River Basin Standardized Melt Progression Event

Site Name	Year Implemented	Modeled Drainage Area	Peak Inflow	Peak Outflow	Peak Flow Reduction	Inflow Volume	Outflow Volume	Volume Reduction
CR-26	Proposed	6.3 Mi^2	94 cfs	0 cfs	100.0%	2,196 Ac-ft *(6.5")*	0 Ac-ft *(0.0")*	100.0%
CR-27	Proposed	56.5 Mi^2	780 cfs	426 cfs	45.4%	17,327 Ac-ft *(5.8")*	12,322 Ac-ft *(4.1")*	28.9%
CR-28	Proposed	55.1 Mi^2	545 cfs	209 cfs	61.7%	9,251 Ac-ft *(3.1")*	4,982 Ac-ft *(1.7")*	46.1%
CR-29	Proposed	100.6 Mi^2	719 cfs	514 cfs	28.5%	16,031 Ac-ft *(3.0")*	13,711 Ac-ft *(2.6")*	14.5%
CR-30	Proposed	199.6 Mi^2	2,124 cfs	2,123 cfs	0.0%	42,817 Ac-ft *(4.0")*	42,268 Ac-ft *(4.0")*	1.3%
URLR-1	Proposed	12.4 Mi^2	323 cfs	0 cfs	100.0%	4,588 Ac-ft *(6.9")*	0 Ac-ft *(0.0")*	100.0%
URLR-2	Proposed	10.0 Mi^2	310 cfs	185 cfs	40.4%	3,436 Ac-ft *(6.4")*	1,221 Ac-ft *(2.3")*	64.5%
URLR-3	Proposed	10.5 Mi^2	240 cfs	165 cfs	31.3%	3,447 Ac-ft *(6.2")*	1,345 Ac-ft *(2.4")*	61.0%
URLR-4	Proposed	5.2 Mi^2	156 cfs	110 cfs	29.5%	1,750 Ac-ft *(6.3")*	1,014 Ac-ft *(3.7")*	42.1%
LRLR-1	Proposed	2.5 Mi^2	168 cfs	0 cfs	100.0%	931 Ac-ft *(7.0")*	0 Ac-ft *(0.0")*	100.0%
LRLR-2	Proposed	12.2 Mi^2	428 cfs	0 cfs	100.0%	3,563 Ac-ft *(5.5")*	0 Ac-ft *(0.0")*	100.0%
LRLR-3	Proposed	14.4 Mi^2	198 cfs	0 cfs	100.0%	1,938 Ac-ft *(2.5")*	0 Ac-ft *(0.0")*	100.0%
LRLR-4	Proposed	7.4 Mi^2	229 cfs	0 cfs	100.0%	1,917 Ac-ft *(4.9")*	0 Ac-ft *(0.0")*	100.0%
LRLR-5	Proposed	24.5 Mi^2	635 cfs	0 cfs	100.0%	5,090 Ac-ft *(3.9")*	0 Ac-ft *(0.0")*	100.0%
LRLR-6	Proposed	11.9 Mi^2	385 cfs	164 cfs	57.4%	3,478 Ac-ft *(5.5")*	876 Ac-ft *(1.4")*	74.8%
LRLR-7	Proposed	23.1 Mi^2	736 cfs	0 cfs	100.0%	6,687 Ac-ft *(5.4")*	0 Ac-ft *(0.0")*	100.0%
LRLR-8 (Ungaged)	Proposed	5.7 Mi^2	228 cfs	0 cfs	100.0%	1,760 Ac-ft *(5.8")*	0 Ac-ft *(0.0")*	100.0%
LRLR-9 (Ungaged)	Proposed	3.5 Mi^2	195 cfs	0 cfs	100.0%	1,172 Ac-ft *(6.3")*	0 Ac-ft *(0.0")*	100.0%
LRLR-10 (Ungaged)	Proposed	41.8 Mi^2	1,099 cfs	687 cfs	37.5%	11,811 Ac-ft *(5.3")*	5,475 Ac-ft *(2.5")*	53.6%
LRLR-11 (Ungaged)	Proposed	21.9 Mi^2	840 cfs	763 cfs	9.2%	6,250 Ac-ft *(5.4")*	4,987 Ac-ft *(4.3")*	20.2%
Identified Proposed On-Channel Main Stem Detention								
TR Mainstem 1	Proposed	79.4 Mi^2	1,850 cfs	728 cfs	60.6%	28,136 Ac-ft *(6.6")*	15,349 Ac-ft *(3.6")*	45.4%
TR Mainstem 2	Proposed	51.6 Mi^2	918 cfs	726 cfs	20.9%	16,645 Ac-ft *(6.0")*	13,981 Ac-ft *(5.1")*	16.0%

Table 3
Flood Water Detention Location Performance Statistics (Proposed Conditions)
Red River Basin Standardized Melt Progression Event

Site Name	Year Implemented	Modeled Drainage Area	Peak Inflow	Peak Outflow	Peak Flow Reduction	Inflow Volume	Outflow Volume	Volume Reduction
TR Mainstem 3	Proposed	215.4 Mi^2	2,672 cfs	1,184 cfs	55.7%	53,209 Ac-ft *(4.6")*	29,453 Ac-ft *(2.6")*	44.6%
CR Mainstem 1	Proposed	174.3 Mi^2	1,438 cfs	317 cfs	78.0%	45,769 Ac-ft *(4.9")*	2,213 Ac-ft *(0.2")*	95.2%
CR Mainstem 2	Proposed	1,288.3 Mi^2	9,230 cfs	8,809 cfs	4.6%	258,575Acft *(3.8")*	241,904Acft *(3.5")*	6.4%
CR Mainstem 3	Proposed	1,103.5 Mi^2	8,882 cfs	8,142 cfs	8.3%	225,364Acft *(3.8")*	206,717Acft *(3.5")*	8.3%
LRLR Mainstem 1	Proposed	3604.7 Mi^2	13,876 cfs	13,608 cfs	1.9%	467,619 Acft *(2.4")*	458,008 Acft *(2.4")*	2.1%
LRLR Mainstem 2	Proposed	5176.2 Mi^2	22,979 cfs	21,946 cfs	4.5%	752,314 Acft *(2.7")*	725,981 Acft *(2.6")*	3.5%

Notes:

*= Peak inflows and discharges for Agassiz Wildlife Refuge have not been determined because there are multiple inlets and outlets throughout the refuge. Peak storage capacity was determined by adding the modeled peak storage values of Agassiz, Parker, Tamarack, Northwest, Pool 8, and Madsen pools.

Table 4
Performance Statistics at Monitoring Locations with Proposed Off-Channel and Tributary Sites and without Additional Proposed Mainstem Detention Locations
Red River Basin Standardized Melt Progression Event

Location	Contributing Drainage Area	Existing Conditions		Proposed Conditions		Percent Reductions	
		Peak Flow	Volume	Peak Flow	Volume	Peak Flow	Volume
USGS Gage 05079000 Red Lake River at Crookston, MN	5,273.3 Mi^2	33,926 cfs	1,022,617 Ac-ft (3.6”)	27,793 cfs	906,283 Ac-ft *(3.2”)*	18.1%	11.4%
USGS Gage 05078500 Clearwater River at Red Lake Falls, MN	1,297.4 Mi^2	15,686 cfs	393,733 Ac-ft (5.7”)	11,190 cfs	323,001 Ac-ft *(4.7”)*	27.7%	17.2%
Thief River near confluence with Red Lake River	1,069.3 Mi^2	10,743 cfs	302,130 Ac-ft (5.3”)	9,232 cfs	288,789 Ac-ft *(5.1”)*	14%	4.4%

Table 5 **Performance Statistics at Monitoring Locations with Proposed Off-Channel and On-Channel Mainstem Detention Locations** *Red River Basin Standardized Melt Progression Event*							
Location	**Contributing Drainage Area**	**Existing Conditions**		**Proposed Conditions**		**Percent Reductions**	
		Peak Flow	**Volume**	**Peak Flow**	**Volume**	**Peak Flow**	**Volume**
USGS Gage 05079000 Red Lake River at Crookston, MN	5,273.3 Mi^2	33,926 cfs	1,022,617 Ac-ft (3.6”)	22,058 cfs	753,585 Ac-ft *(2.7”)*	35.0%	26.3%
USGS Gage 05078500 Clearwater River at Red Lake Falls, MN	1,297.4 Mi^2	15,686 cfs	393,733 Ac-ft (5.7”)	8,852 cfs	247,185 Ac-ft *(3.6”)*	42.7%	37.2%
Thief River near confluence with Red Lake River	1,069.3 Mi^2	10,743 cfs	301,976 Ac-ft (5.3”)	6,454 cfs	249,533 Ac-ft *(4.4”)*	39.9%	17.4%

Figures

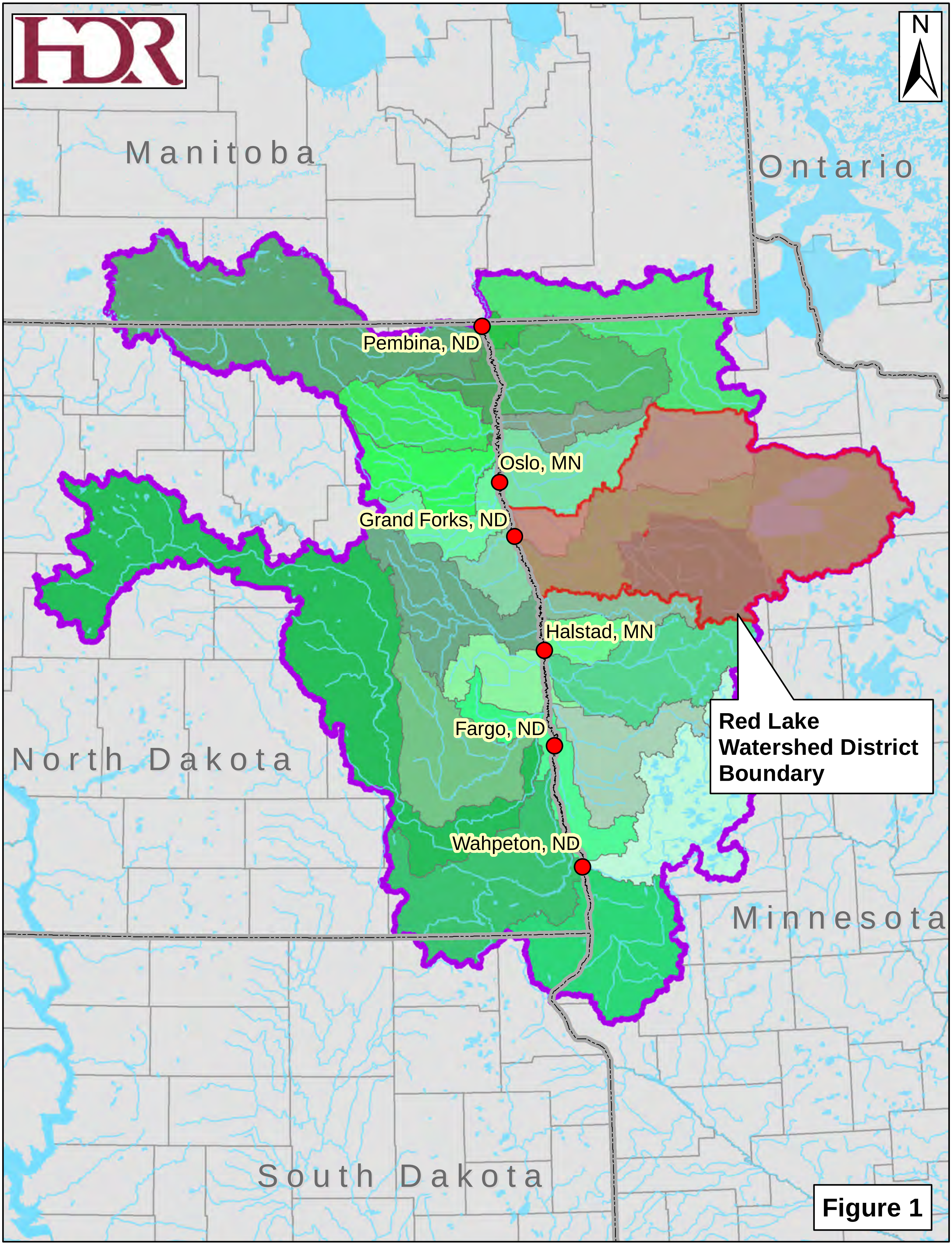

Manitoba
Ontario
Pembina, ND
Oslo, MN
Grand Forks, ND
Halstad, MN
Fargo, ND
Wahpeton, ND
Red Lake Watershed District Boundary
North Dakota
Minnesota
South Dakota
N

Figure 1

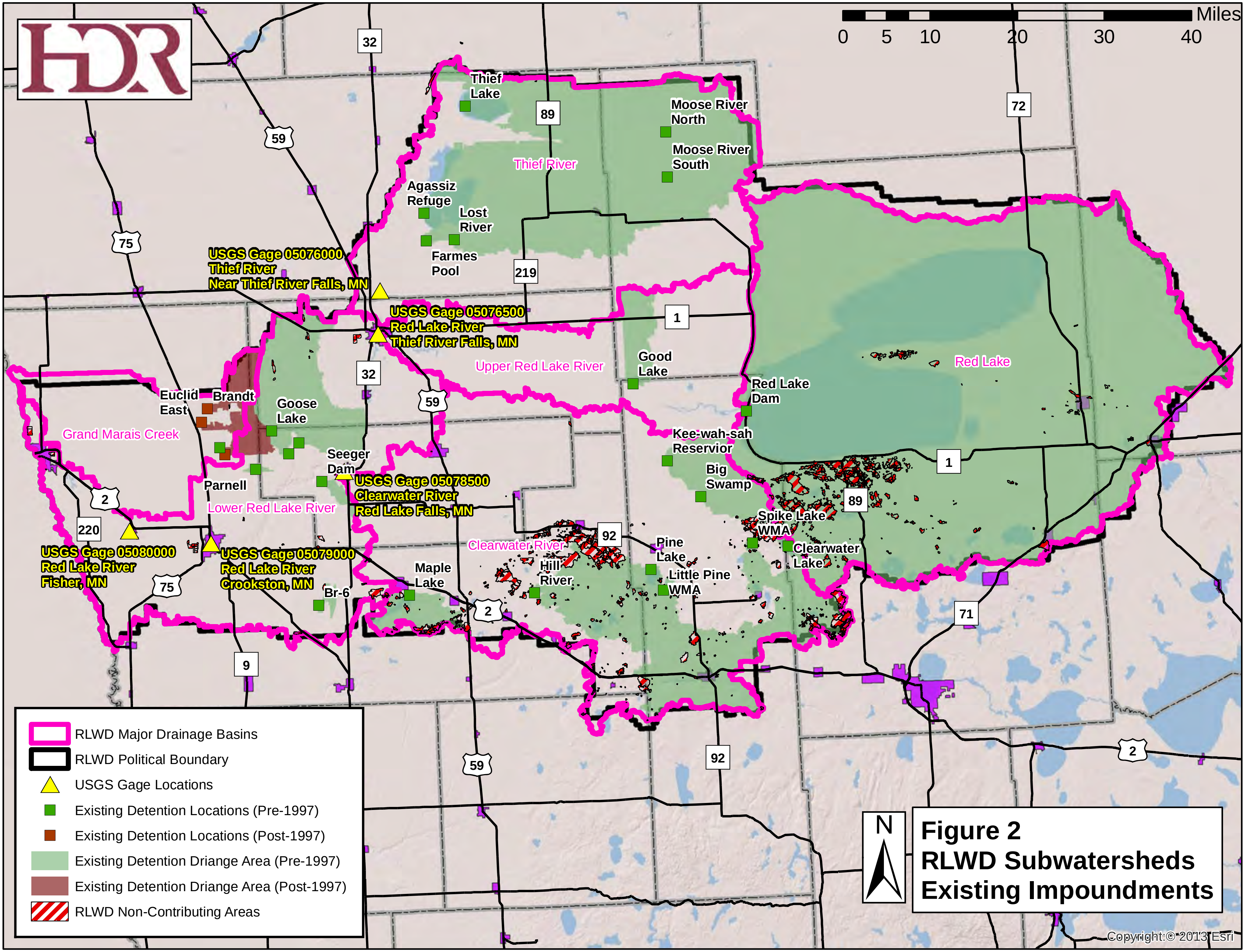


Figure 2
RLWD Subwatersheds
Existing Impoundments

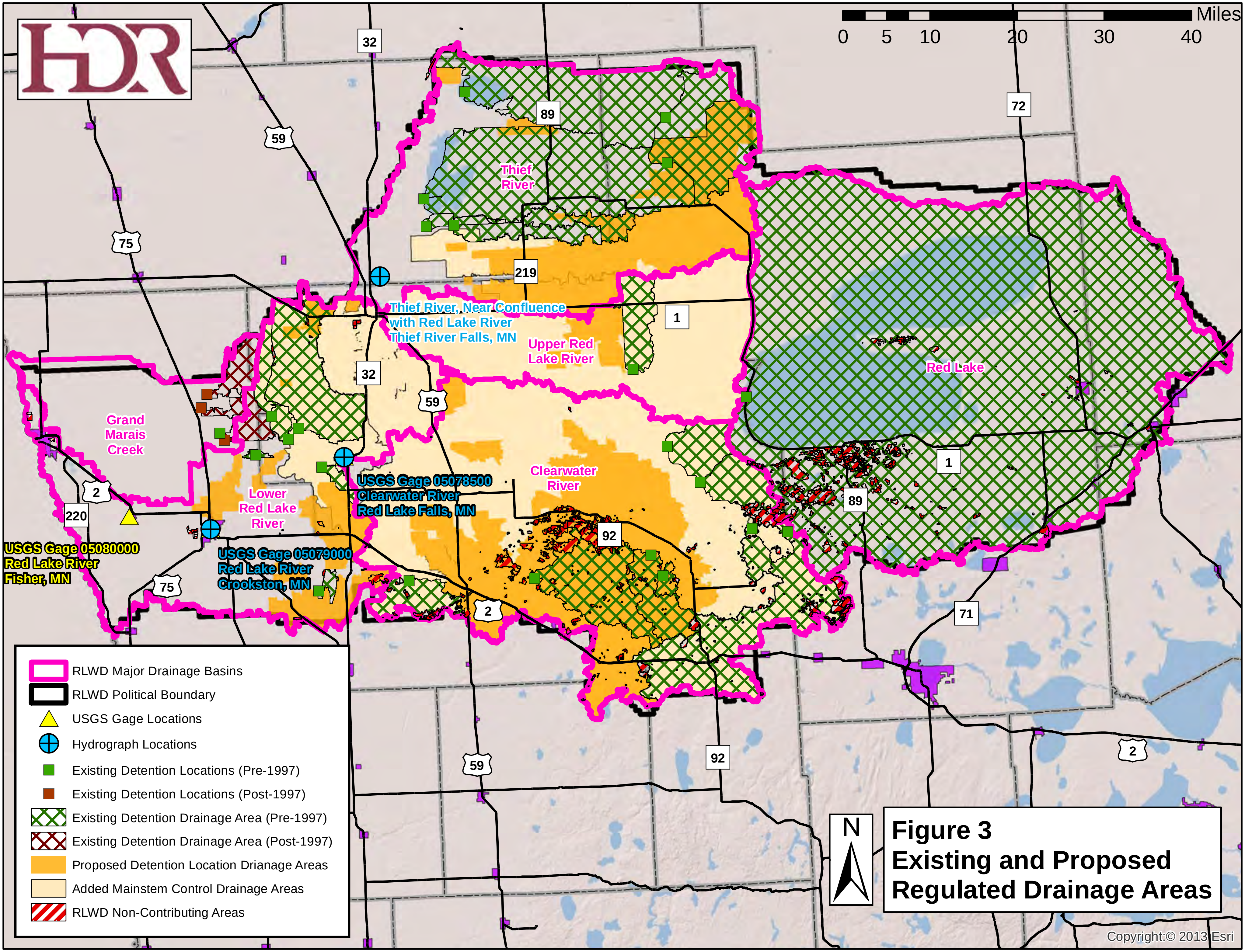


Figure 3
Existing and Proposed Regulated Drainage Areas

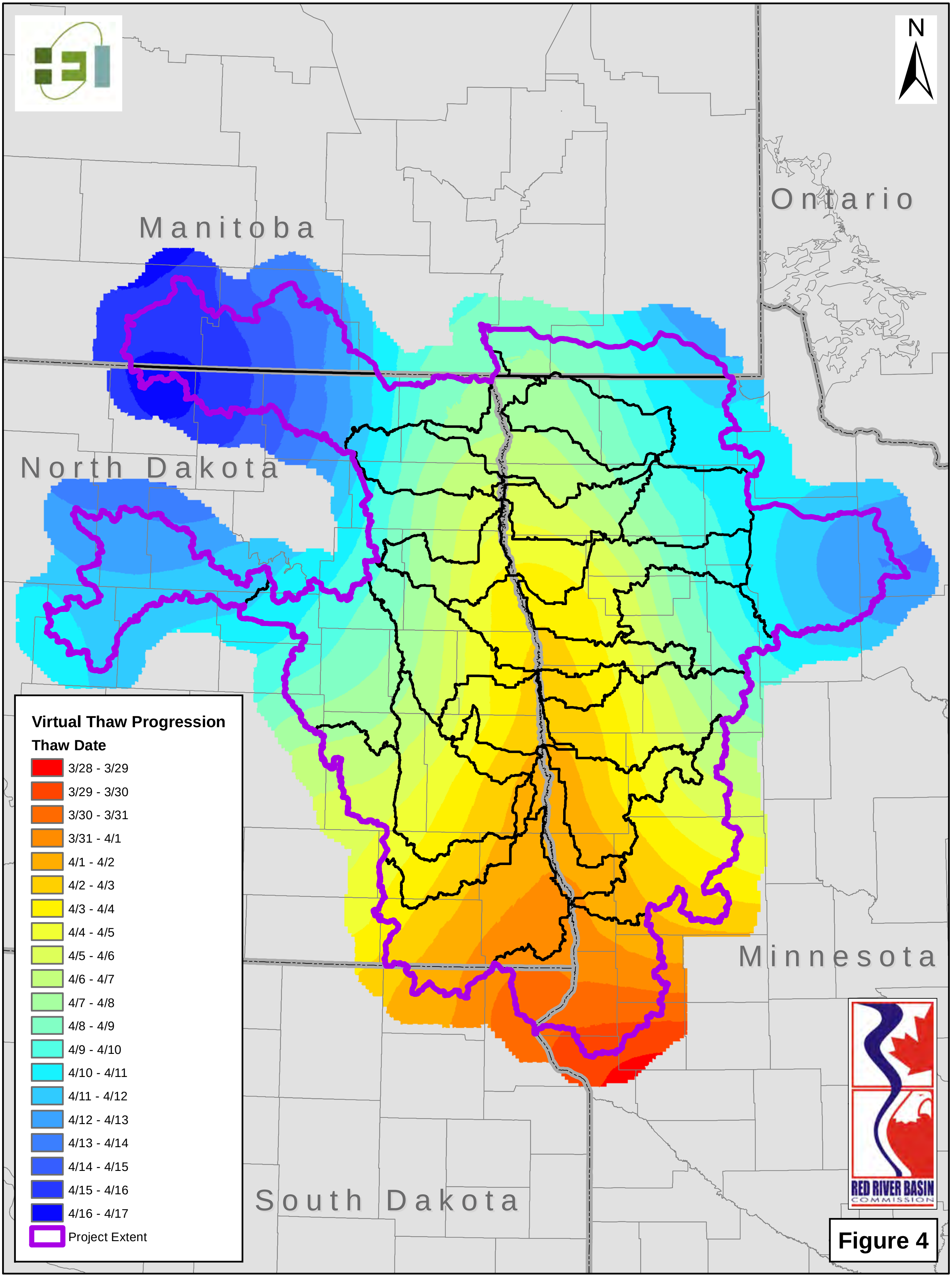

Manitoba
Ontario
North Dakota
Minnesota
South Dakota
N
Virtual Thaw Progression
Thaw Date
3/28 - 3/29
3/29 - 3/30
3/30 - 3/31
3/31 - 4/1
4/1 - 4/2
4/2 - 4/3
4/3 - 4/4
4/4 - 4/5
4/5 - 4/6
4/6 - 4/7
4/7 - 4/8
4/8 - 4/9
4/9 - 4/10
4/10 - 4/11
4/11 - 4/12
4/12 - 4/13
4/13 - 4/14
4/14 - 4/15
4/15 - 4/16
4/16 - 4/17
Project Extent
RED RIVER BASIN
COMMISSION

Figure 4

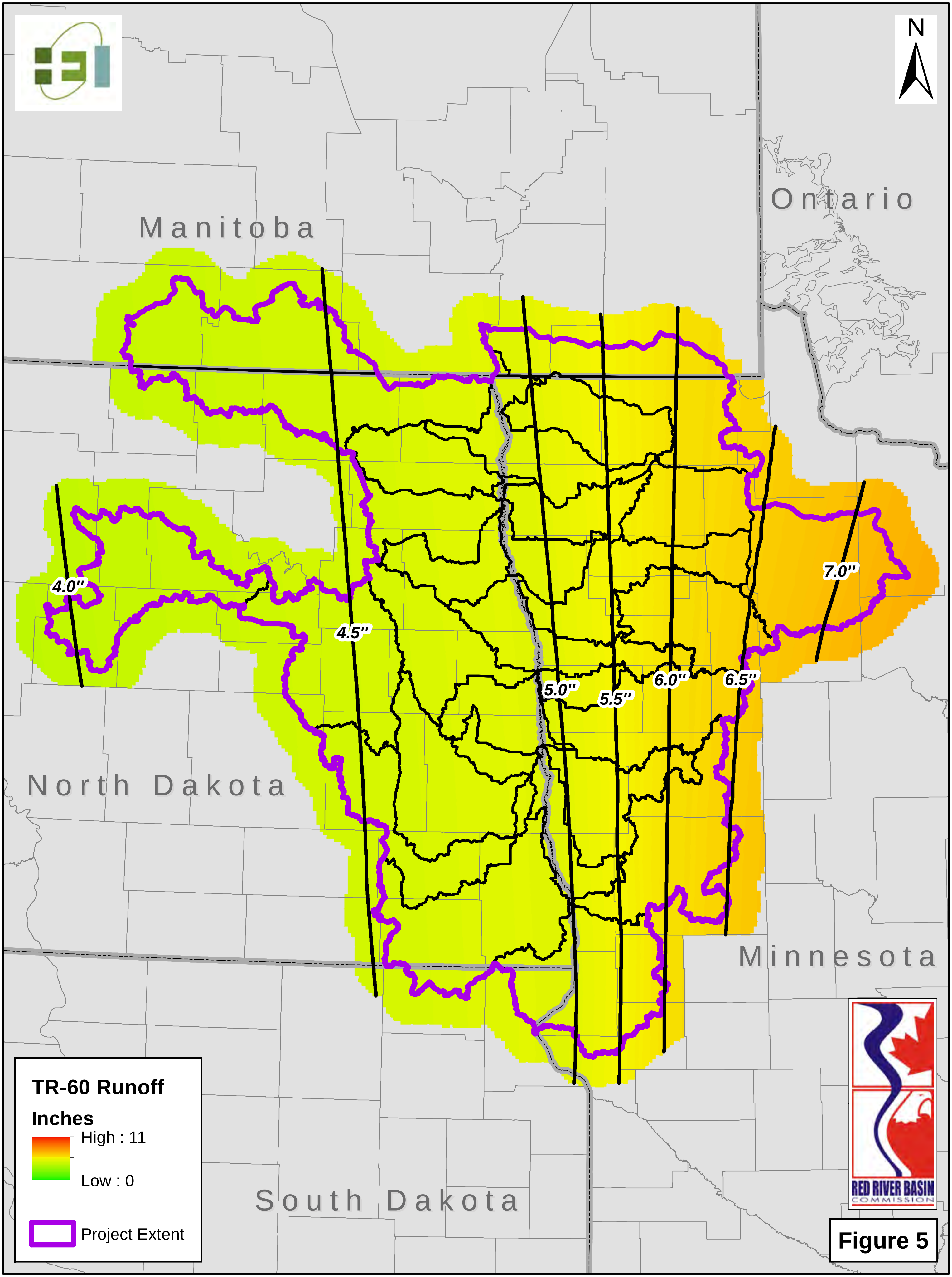

N
Manitoba
Ontario
North Dakota
Minnesota
South Dakota
4.0"
4.5"
5.0"
5.5"
6.0"
6.5"
7.0"
TR-60 Runoff
Inches
High : 11
Low : 0
Project Extent
RED RIVER BASIN
COMMISSION

Figure 5

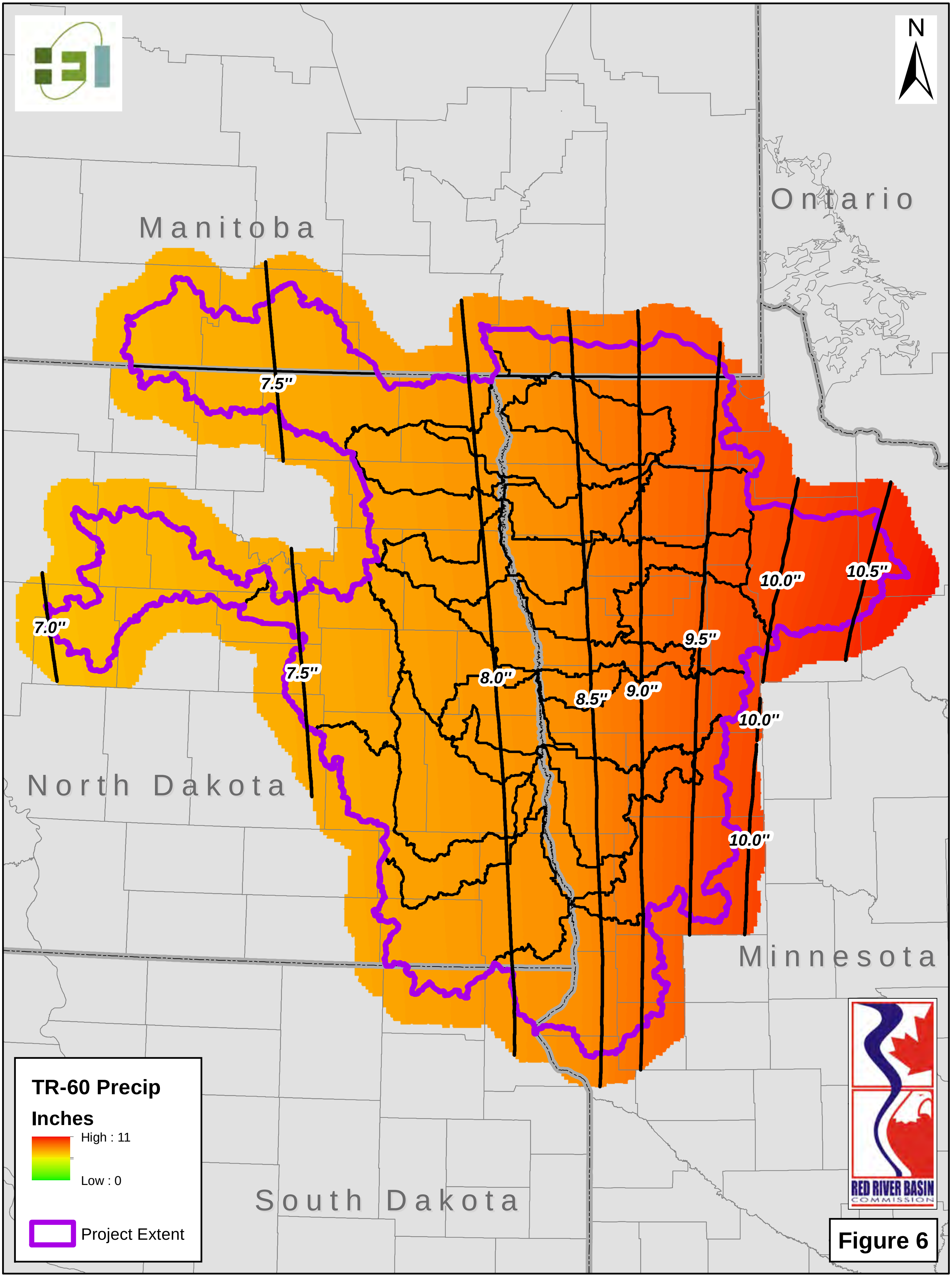

N
Manitoba
Ontario
North Dakota
Minnesota
South Dakota
7.0"
7.5"
7.5"
8.0"
8.5"
9.0"
9.5"
10.0"
10.0"
10.0"
10.5"
TR-60 Precip
Inches
High : 11
Low : 0
Project Extent
RED RIVER BASIN
COMMISSION

Figure 6

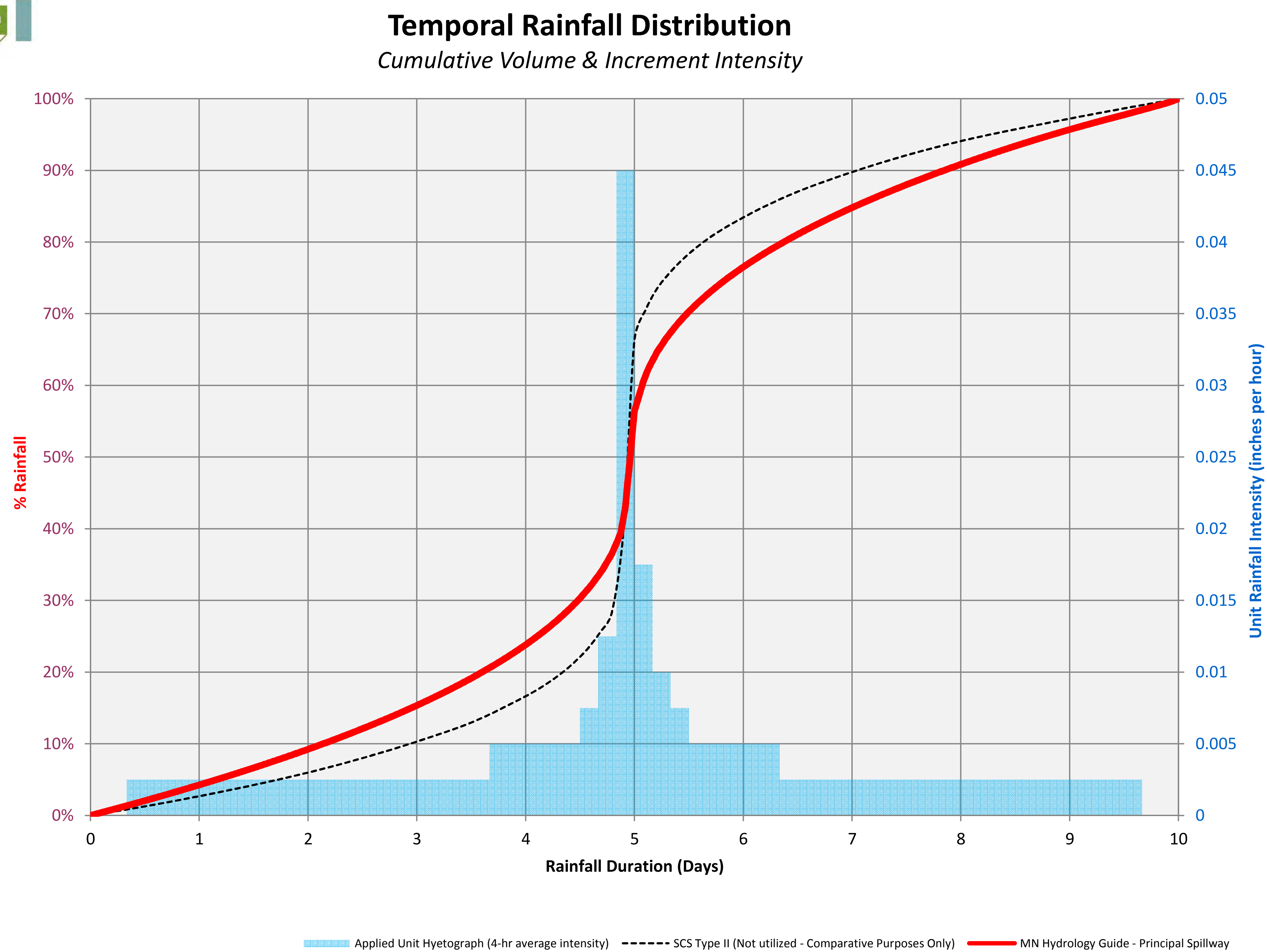
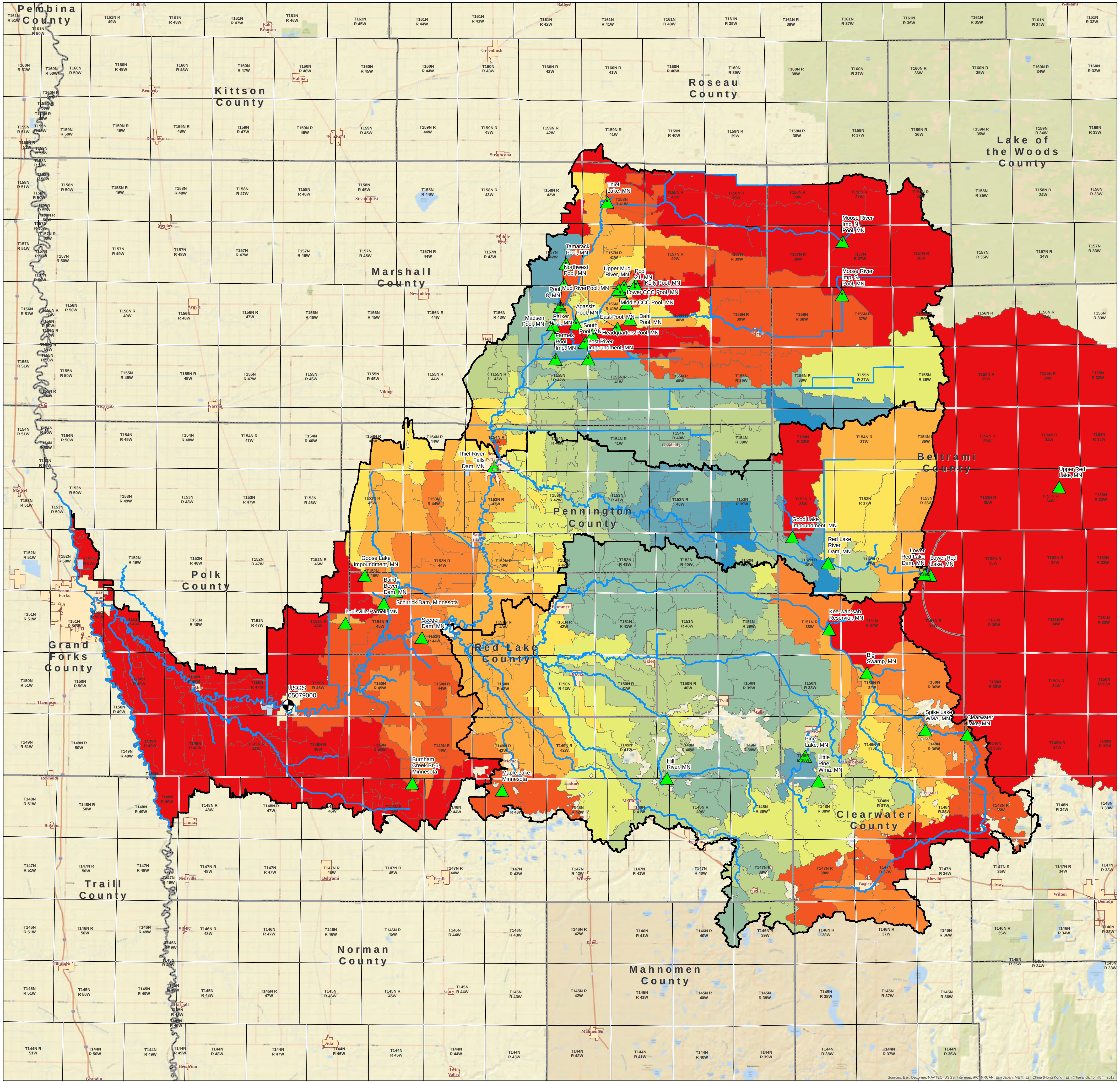

Temporal Rainfall Distribution
Cumulative Volume & Increment Intensity
% Rainfall
Unit Rainfall Intensity (inches per hour)
Rainfall Duration (Days)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0.05
0.045
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
0 1 2 3 4 5 6 7 8 9 10
Applied Unit Hyetograph (4-hr average intensity)
SCS Type II (Not utilized - Comparative Purposes Only)
MN Hydrology Guide - Principal Spillway

Figure 7



0 2.5 5 10 15 20 Miles

Kilometers 0 2.5 5 10 15 20

Hydrologic Impacts

Impact to Crookston Gage

- -0.12 to -0.09%
- -0.09 to -0.06%
- -0.06 to -0.05%
- -0.05 to -0.04%
- -0.04 to -0.03%
- -0.03 to -0.02%
- -0.02 to -0.017%
- -0.017 to -0.01%
- -0.01 to 0%
- 0%
- Drainage Line
- Crookston Gage
- Existing Impoundment

Values represent the expected change (reduction) in peak flow at the Crookston Gage for each square mile detained in a subbasin. Blue colors are subbasins that highly influence Crookston peak flows. Red colors indicate subbasins that have limited influence on Crookston peak flows.

Project Location

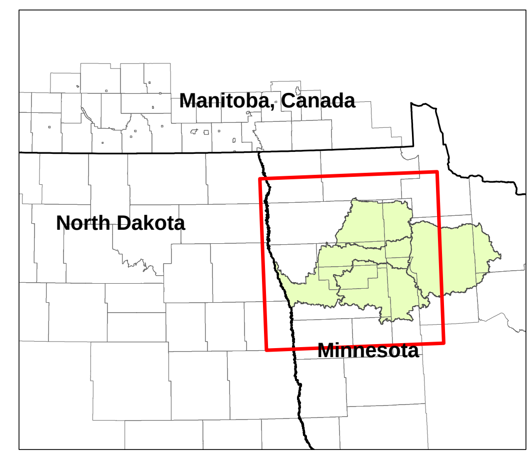


Figure 8
Hydrologic Impact Zones
Red Lake River, MN

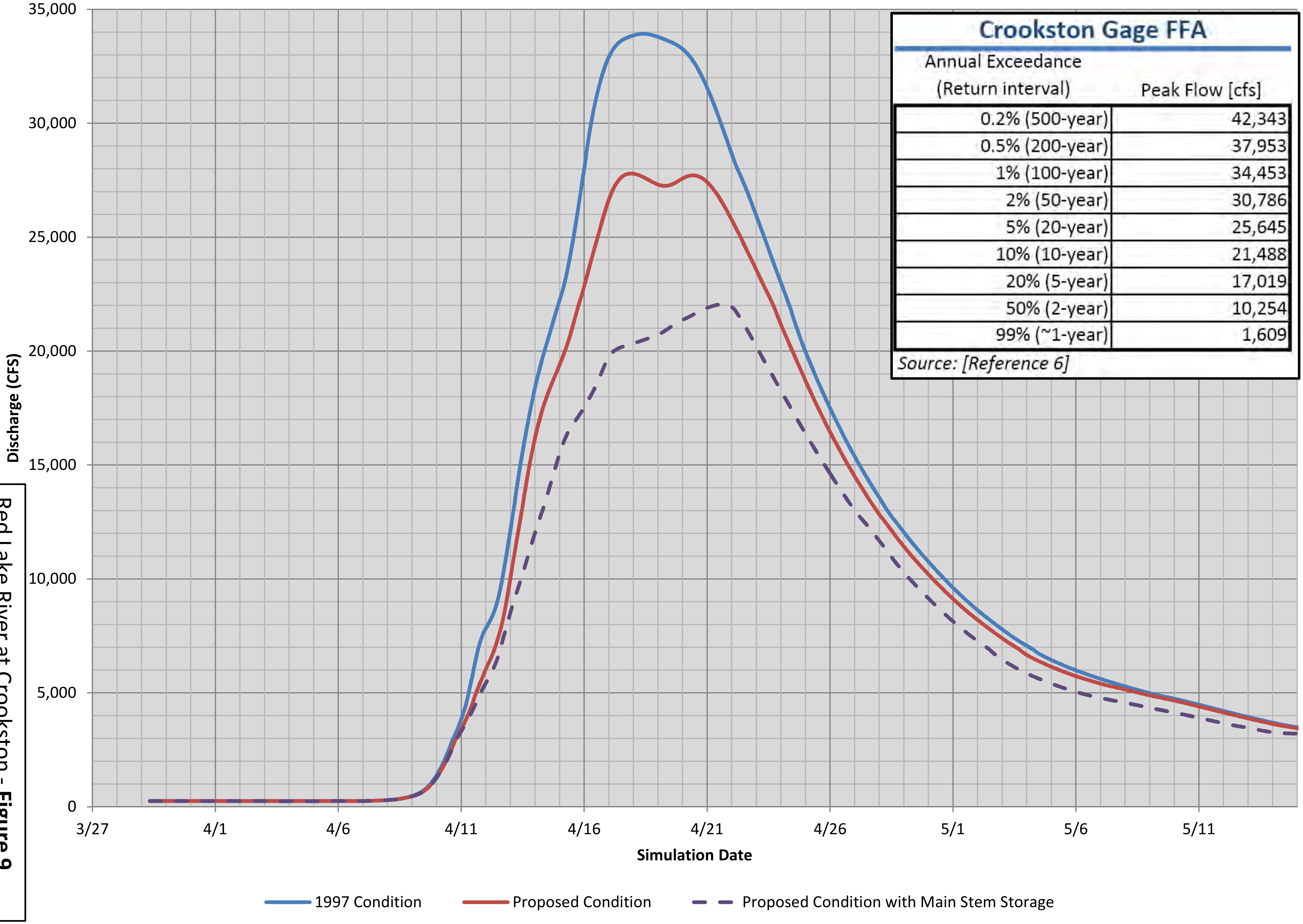
Notes: The HEC-HMS model from the Red River HMS Phase 2 project and snow melt progression was modeled under existing conditions. Each subbasin in the watershed was removed from the analysis to detemine the sensitivity of storage in the subbasin to watershed outlet peak flow.

October 31, 2013

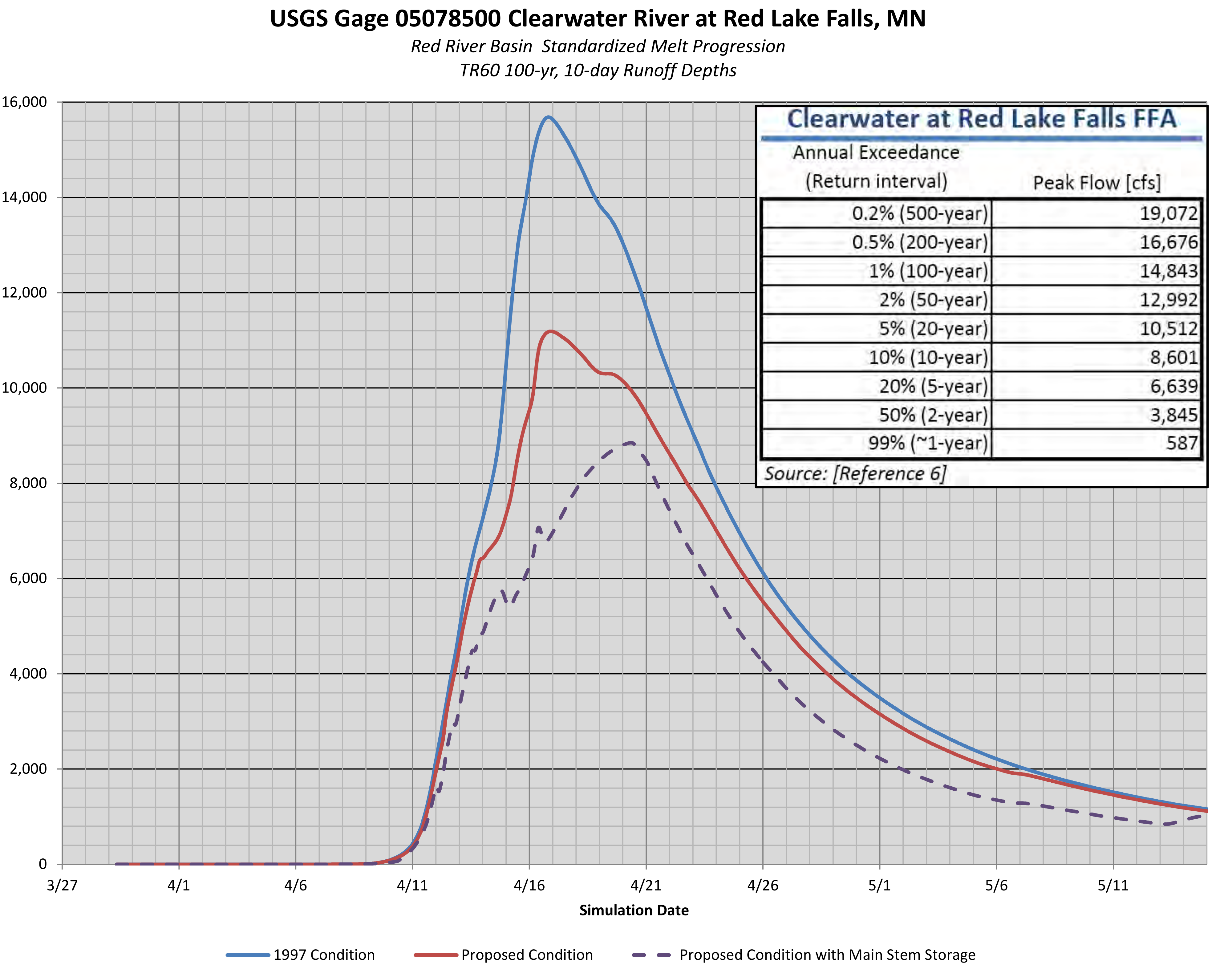
HDR

USGS Gage 05079000 Red Lake River at Crookston, MN

Red River Basin Standardized Melt Progression
TR60 100-yr, 10-day Runoff Depths

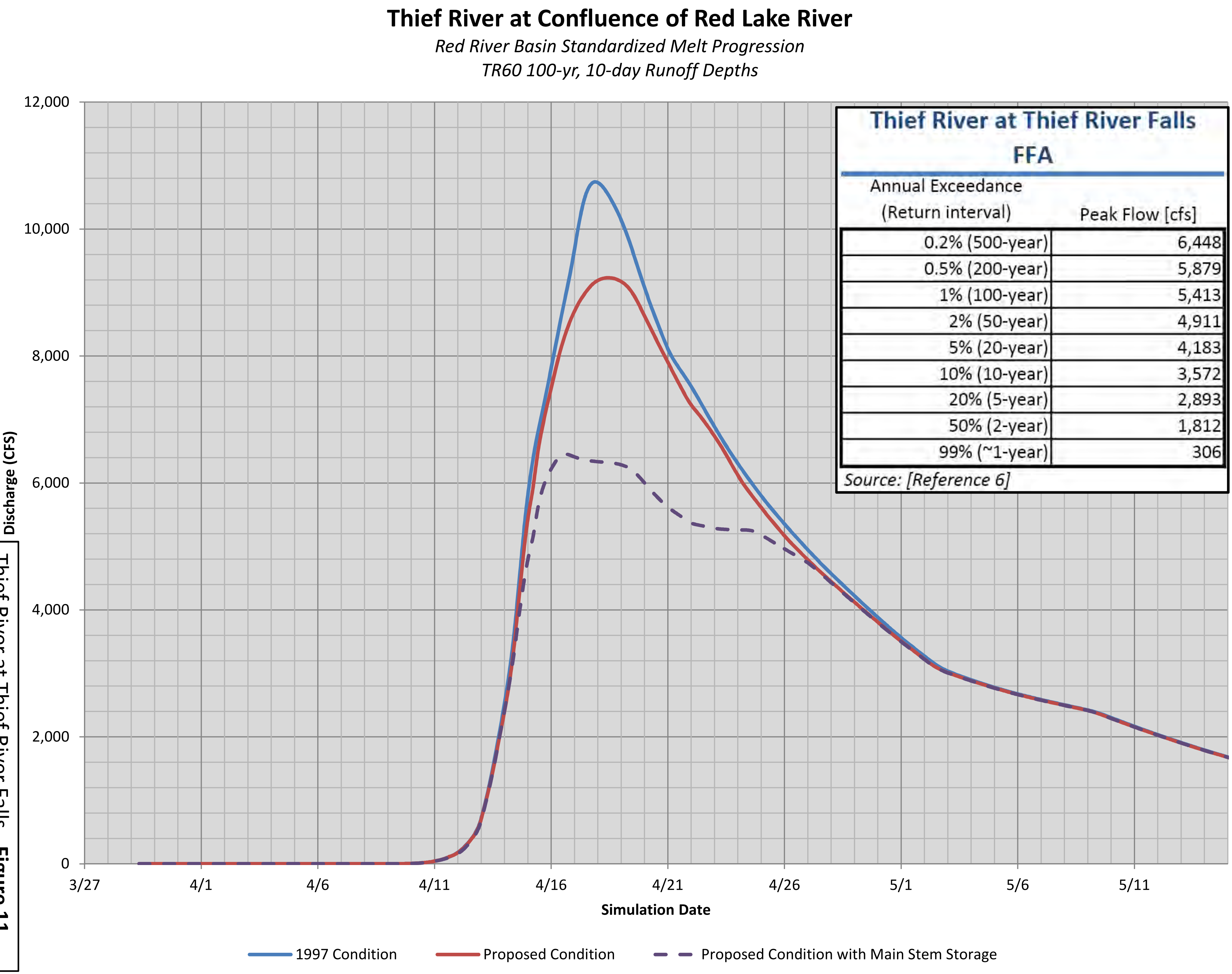


Red Lake River at Crookston - **Figure 9**



Annual Exceedance (Return interval)	Peak Flow [cfs]
0.2% (500-year)	19,072
0.5% (200-year)	16,676
1% (100-year)	14,843
2% (50-year)	12,992
5% (20-year)	10,512
10% (10-year)	8,601
20% (5-year)	6,639
50% (2-year)	3,845
99% (~1-year)	587

Clearwater R. at Red Lake Falls - **Figure 10**



Thief River at Thief River Falls - **Figure 11**