Prepared by/for:

Mississippi Valley Division

St. Paul District

Souris River Watershed

Corps Water Management System Report

U.S. Army Corps of Engineers

September 2020

Date	Principal Author	Comments
03/03/2020	Emily Moe, MVP	Initial Draft
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11/18/2020	Emily Moe, MVP	Draft Returned to MMC Documentation Team.
11/18/2020	J. Darville, MMC	Final Review Complete. Report Finalized.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

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Prepared

The results, findings, and recommendations provided in this report are technically sound and consistent with current Corps of Engineers practice and MMC standard operating procedures (SOP) technical manual processes.

Emily Moe ______________________ November 18, 2020

Prepared by
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CWMS Lead

Date

Checked

The results, findings, and recommendations provided in this report are technically sound and consistent with current Corps of Engineers practice and MMC standard operating procedures (SOP) technical manual processes.

Jennifer L Darville ______________________ November 18, 2020

Checked by
Jennifer Darville
MMC Technical Editor

Date

Reviewed and Approved

The results, findings, and recommendations provided in this report are technically sound and consistent with current Corps of Engineers practice and MMC standard operating procedures (SOP) technical manual processes.

______________________________________ ________________________

Approved by
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Date

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PAGES 1-84 have been removed from this version of the report as they do not pertain to the Souris River Watershed Corps Water Management System HEC-RAS model development.

Section 8

Hydrologic Engineering Center-River Analysis System Model Development

8.1 STATUS OF DISTRICT'S EXISTING HYDROLOGIC ENGINEERING CENTER-RIVER ANALYSIS SYSTEM MODEL(S)

A summary of all models received is:

- Saskatchewan Power Corporation (SaskPower) unsteady hydraulic model of the Souris River from Rafferty Dam to the USGS gage near Sherwood, ND (Barr 2018)
- USACE unsteady hydraulic model of the Souris River from Rafferty Dam to the USGS gage near Westhope, ND (USACE 2016)

These two main models formed the basis of the unsteady, HEC-RAS model. The 2018 model utilized new LiDAR data for a large portion of the model reach. The Water Security Agency of Saskatchewan (WSA) had expressed concern regarding the model calibration. The flows used for the 2011 flood calibration were average daily flows. There was additional concern that the modeler did not use all of the provided data because it was provided too late in the project schedule. The terrain generated for the model converted the LiDAR into a 3m resolution terrain and the WSA wanted the model to be at a 1m resolution. The model and terrain were not in the correct projection because feet was used instead of US feet.

The 2016 model utilized LiDAR available at the time. Since the 2016 model was finalized, Ward County had new LiDAR obtained. The cross section spacing did not meet CWMS criteria. Some 2014 channel bathmetry data between Towner and Bantry had not been included in the model. Several bridges had been missed and several more had been replaced or added since this model was completed.

The final unsteady flow models developed for the Souris River Watershed was developed in HEC-RAS 5.0.7. It consists of these three models:

- Souris River from Rafferty Reservoir to Lake Darling Dam (River Stations 640.31 to 444.86) including Long Creek from Boundary dam (River Stations 3.13 to 1.14) and Moose Mountain Creek from Grant Devine dam (River Stations 4.85 to 0.09) and an in-channel 2D area at the confluence of Long Creek and the Souris River near the City of Estevan, Saskatchewan
- Souris River from Lake Darling Dam to Verendrye (River Stations 444.77 to 323.43), including the Des Lacs River (River Station 80.759 to 0.042) and three off-channel 2D areas representing the left overbank (protected area) in the City of Minot, North Dakota, right overbank (protected area) in the City of Minot and the suburban sprawl downstream of Minot, and left overbank for the bypass channel near the Community of Logan, North Dakota
- Souris River from Verendrye to Westhope (River Stations, Souris River 346.34 to 170.91), including the Wintering River, Willow Creek and Deep River

The overall model was broken up into three smaller models based on guidance from the HEC. The area modeled covers 155 river miles in Saskatchewan and 283 river miles in North Dakota. There are four 2D flow areas in the model. Initially the model was attempted as a single model but, needed to be broken up in the CAVI at Lake Darling Dam and for ResSIM operations of Lake Darling Dam. The individual models greatly reduce run times and complexity. The individual models allows for just the area of interest to be run when operational questions arise versus the entire Souris River with faster results and the ability to make operational decisions sooner.

The reaches of the models are:

- Souris – RaffertyNormal: Spans the Souris River from Rafferty dam normal outlet to the confluence with the spillway flows from Rafferty dam immediately upstream of a railroad bridge.
- Souris Spill – RaffertySpill: Spans from the spillway of Rafferty dam to the confluence with the Rafferty dam normal outlet flows immediately upstream of a railroad bridge.
- Souris – Upper: Spans the Souris River from the confluence of the flows from RaffertyNormal and RaffertySpill to the Estevan 2D Flow Area.
- Estevan 2D Flow Area: This is an in-channel 2D Flow Area that spans from Souris River – Upper and Long Creek -2 to Souris River – Long_to_MooseMtn. This complex area has a split in the Souris River flows and has two locations where Long Creek flows enter one part of the Souris River before joining back together.
- Long – 2: Spans the length of Long Creek from Boundary dam outlet to the confluence with the Souris River at the Estevan 2D Flow Area.
- Souris - Long_to_MooseMtn: Spans the Souris River from the Estevan 2D Flow Area to the confluence with Moose Mountain Creek.
- Moose Mtn – Moose Mtn: Spans the length of Moose Mountain Creek from Grant Devine dam outlet to the confluence with the Souris River.
- Souris – MooseMtn2DesLacs: Spans the Souris River from the confluence with Moose Mountain Creek to the confluence with the Des Lacs River. This span crosses the Saskatchewan – North Dakota border.
- Des Lacs – Des Lacs: Spans the Des Lacs River from the outlet of the Des Lacs National Wildlife Refuge to the confluence with the Souris River.
- Souris – DesLacsWintering: Spans the Souris River from the confluence with the Des Lacs River to the confluence with the Wintering River. There are three off-channel 2D Flow Areas in the reach: Minot LOB, Minot DS_ROB, and Logan_Bypass.
- Wintering – Wintering: Spans the Wintering River from the USGS gage near Karlsrhue to the confluence with the Souris River.
- Souris – Wintering2Willow: Spans the Souris River from the confluence with the Wintering River to the confluence with Willow Creek.
- Willow – Willow: Spans the Willow Creek from the USGS gage near Willow City to the confluence with the Souris River.
- Souris – Willow_to_Deep: Spans the Souris River from the confluence with Willow Creek to the confluence with the Deep River.
- Deep – Deep: Spans the Deep River from the USGS gage near Upham to the confluence with the Souris River.
- Souris – Deep_to_Westhope: Spans the Souris River from the confluence with the Deep River to the USGS gage on the Souris River near Westhope.

8.2 BOUNDARY CONDITIONS

Flow hydrographs developed in HEC-HMS were used as inflows to the Souris River watershed HEC-RAS model at the upstream end of reaches and at lateral inflows from contributing sub-basins. Rating curves from USGS gages were used for downstream boundary conditions for the Lake Darling Dam to Verendrye and Verendrye to Westhope models. The pool elevation at Lake Darling Dam was used for the downstream boundary condition for the Rafferty to Lake Darling Dam model. Tables 8-1 through 8-3 provides a summary of the unsteady boundary conditions, file names, and file paths.

Table 8-1. Boundary Conditions for the Souris River Watershed Hydrologic Engineering Center-River Analysis System Verendrye to Westhope Model

River	Reach	River Station	Boundary Condition Type	DSS File Name	DSS Path Name
Souris	Deep_to_WestHope	172.03	Flow Hydrograph	\\forecast.dss	//SO11LG_Westhope/FLOW-LOCAL//1HOUR/BASE------0/
Souris	Deep_to_WestHope	187.5	Flow Hydrograph	\\forecast.dss	//SO12LJ_Dam341/FLOW-LOCAL//1HOUR/BASE------0/
Souris	Deep_to_WestHope	196.34	Flow Hydrograph	\\forecast.dss	//SO14AJ_Dam332/FLOW-LOCAL//1HOUR/BASE------0/
Souris	Deep_to_WestHope	196.87	Flow Hydrograph	\\forecast.dss	//SO14J_DeepRivConf/FLOW-LOCAL//1HOUR/BASE------0/
Souris	Willow_to_Deep	201.77	Flow Hydrograph	\\forecast.dss	//SO15LJ_Dam326/FLOW-LOCAL//1HOUR/BASE------0/
Souris	Willow_to_Deep	204.96	Flow Hydrograph	\\forecast.dss	//SO15J_Dam326/FLOW-LOCAL//1HOUR/BASE------0/
Souris	Willow_to_Deep	209.51	Flow Hydrograph	\\forecast.dss	//SO16LJ_Dam320/FLOW-LOCAL//1HOUR/BASE------0/
Souris	Willow_to_Deep	215.04	Flow Hydrograph	\\forecast.dss	//SO16J_Dam320/FLOW-LOCAL//1HOUR/BASE------0/
Souris	Willow_to_Deep	226.06	Flow Hydrograph	\\forecast.dss	//SO17J_SaylerPool320/FLOW-LOCAL//1HOUR/BASE------0/
Willow	Willow	10.4	Flow Hydrograph	\\forecast.dss	//WI02G_WillowCity/FLOW//1HOUR/BASE------0/
Souris	Wintering2Willow	245.53	Flow Hydrograph	\\forecast.dss	//SO18G_Bantry/FLOW-LOCAL//1HOUR/BASE------0/
Souris	Wintering2Willow	272.96	Flow Hydrograph	\\forecast.dss	//SO19J_Towner/FLOW-LOCAL//1HOUR/BASE------0/
Souris	Wintering2Willow	303.02	Flow Hydrograph	\\forecast.dss	//SO20J_WinteringRiverConf/FLOW-LOCAL//1HOUR/BASE------0/
Souris	DesLacsWintering	323.43	Flow Hydrograph	\\forecast.dss	//SO21G_Verendrye/FLOW-LOCAL//1HOUR/BASE------0/
Deep	Deep	7.82	Flow Hydrograph	\\forecast.dss	//DP01J_DeepRiverTown/FLOW-LOCAL//1HOUR/BASE------0/
Deep	Deep	20.9	Flow Hydrograph	\\forecast.dss	//DP02G_Upham/FLOW//1HOUR/BASE------0/
Souris	DesLacsWintering	346.34	Flow Hydrograph	\\forecast.dss	//SO22J_Velva/FLOW//1HOUR/BASE------0/
Wintering	Wintering	16.38	Flow Hydrograph	\\forecast.dss	//WN01G_KARLSRUHE/FLOW-LOCAL/1HOUR/BASE------0/

Table 8-2. Boundary Conditions for the Souris River Watershed Hydrologic Engineering Center-River Analysis System Lake Darling Dam to Verendrye Model

River	Reach	River Station	Boundary Condition Type	DSS File Name	DSS Path Name
Souris	DesLacs Wintering	323.43	Flow Hydrograph	\\forecast.dss	//SO21G_Verendrye/FLOW-LOCAL//1HOUR/BASE------0/
Souris	DesLacs Wintering	354.45	Flow Hydrograph	\\forecast.dss	//SO22J_Velva/FLOW-LOCAL//1HOUR/BASE------0/
Souris	DesLacs Wintering	367.7	Flow Hydrograph	\\forecast.dss	//SO23J_Sawyer/FLOW-LOCAL//1HOUR/BASE------0/
Souris	DesLacs Wintering	378.78	Flow Hydrograph	\\forecast.dss	//SO24J_PuppDog/FLOW-LOCAL//1HOUR/BASE------0/
Souris	DesLacs Wintering	393.12	Flow Hydrograph	\\forecast.dss	//SO25J_MinotEast/FLOW-LOCAL//1HOUR/BASE------0/
Souris	DesLacs Wintering	402.55	Flow Hydrograph	\\forecast.dss	//SO26J_MinotGassman/FLOW-LOCAL//1HOUR/BASE------0/
Souris	DesLacs Wintering	403.54	Flow Hydrograph	\\forecast.dss	//SO26G_Minot/FLOW-LOCAL//1HOUR/BASE------0/
Souris	DesLacs Wintering	410.61	Flow Hydrograph	\\forecast.dss	//SO27J_Burlington/FLOW-LOCAL//1HOUR/BASE------0/
Des Lacs	Des Lacs	8.796	Flow Hydrograph	\\forecast.dss	//DL02J_UpstreamTasker/FLOW-LOCAL//1HOUR/BASE------0/
Des Lacs	Des Lacs	21.761	Flow Hydrograph	\\forecast.dss	//DL032G_Foxholm/FLOW-LOCAL//1HOUR/BASE------0/
Des Lacs	Des Lacs	80.759	Flow Hydrograph	\\forecast.dss	//DL02LJ_LowerDesLacs8/FLOW//1HOUR/BASE------0/
Souris	MooseMtn 2DesLacs	430.1	Flow Hydrograph	\\forecast.dss	//SO28G_Foxholm/FLOW-LOCAL//1HOUR/BASE------0/
Souris	MooseMtn 2DesLacs	444.77	Flow Hydrograph	\\forecast.dss	//Lake Darling-Pool/FLOW-OUT//1HOUR/BASE------0/

Table 8-3. Boundary Conditions for the Souris River Watershed Hydrologic Engineering Center-River Analysis System Rafferty Dam to Lake Darling Dam Model

River	Reach	River Station	Boundary Condition Type	DSS File Name	DSS Path Name
Souris	MooseMtn 2DesLacs	430.15	Flow Hydrograph	\\forecast.dss	//SO28G_Foxholm/FLOW-LOCAL//1HOUR/BASE------0/
Souris	MooseMtn 2DesLacs	444.86	Flow Hydrograph	\\forecast.dss	//Lake Darling-Pool/ELEV//1HOUR/BASE------0/
Souris	MooseMtn 2DesLacs	469.97	Flow Hydrograph	\\forecast.dss	//SO29J_Darling/FLOW-LOCAL//1HOUR/BASE------0/
Souris	MooseMtn 2DesLacs	474.22	Flow Hydrograph	\\forecast.dss	//SO30J_Tolley/FLOW-LOCAL//1HOUR/BASE------0/
Souris	MooseMtn 2DesLacs	508.56	Flow Hydrograph	\\forecast.dss	//SO31G_Sherwood/FLOW-LOCAL//1HOUR/BASE------0/
Souris	MooseMtn 2DesLacs	554.71	Flow Hydrograph	\\forecast.dss	//SO32J_Oxbow/FLOW-LOCAL//1HOUR/BASE------0/
Moose Mtn	Moose Mtn	4.85	Flow Hydrograph	\\forecast.dss	//Grant Devine Lake-Pool/FLOW-OUT//1HOUR/BASE------0/
Souris	Long_to_ MooseMtn	615.5	Flow Hydrograph	\\forecast.dss	//SO33J_RochePercee/FLOW-LOCAL//1HOUR/BASE------0/
Souris	Long_to_ MooseMtn	633.45	Flow Hydrograph	\\forecast.dss	//SO34J_Estevan/FLOW//1HOUR/BASE------0/
Long	2	3.13	Flow Hydrograph	\\forecast.dss	//LO01LG_BoundaryInflow/FLOW//1HOUR/BASE------0/
Souris	RaffertyNormal	640.31	Flow Hydrograph	\\forecast.dss	//Rafferty Reservoir-Pool/FLOW-OUT//1HOUR/BASE------0/

8.3 MODEL PARAMETERS

8.3.1 Coordinate System

The coordinate system used for this project was ‘USA Contiguous Albers Equal Area Conic USGS version,’ which is consistent with the Mapping Modeling and Consequence Center’s (MMC) guidance. The linear units used are US feet.

8.3.2 Vertical Datum

The vertical datum used for this modeling effort is North America Vertical Datum 1988 (NAVD 88). The LiDAR provided by the Minnesota County data sets were already in NAVD 88. The gage data was converted from NGVD 29 to NAVD 88 based on datum adjustments provided by MVP survey personnel.

8.3.3 Terrain

The model terrain originated from four North Dakota county LiDAR data sets and a LiDAR data set from Saskatchewan. The GIS team member compiled the LiDAR together to create the terrain. Once the data manipulation was complete, the data was reviewed and provided to the HEC-RAS team member. See Section 4 Data Compilation, Digital Elevation Model for further information.

8.3.4 Cross Sections

The initial cross section layout was taken from the 2016 USACE HEC-RAS model. Additional cross sections were added to meet MMC modeling criteria with a maximum channel length between cross sections of approximately 2500 feet. The cross sections were also moved to better address the topography, addition of storage areas / 2D areas, proximity to structures, extended to capture the full flooded extent, and to ensure the cross section cut line was perpendicular to the channel centerline.

8.3.5 Manning's n Values

Manning's n values in the cross sections were within the range of generally accepted values, consistent with *Open Channel Hydraulics* by Chow. Initially, Manning's n values used were similar to those used in the previous HEC-RAS models. Final Manning's n values in the 1D area range from 0.028-0.037 in the channel, and 0.06-0.1 in the overbanks. Manning's n values in the 2D areas in North Dakota were based on the National Land Cover Database (NLCD) 2016 Land Cover data set. The bypass channel near Logan in the Logan_Bypass 2D flow area was entered as a polygon override area for the Manning's n value. The Manning's n values in the Estevan 2D area were based on using 0.06 in the overbank areas and defining polygons for the flowing channels and entering them as override areas.

8.3.6 Lateral Structures

All lateral structures in the models were redone to better follow high ground and/or levees, define additional storage areas, improve the layout in regards to cross sections and structures, and geo-reference the lateral structures. Lateral structure elevations were taken from surveyed levee elevations, National Levee Database (NLD) and LiDAR as a last resort, especially in Saskatchewan.

8.3.7 Bridges

Several bridges were missing in the existing models. Data for new bridges on US, North Dakota, county or city roads were obtained from the county or city in which they were located usually in the form of bridge drawings. A couple of bridges were discovered simply from looking at aerial photos over time, generally using the historical imagery feature of Google Earth to determine a rough time period over which the bridge was put in place. These two bridges that were discovered in this manner were brought to the attention of the county engineer to obtain more information of which there was none other than finding out that they were "approved" as at-grade, slab bridges. The data for these two at-grade, slab bridges was assumed based on other small bridges in the area. See Table 8-4.

Table 8-4. Bridges Added to the Hydrologic Engineering Center-River Analysis System Model

Bridge Description	River	Reach	River Station
Minot NW US Hwy 83 Bypass Southbound (new)	Souris	DesLacsWintering	400.15
Minot NW US Hwy 83 Bypass Northbound (replacement)	Souris	DesLacsWintering	400.13
Minot Broadway (US Hwy 83) Viaduct (Southbound & Northbound replacements)	Souris	DesLacsWintering	396.38
ATV access (Pre 9/1997)	Souris	DesLacsWintering	378.3
Gravel Pit access (Before 6/2017)	Souris	DesLacsWintering	371.58
49th St N (replacement)	Souris	DesLacsWintering	330.47
ND Hwy 14 (replacement)	Souris	Wintering2Willow	272.93

A bridge on the Des Lacs River was removed from the model simply because the river had formed a cutoff from the original channel meander sometime between August 2013 and May 2016. Several bridges on the Souris River between Verendrye and Towner seemed to have been removed because they had been severely damaged during recent flood events (2011 and 2013). Table 8-5 provides the bridges that were removed and their locations.

Table 8-5. Bridges Removed from the Hydrologic Engineering Center-River Analysis System Model

Bridge Description	River	Reach	River Station
Field Crossing, wooden bridge	Des Lacs River	Des Lacs	40.83
58th Street	Souris	Wintering2Willow	289.79
Old US Hwy 2	Souris	Wintering2Willow	283.08
Follman Road	Souris	Wintering2Willow	275.485

8.3.8 Inline Structures

The HEC-RAS models contain 44 inline structures. In Saskatchewan there were seven inline structures; with two inline structures modeled using as-built plan sets and one modeled based on survey data. In North Dakota there were 7 inline structures modeled from as-built plan sets for US Fish and Wildlife Service dams; 5 inline structures from USGS gage measurement sites, 5 inline structures for irrigation organization purposes, and 15 inline structures built by USACE as part of the Souris River Basin Flood Control project mostly as grade control for the many oxbow cutoffs. The USACE inline structures were modeled using as-built plan sets and updated with survey data when available. When no other information was available the profile of the weir was taken from LiDAR data. Lake Darling Dam was removed from the models because the model reaches were broken at Lake Darling Dam.

8.3.9 Ineffective Areas

Ineffective flow areas at bridges were set to the expected slope of the water surface profile across the bridge. Ineffective flow areas in other areas were set to assist flow transition around topographical features. Due to the complexity of the models and based on guidance from the HEC all of the ineffective flow areas were set to permanent.

8.3.10 HTab Parameters

The hydraulic property table (HTab) parameters were adjusted for better performance in the unsteady flow model. Smaller increment sizes were used to increase the number of slices and hence model accuracy. In addition, the HTab parameters were adjusted for the bridges to better define the HTab curves for the bridges.

8.4 MODEL CALIBRATION

Model calibration was approached differently in Saskatchewan and North Dakota due to differences in data collection and availability.

In North Dakota calibration was conducted based on rating curves created from discharge and stage measurements at USGS gages from 2011 to present. The 2011 flood of record was much larger than any other floods and in some areas there were significant changes to the channel geometry as a result of the flood. The HEC-RAS calculated rating curves were compared to the rating curves from the USGS discharge measurement data to verify that the HEC-RAS model was responding appropriately for a given flow. The calibration process involved a fictitious event similar to but larger than the 2011 flood event, such that the entire hydrograph had a very wide range of flows. It is believed that calibrating to the observed data and rating curves with a fictitious events is sufficient, but continuous calibration will result in a more accurate model.

In Saskatchewan, the only Environment Canada stream gages are located at the upstream ends of each river reach providing upstream boundary condition data but, there are no gages located along the Souris River between Rafferty, Boundary, and Grant Devine Dams and the USGS gage near Sherwood, North Dakota just downstream of the Saskatchewan and North Dakota border even though there are over 130 river miles in between these gages. There were no discharge measurements to use for calibration. The only calibration data available comes from the 2011 flood event and consists of water surface elevations at different times during the flood event. These water surface elevation data points fall within a reach between Rafferty Dam and near the City of Oxbow. Calibration in Saskatchewan proved to be difficult. The 2011 flood event was used for the calibration in Saskatchewan because the pool elevation at Lake Darling Dam could be used as the downstream boundary condition.

During the calibrating process of the HEC-RAS model, various parameters were adjusted with the attempt to match the rating curves and observed data. Manning’s n values, ineffective flow areas, weir coefficients, and hydraulic tab parameters were the main features adjusted during the calibration efforts.

Ideally, the model results would be compared to observed stage and flow hydrographs for specific events, but due to time and data restrictions, the model was calibrated based on rating curves and observed data. Due to time and data constraints, the 2011 flood event was used for model verification.

These USGS gages provided calibration data for the HEC-RAS model in North Dakota:

- Souris River near Sherwood, ND, USGS 05114000
- Souris River near Foxholm, ND, USGS 05116000
- Souris River above Minot, ND, USGS 05117500
- Souris River at Broadway Bridge at Minot, ND, USGS 05117600
- Souris River at Logan, ND, USGS 480911101090200
- Souris River at Verendrye, ND USGS 05120000
- Souris River near Bantry, ND, USGS 05122000
- Souris River near Westhope, ND, USGS 05124000

These gages reported both stage and flow values and use NAVD 88. The USGS gage at Logan, North Dakota is a temporary, rapid deployment gage that the North Dakota State Water Commission funds during flood years to provide critical information for the communities downstream of Minot, North Dakota. The gage is resurveyed and set to the same vertical datum each year at the same georeferenced location to provide consistency. The Souris River gage near Westhope is the downstream boundary of the model and the rating curve there is the downstream boundary condition.

The 2011 flood of record had extreme flood fighting used in the City of Minot. The 1 percent annual chance exceedance event before 2011 was 5,000 cfs. After the hydrology was redone in 2013, the 1 percent annual chance exceedance event increased to 10,000 cfs. In comparison, the annual peak flow for 2011 at Minot was 26,900 cfs. A very high emergency levee was built on the upstream side of Broadway Bridge to keep emergency vehicle access open between both sides of the river which resulted in peak water surface at the upstream side of the bridge much higher than would have been expected without the emergency levee in place. Because the geometry does not have this emergency levee in place, the artificially high data points from the 2011 flood event were excluded from the rating curve for higher flows when the emergency levee was in place.

Flow roughness factors were used along the length of the Souris River model geometry to take into account the reduction in roughness at high flows to aid in calibration. The weir coefficients of the many lateral structures along the Souris River were also adjusted to calibrate the model.

8.5 CALIBRATION EVENTS AND RESULTS

The results of the calibration efforts can be found in the rating curves in Figure 8-1 to Figure 8-11, from upstream to downstream. The results for the fictitious calibration event are plotted against the gage rating curves and measured data. In most cases the RAS rating curves follow the rating curve and/or within the observed data. While calibrating there were areas of greater difficulty, but in most cases calibration was possible for a majority of the flows along the rating curves.

The main challenging area in North Dakota was at the Verendrye gage which is complicated by the large complex of the Eaton Irrigation District between the Bantry and Verendrye USGS gages. The Eaton Irrigation District has an inline dam and many storage areas, lateral structures and storage area connections. The condition of any gates on these structures as well as the regular operation is unknown. It was verified with the Eaton Irrigation District that all of the gates on all of the structures in the lateral structures and storage area connections were wide open during the 2011 flood event so these same conditions were assumed for the calibration event. No calibration data was available within the Eaton Irrigation District.

In Saskatchewan the entire reach was challenging due to the lack of data. The only gage data available was at the upstream boundaries of all of the reaches which defined the upstream boundary condition. No discharge measurements. There are no gages in Saskatchewan on the Souris River from downstream of Rafferty Reservoir to the USGS gage near Sherwood even though there are over 130 river miles in between these gages.

Figures 8-1 through 8-8 show the HEC-RAS calibration results at the USGS gages along the Souris River.

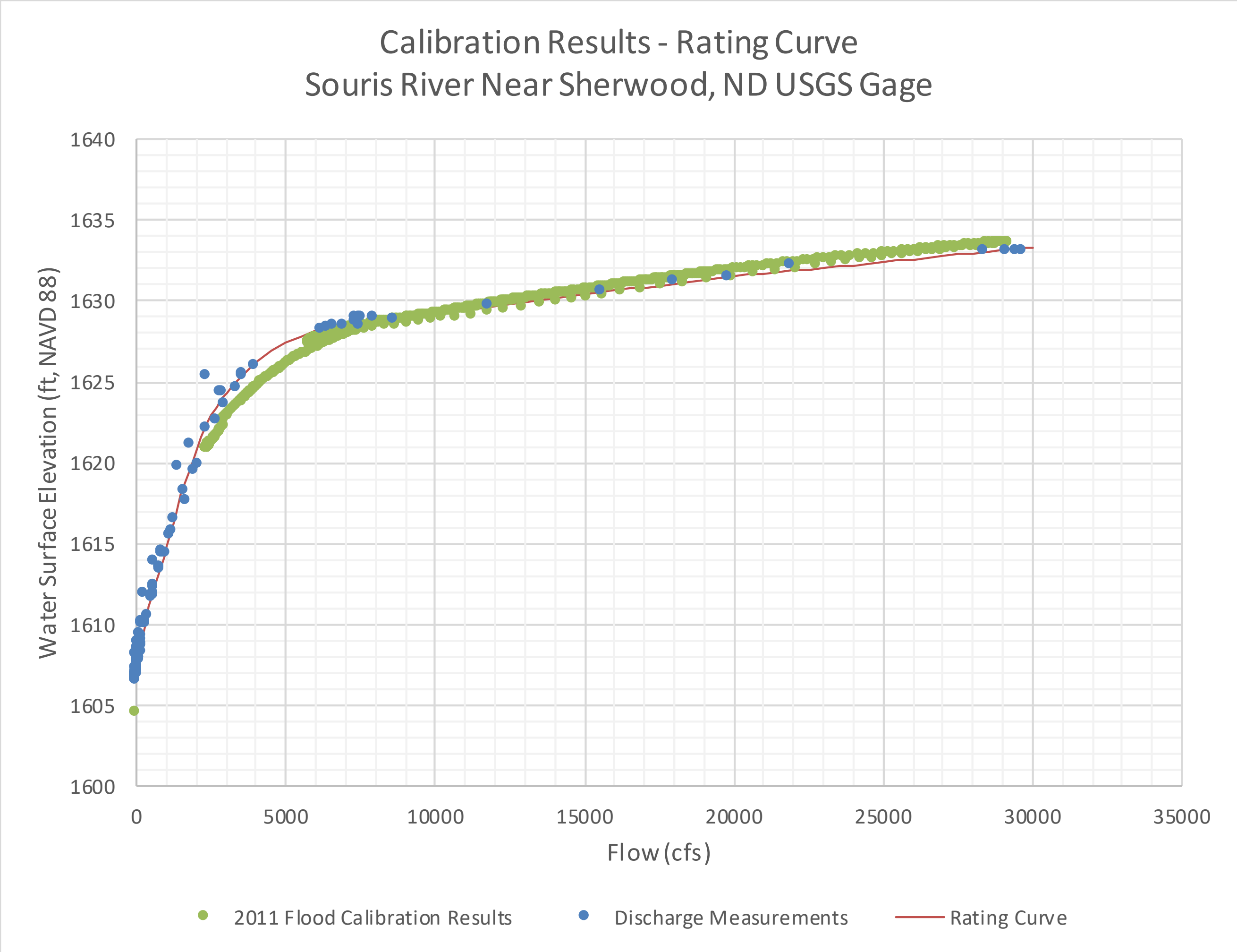

Figure 8-1. Rating Curve Calibration - 2011 Flood Event Souris River Near Sherwood (USGS 05114000)

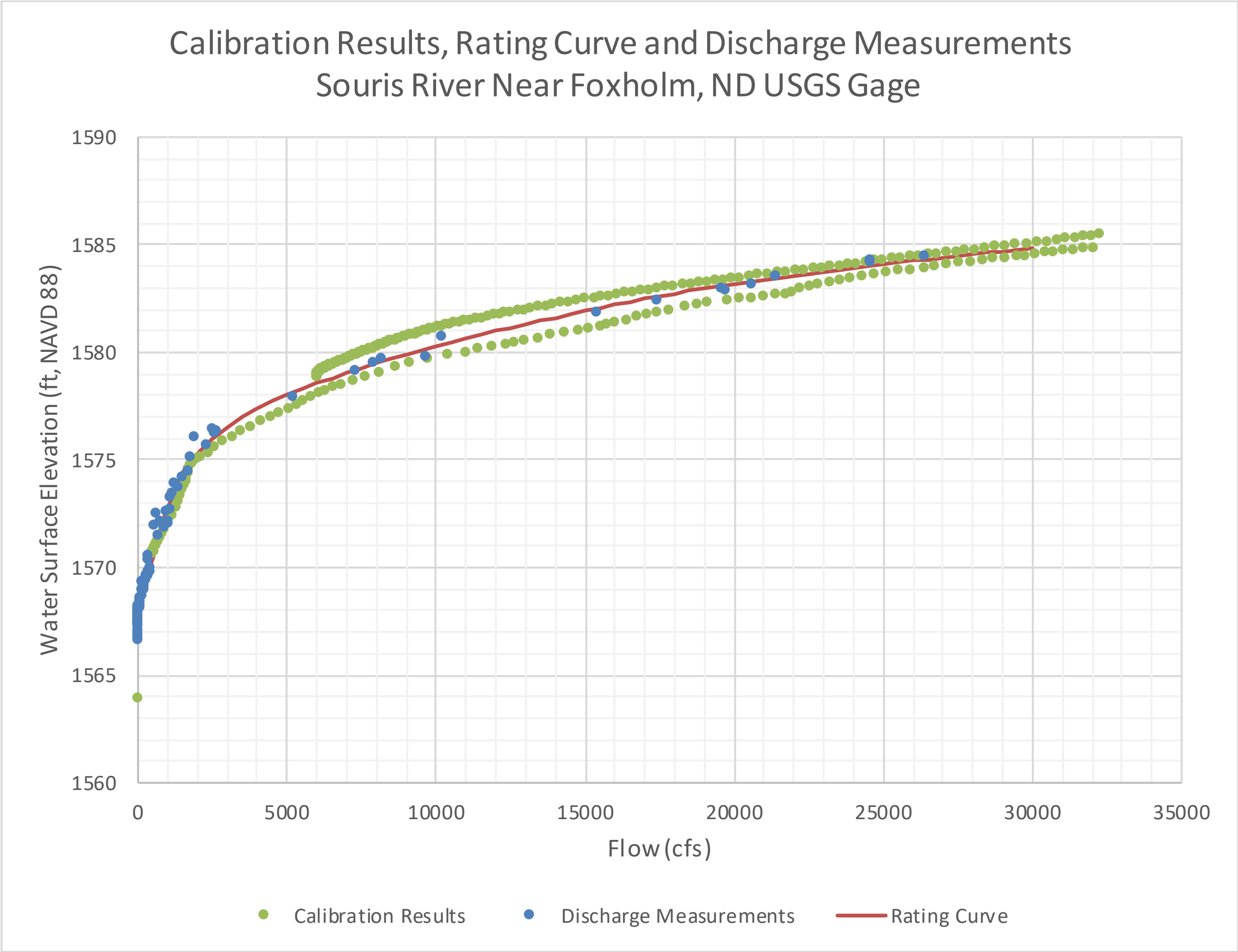

Figure 8-2. Rating Curve Calibration - Souris River near Foxholm (USGS 05116000)

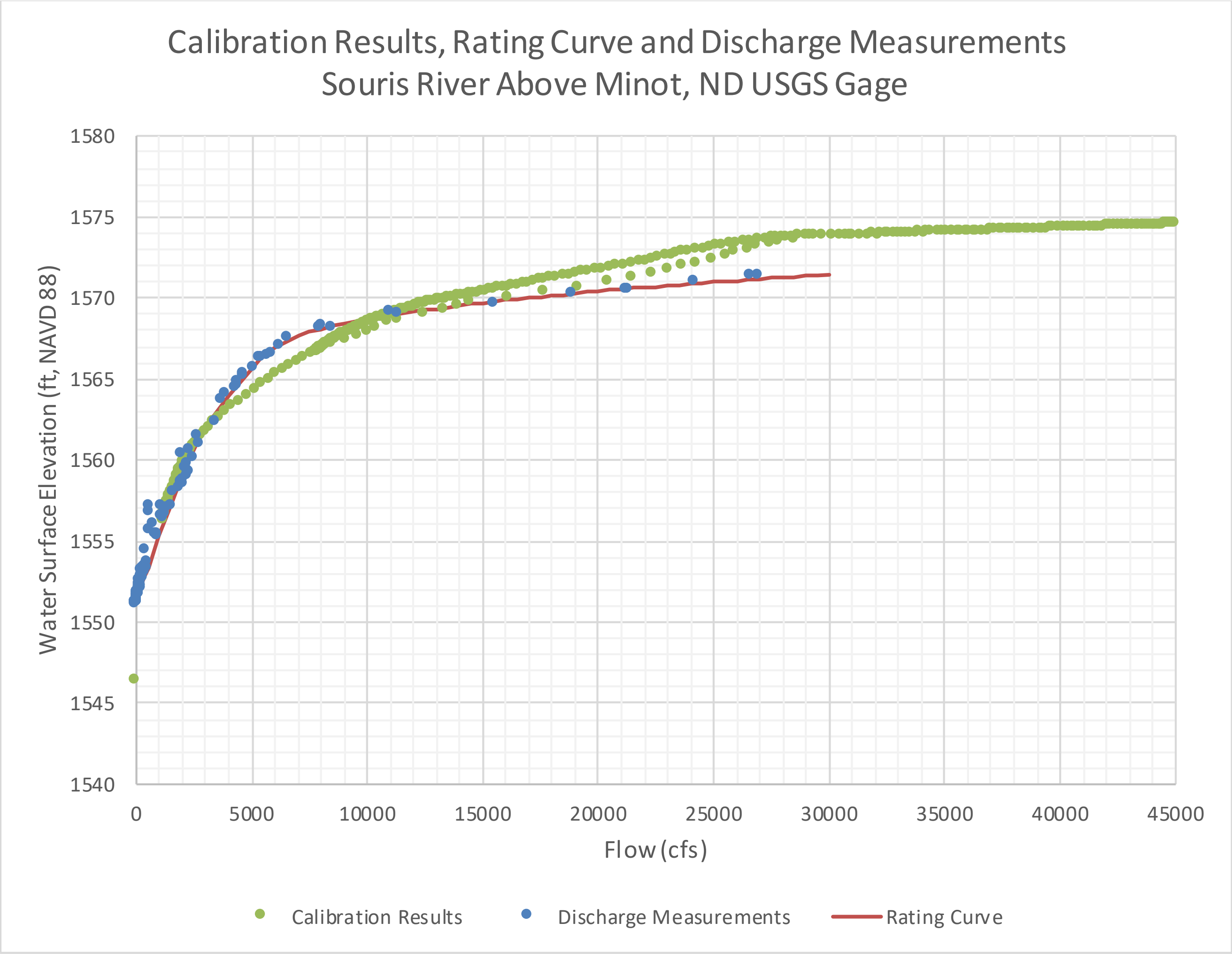

Figure 8-3. Rating Curve Calibration - Souris River above Minot (USGS 05117500)

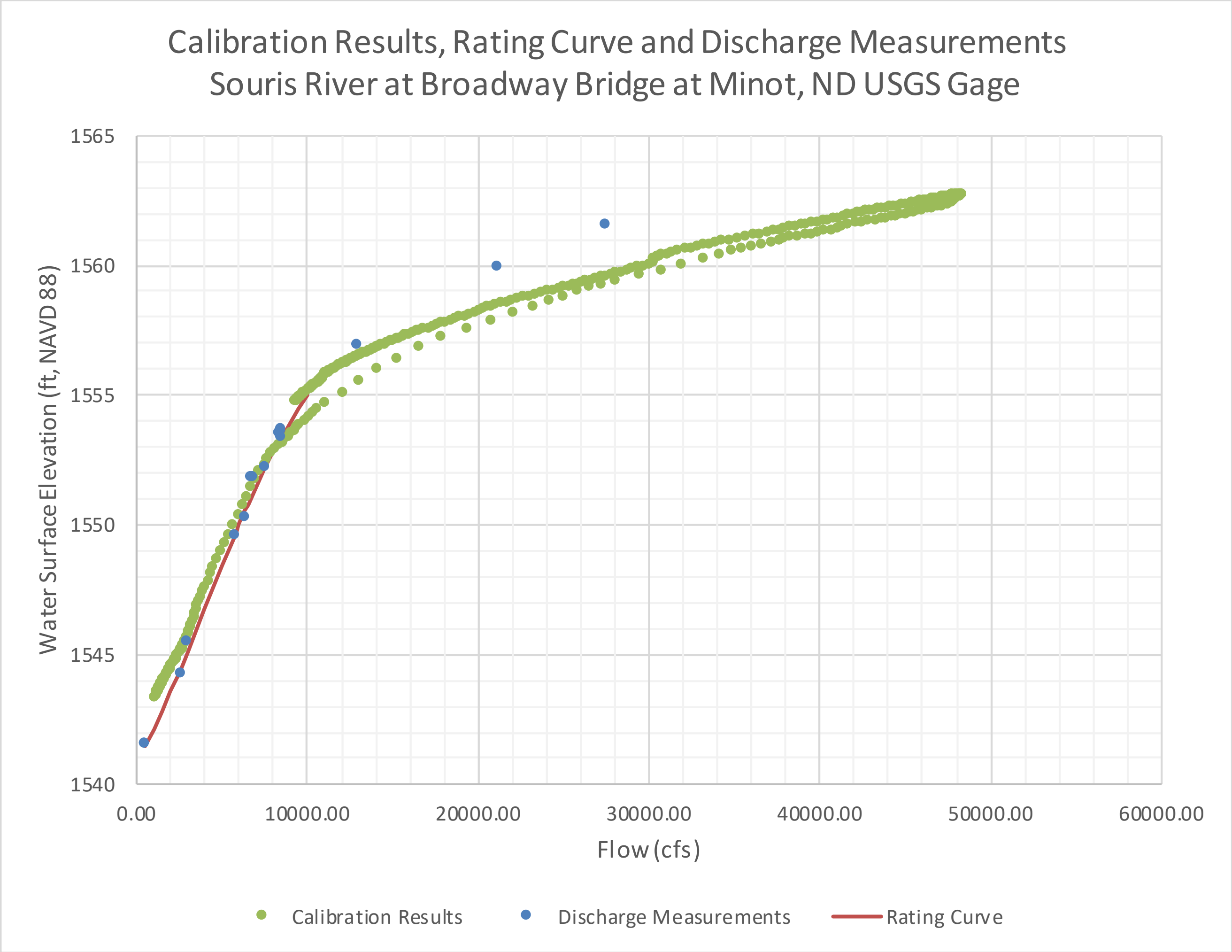

Figure 8-4. Rating Curve Calibration - Souris River at Minot Broadway Bridge (USGS 05117600)

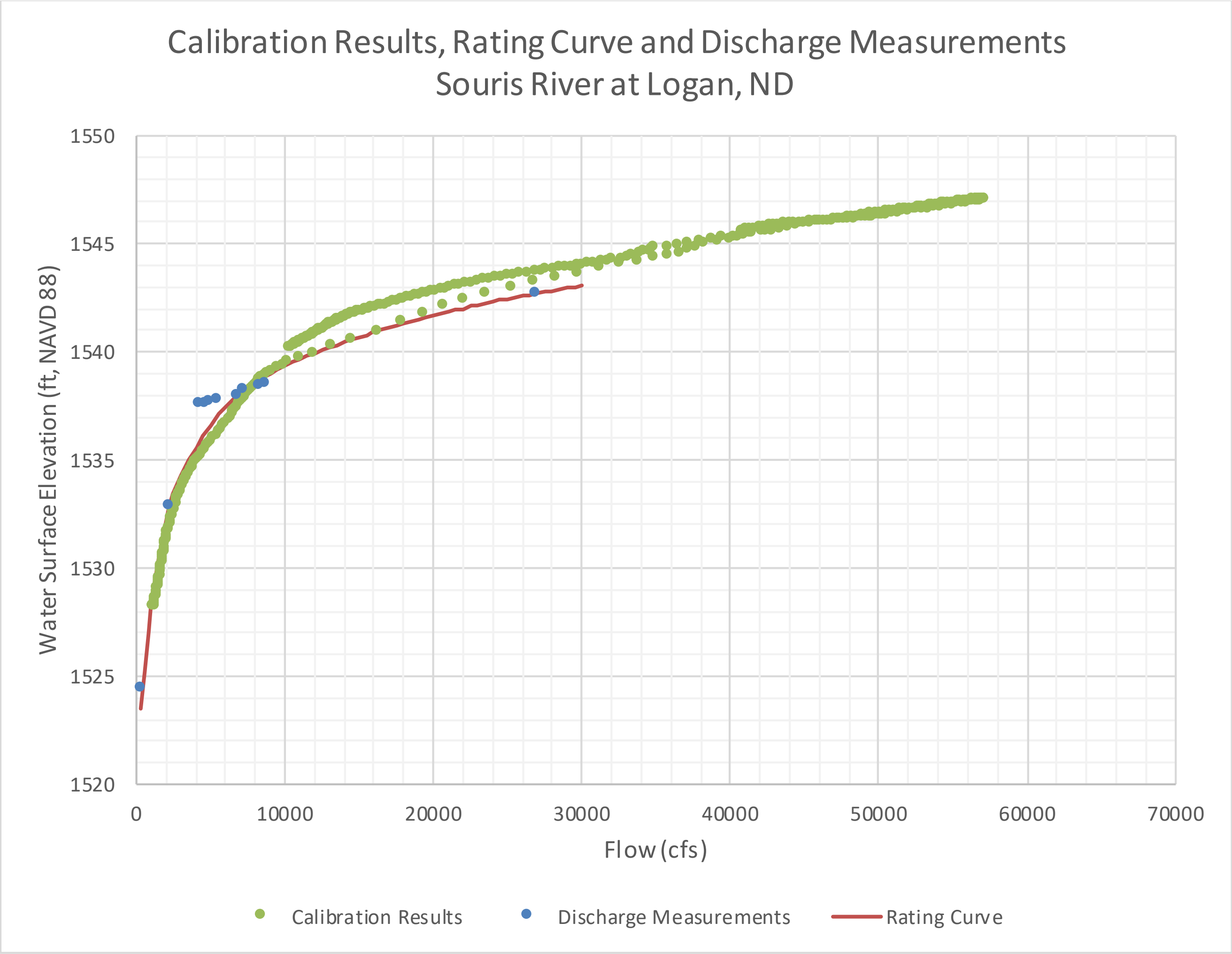

Figure 8-5. Rating Curve Calibration - Souris River at Logan (USGS 480911101090200)

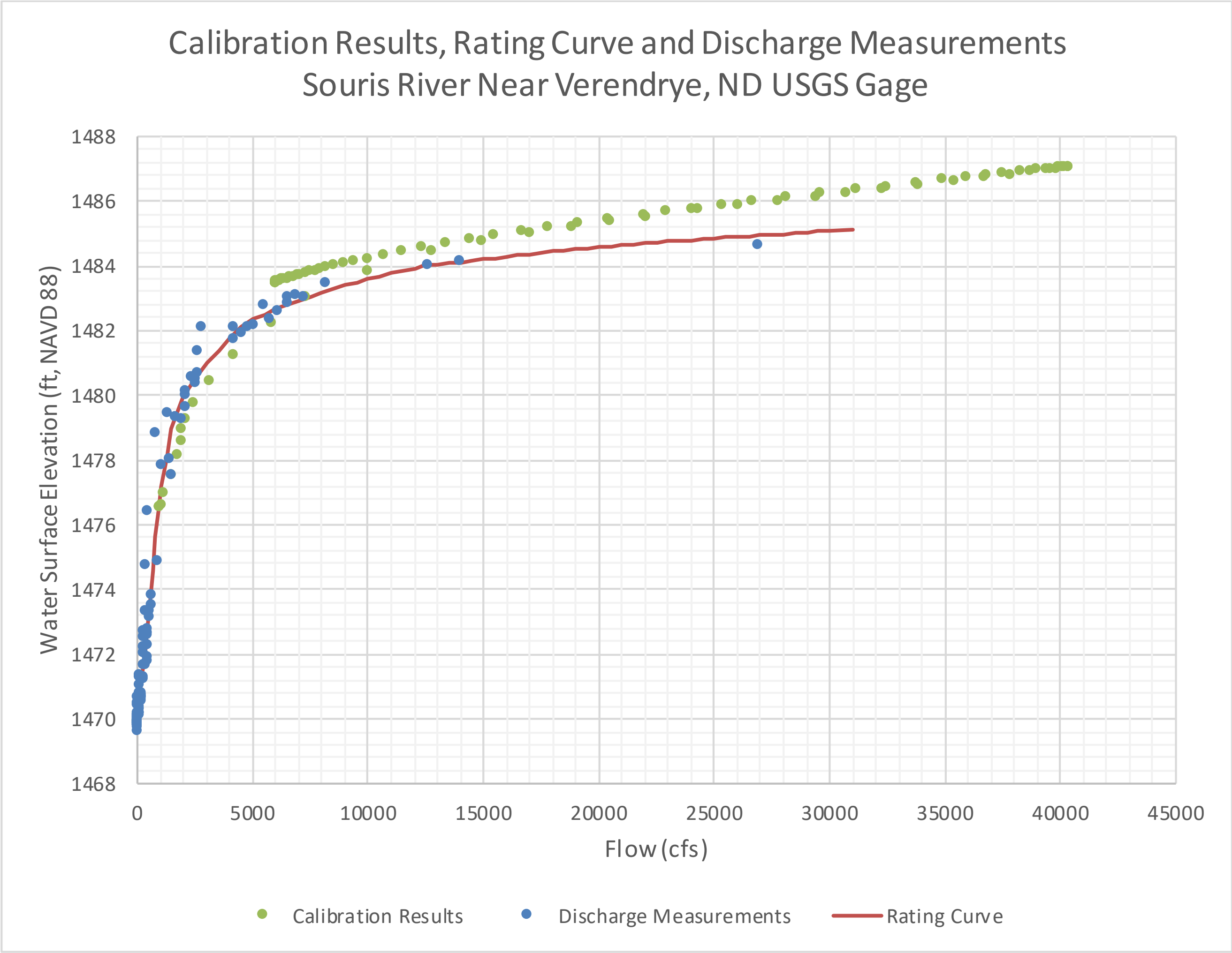

Figure 8-6. Rating Curve Calibration - Souris River near Verendrye (USGS 05120000)

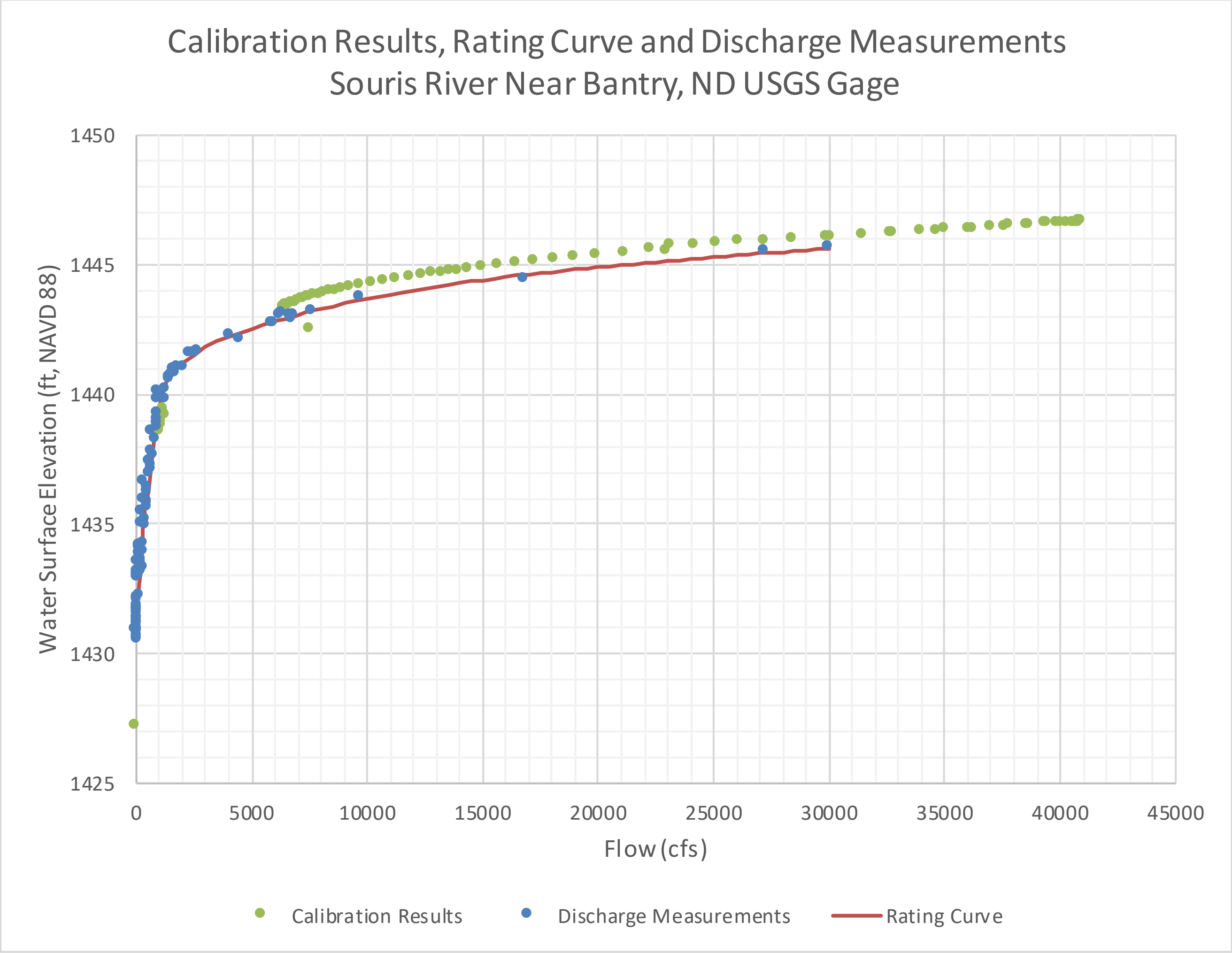

Figure 8-7. Rating Curve Calibration - Souris River near Bantry (USGS 05122000)

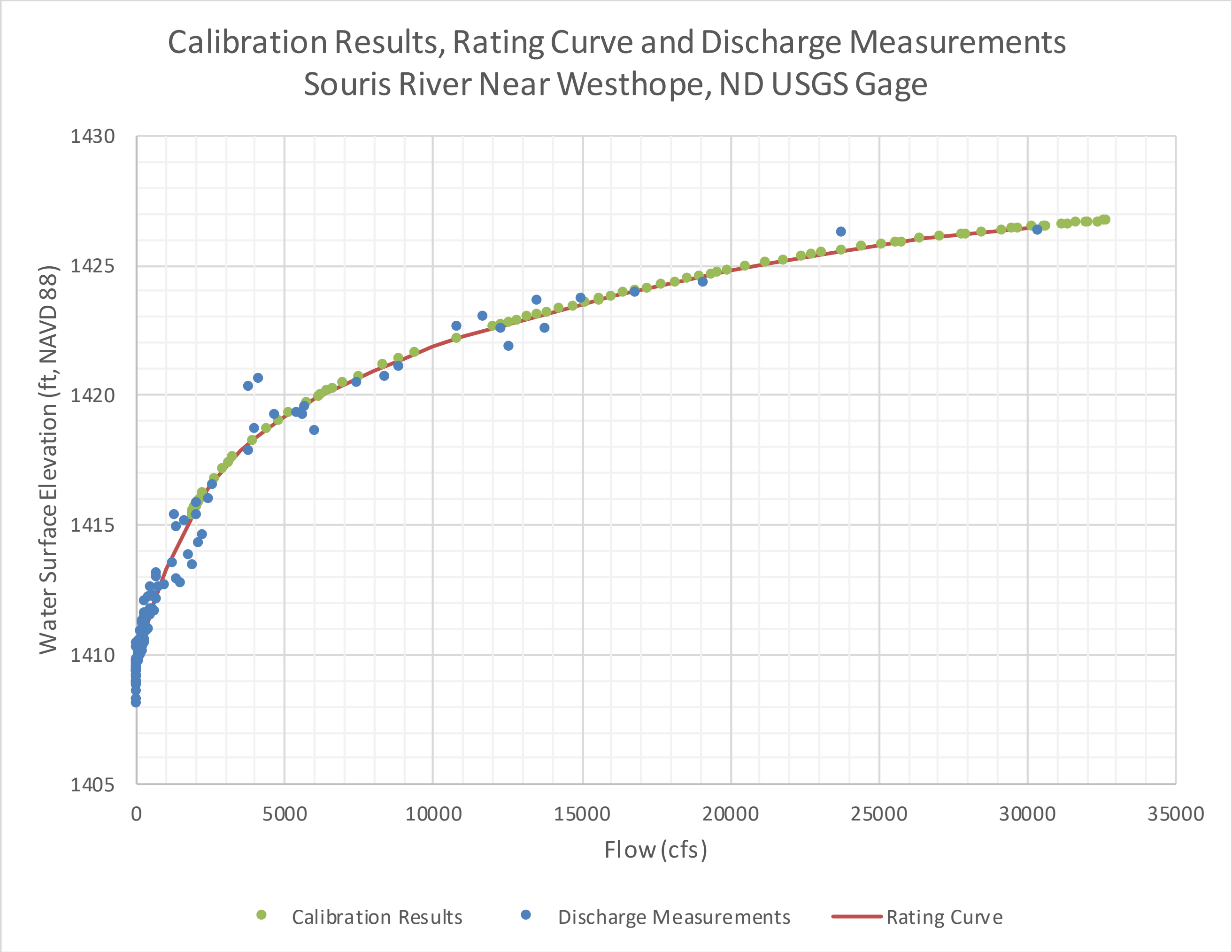

Figure 8-8. Rating Curve Calibration - Souris River near Westhope (USGS 05124000)

8.6 VERIFICATION EVENTS AND DISCUSSION

The 2011 flood event was used for model verification. The dates of the 2011 flood event used are listed in Table 8-6. Modeling actually started in May due to the prolonged flood event with multiple smaller peaks before the large one; however, the results presented use the timeframes below.

Table 8-6. 2011 Flood Event used for Hydrologic Engineering Center-River Analysis System Verification

Hydrologic Engineering Center-River Analysis System Simulation Period				
Model	Start Date	Start Time	End Date	End Time
Rafferty to Lake Darling	06/14/2011	12:00	07/07/2011	00:00
Lake Darling Dam to Verendrye	06/19/2011	12:00	07/13/2011	18:00
Verendrye to Westhope	06/19/2011	12:00	07/13/2011	18:00

The verification results can be found in Figure 8-11 to Figure 8-23. Flood event verification compared the hydrographs of the modeled event with the hydrograph of the gage data for the same flood event. The flow hydrograph is shown for all of the gage locations in North Dakota except for Logan and Minot Broadway since the gage record there only records stage. The Logan and Minot Broadway gages and all of the locations in Saskatchewan are shown using a stage hydrograph.

In Saskatchewan the entire reach was challenging due to the lack of data. As stated before, the only gage data available was at the upstream boundaries of all of the reaches which defined the upstream boundary condition. There were no available discharge measurements along the rest of the reach. The flows from local runoff were estimated based on the North Central River Forecast Center's modeled flows and provide a source of uncertainty. Another possible source of error could be in the vertical datum conversion from the Geodetic Survey of Canada 1928 to NAVD 88. All of the surveyed water surface elevations in Saskatchewan were much lower than the modeled simulation shows with the stage hydrograph, although the shape of the surveyed data points does seem to follow the modeled hydrograph.

Also in Saskatchewan, there are many storage areas, lateral structures and storage area connections in the reach between Rafferty reservoir and through Estevan. Additionally, the area near Estevan is very complex. The Souris River splits, on one of the splits Long Creek enters and joins the partial Souris River flows before coming back together with the other split of the Souris River. This complex area is shown in Figure 8-9. The left image shows the geometry at the 25 percent review with the three junctions, and each individual river along with the many storage areas. The right image shows the final geometry where the entire confluence area has been changed into a 2D flow area.

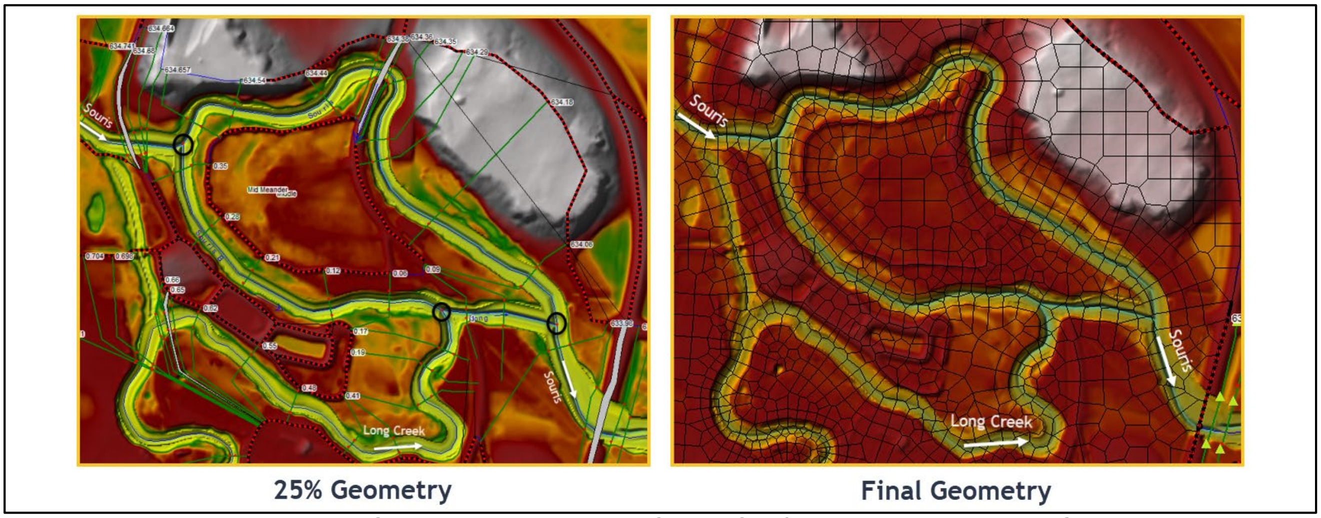

Figure 8-9. Souris River and Long Creek Confluence near Estevan, SK

The routing of flows through the geometry seems to have shifted the peak water surface elevation or flow slightly in many locations. Refining the calibration and verification further was beyond the scope of the CWMS project.

Figures 8-10 through 8-23 show the HEC-RAS verification results at key locations within the watershed.

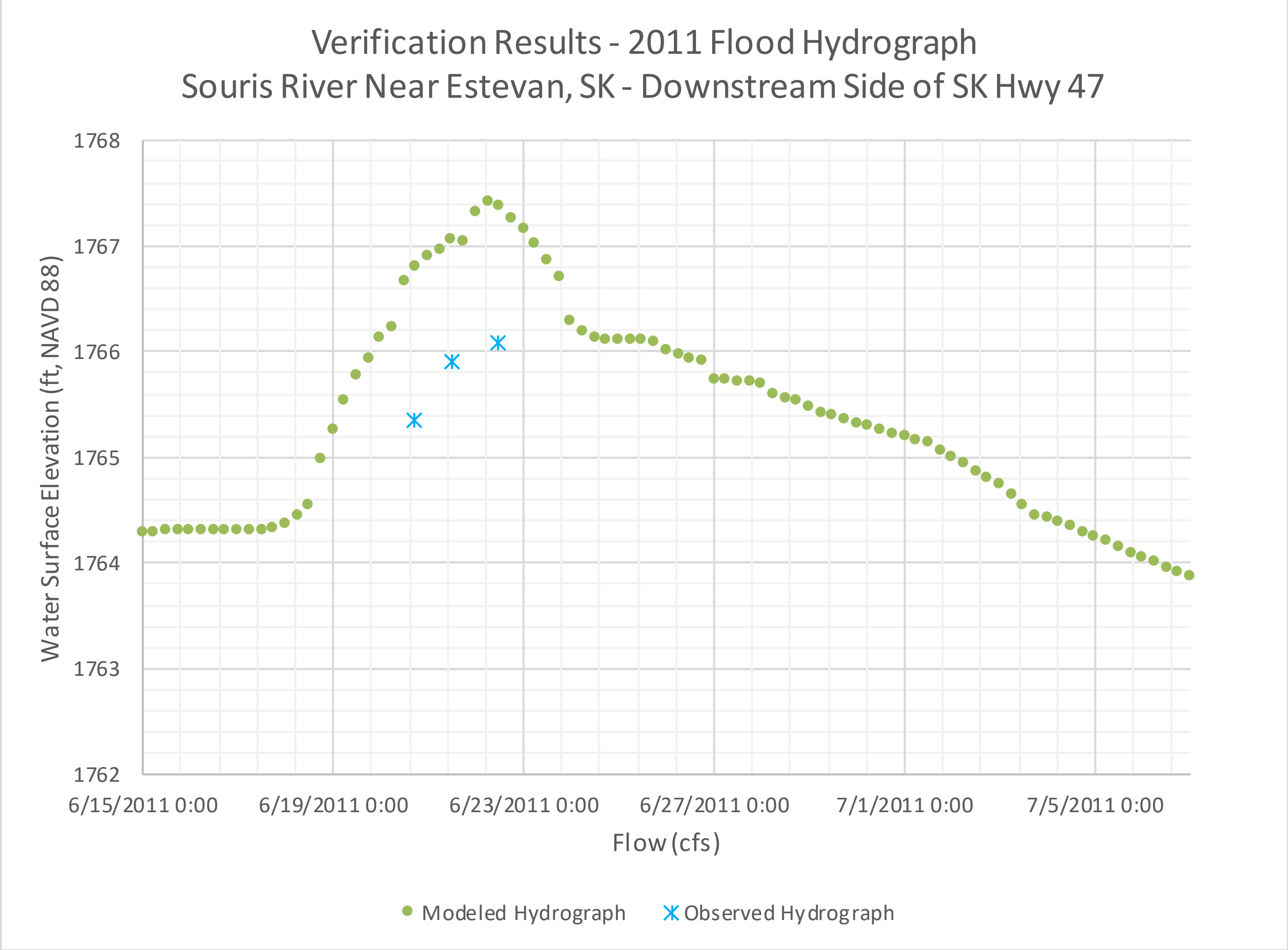

Figure 8-10. Verification - 2011 Flood Souris River Near Estevan, DS side of SK Hwy 47

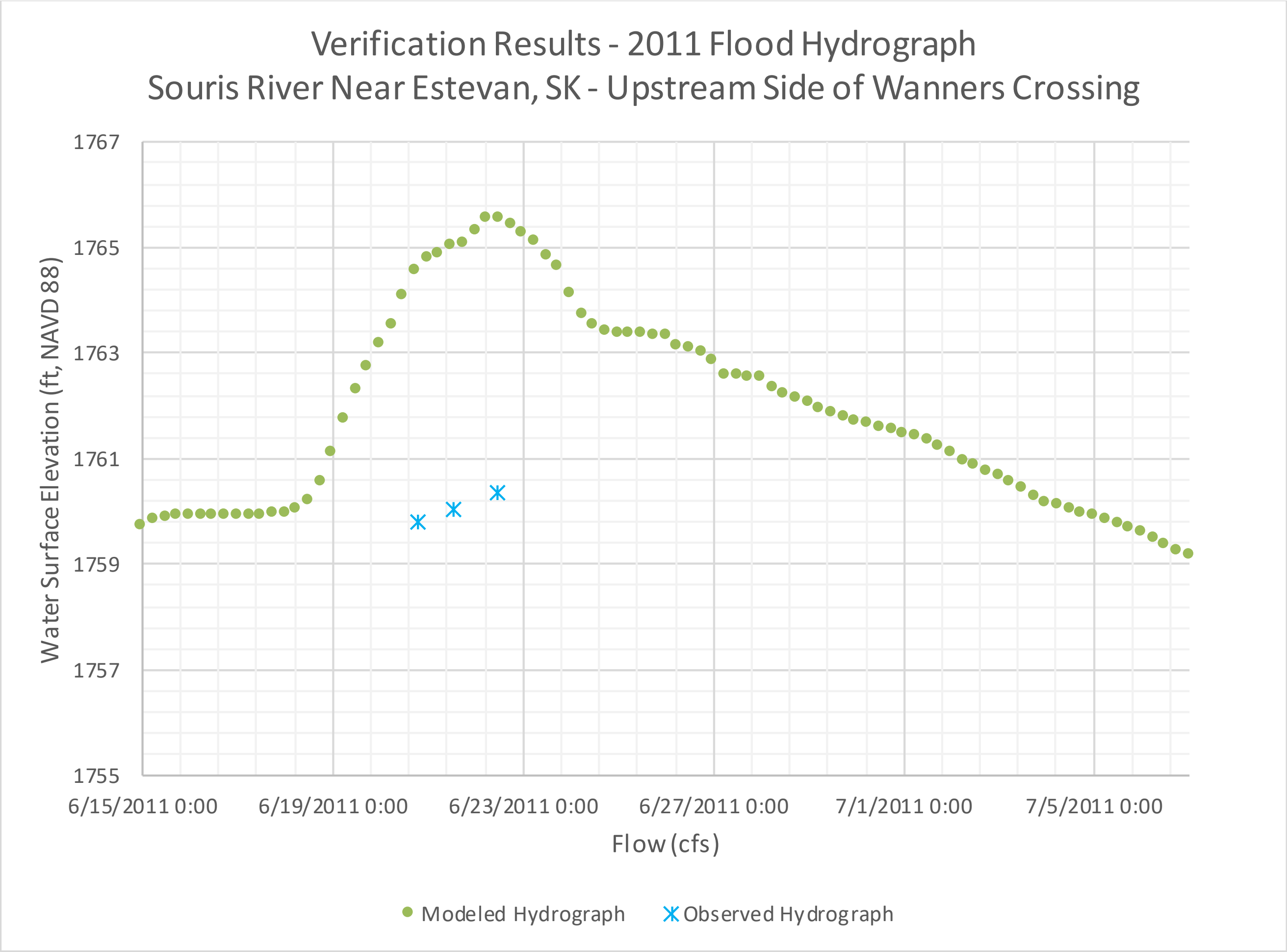

Figure 8-11. Verification - 2011 Flood Souris River Near Estevan, DS side of Wanners Crossing

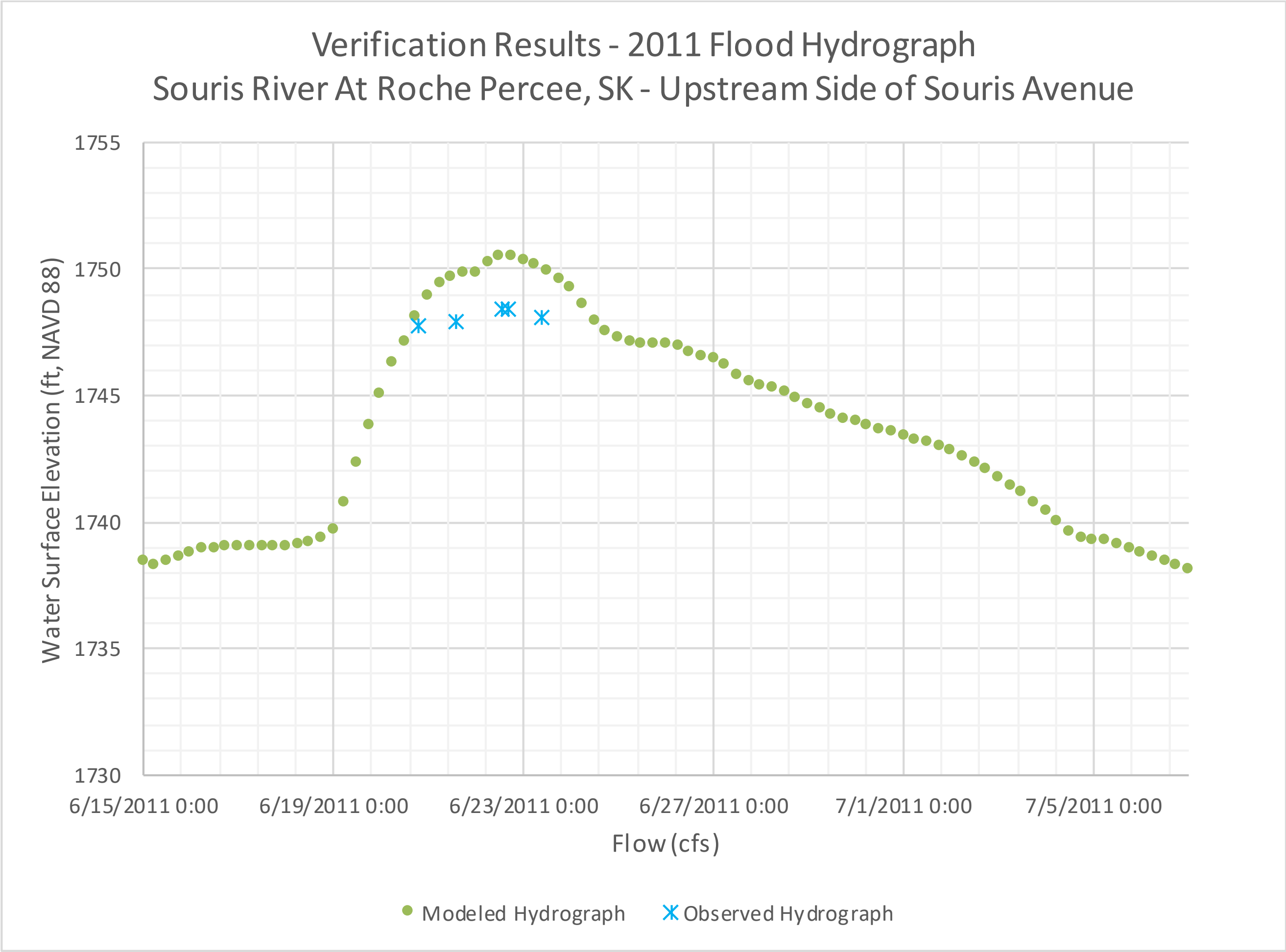

Figure 8-12. Verification - 2011 Flood Souris River Near Roche Percee, US Side of Souris Avenue

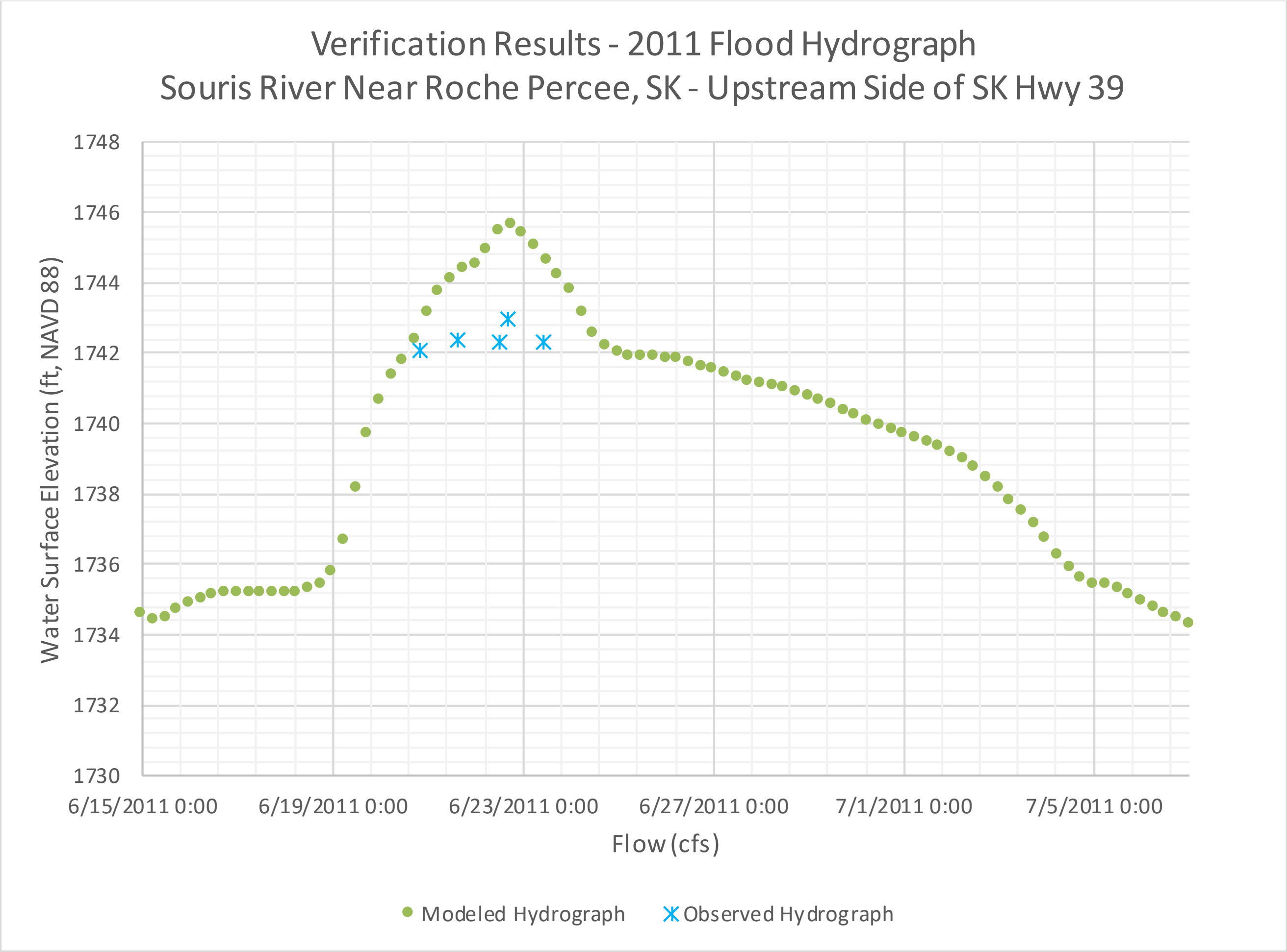

Figure 8-13. Verification - 2011 Flood Souris River Near Roche Percee, US Side of SK Hwy 39

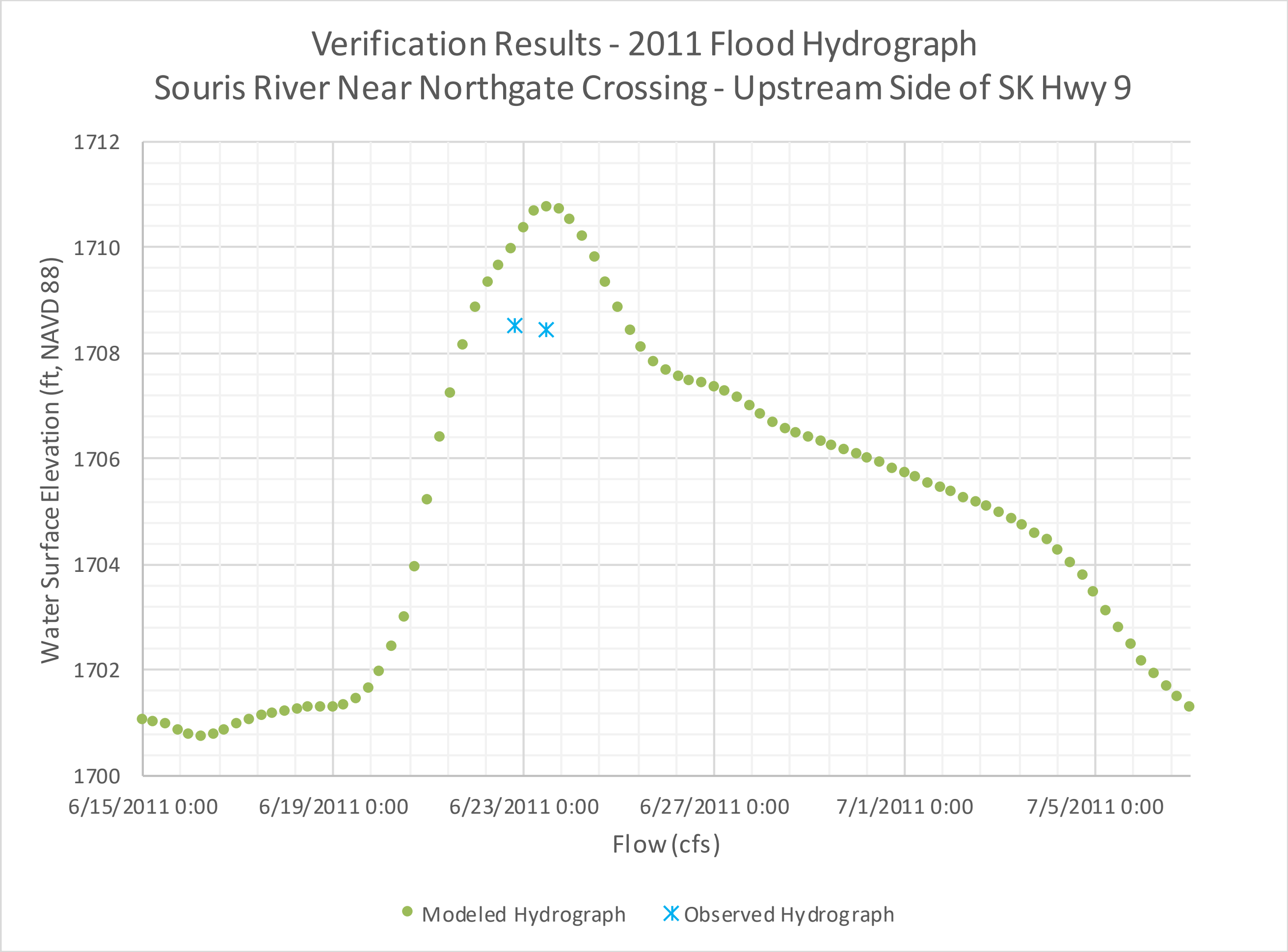

Figure 8-14. Verification - 2011 Flood Souris River Near Northgate, US Side of SK Hwy 9

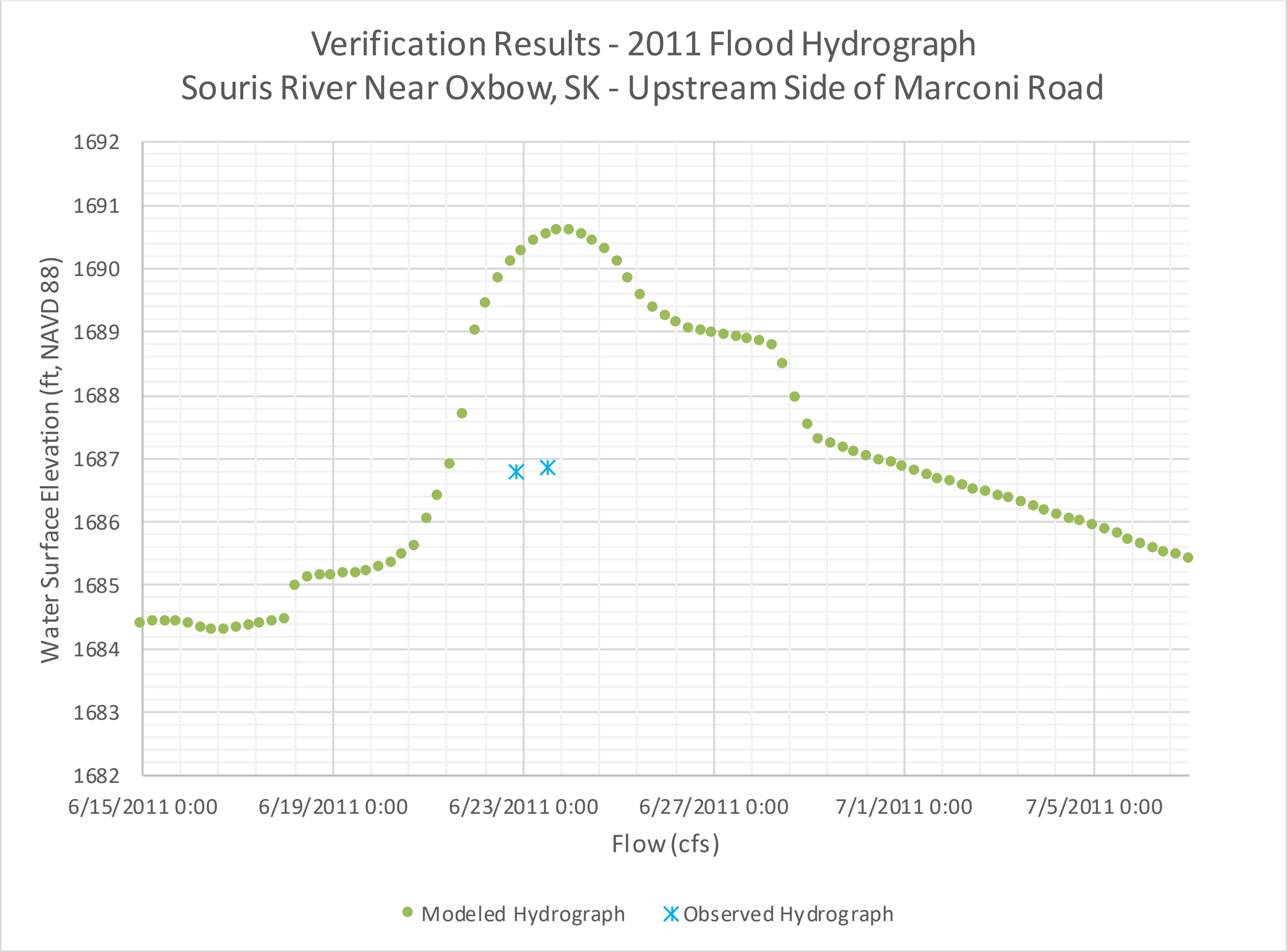

Figure 8-15. Verification - 2011 Flood Souris River Near Oxbow, US side of Marconi Road

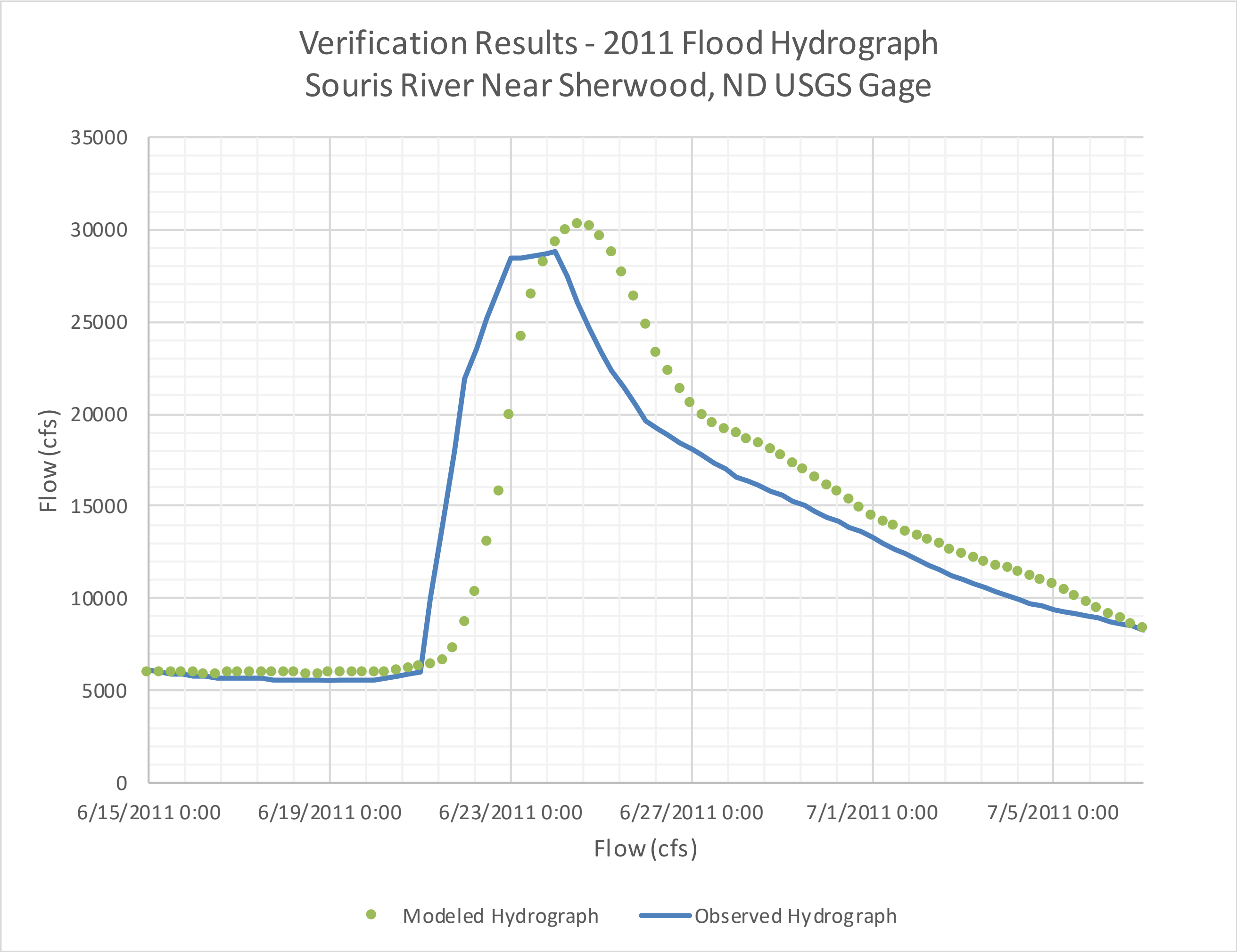

Figure 8-16. Verification - 2011 Flood Souris River Near Sherwood (USGS 05114000)

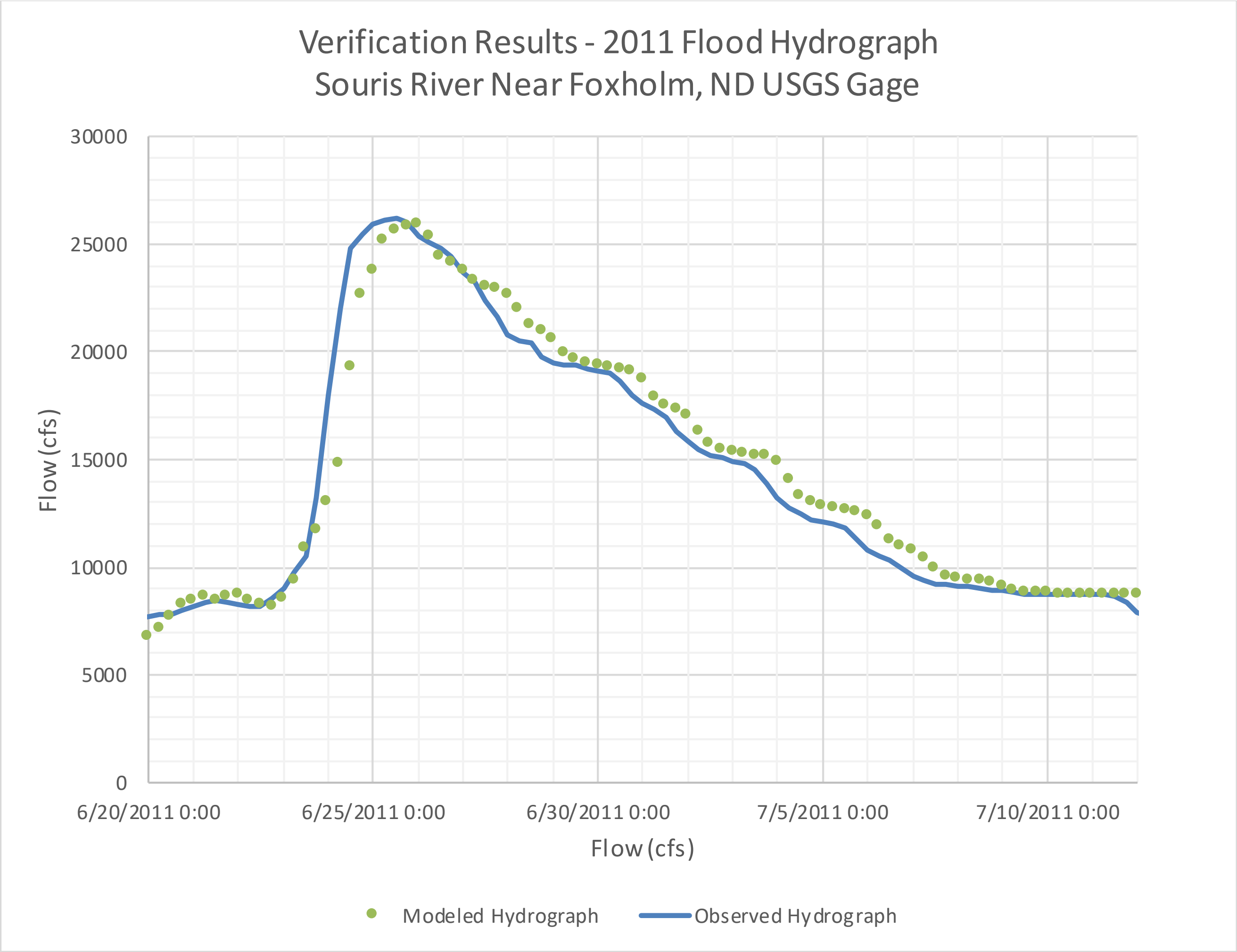

Figure 8-17. Verification - 2011 Flood Souris River Near Foxholm (USGS 05116000)

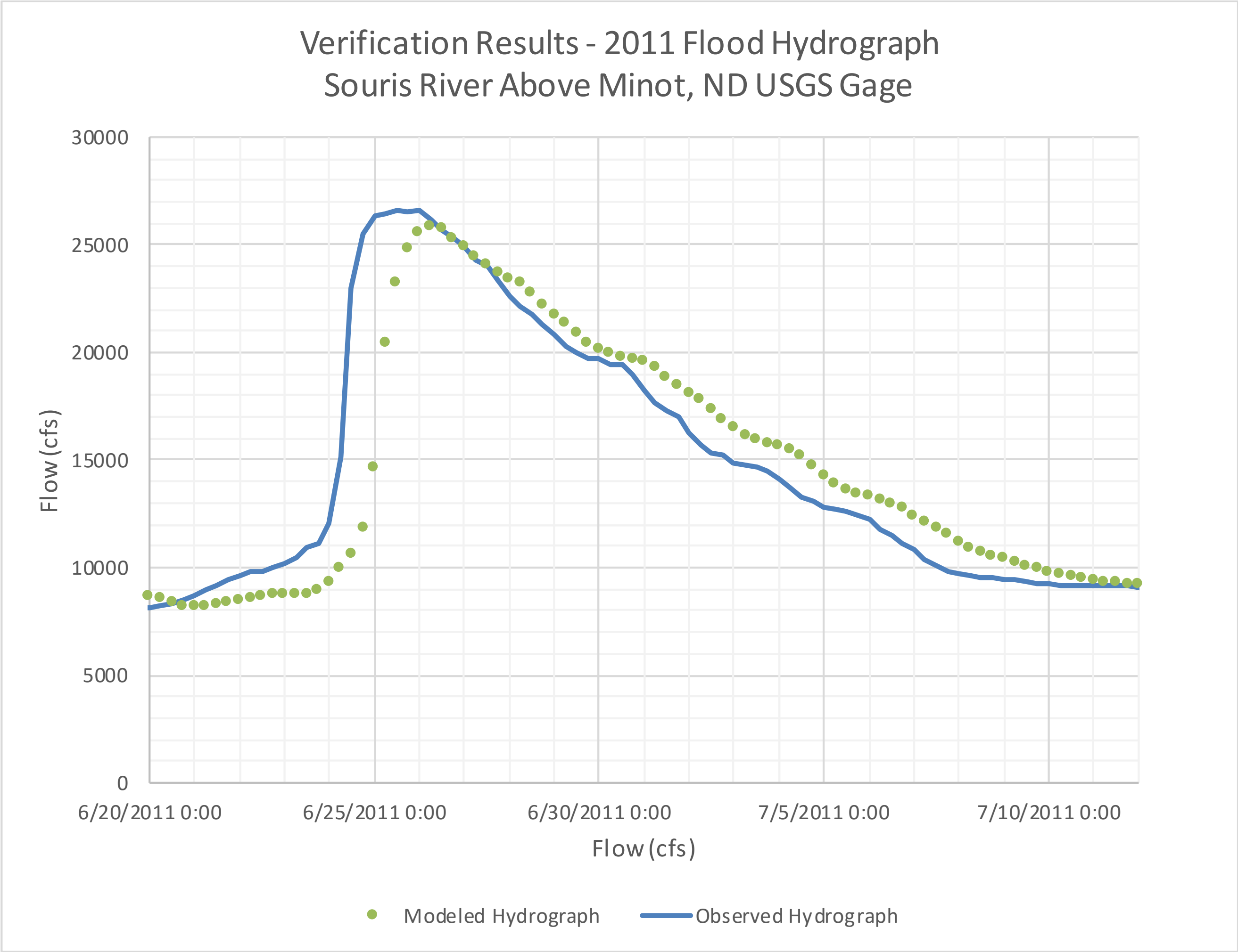

Figure 8-18. Verification - 2011 Flood Souris River Above Minot (USGS 05117500)

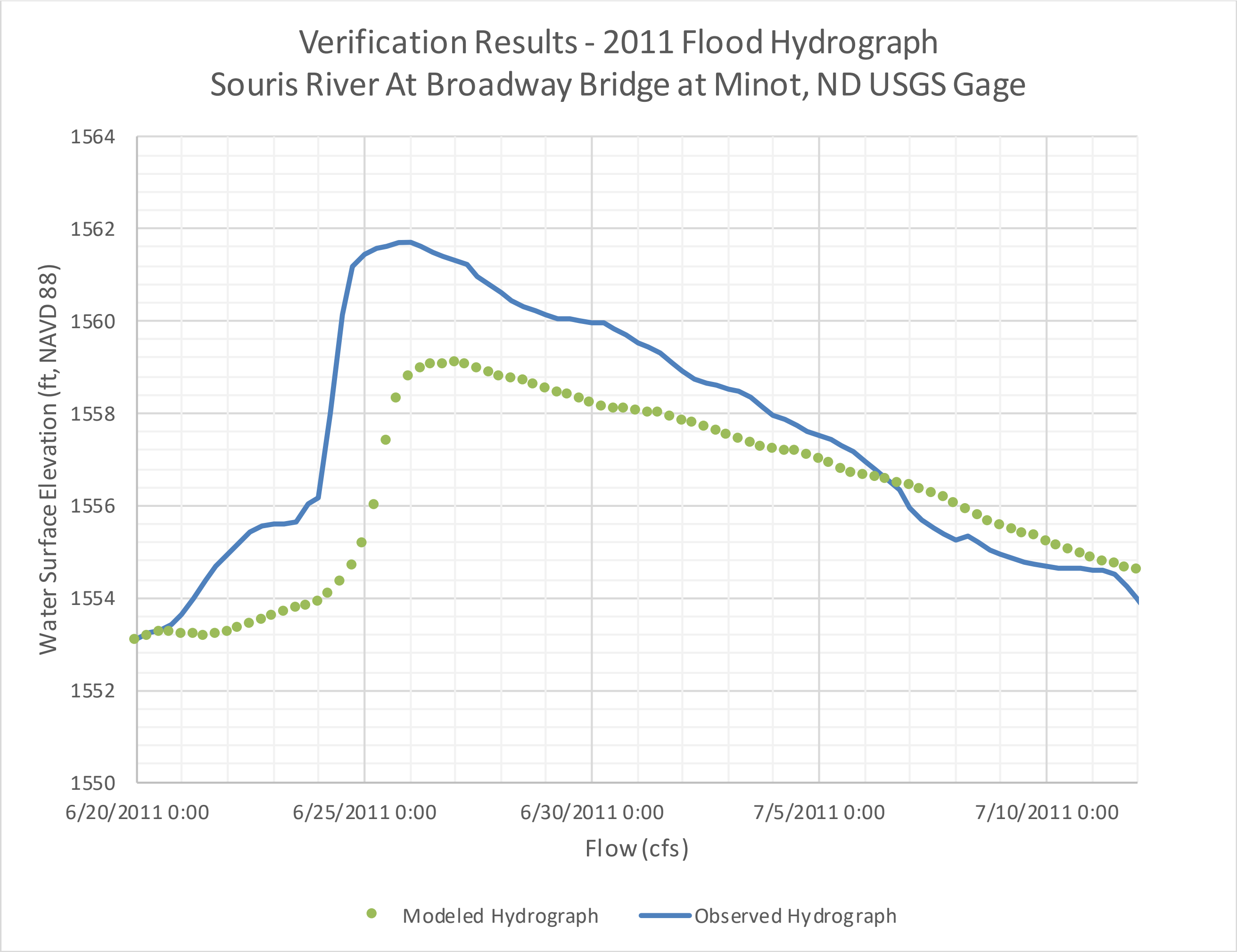

Figure 8-19. Verification - 2011 Flood Souris River At Minot Broadway (USGS 05117600)

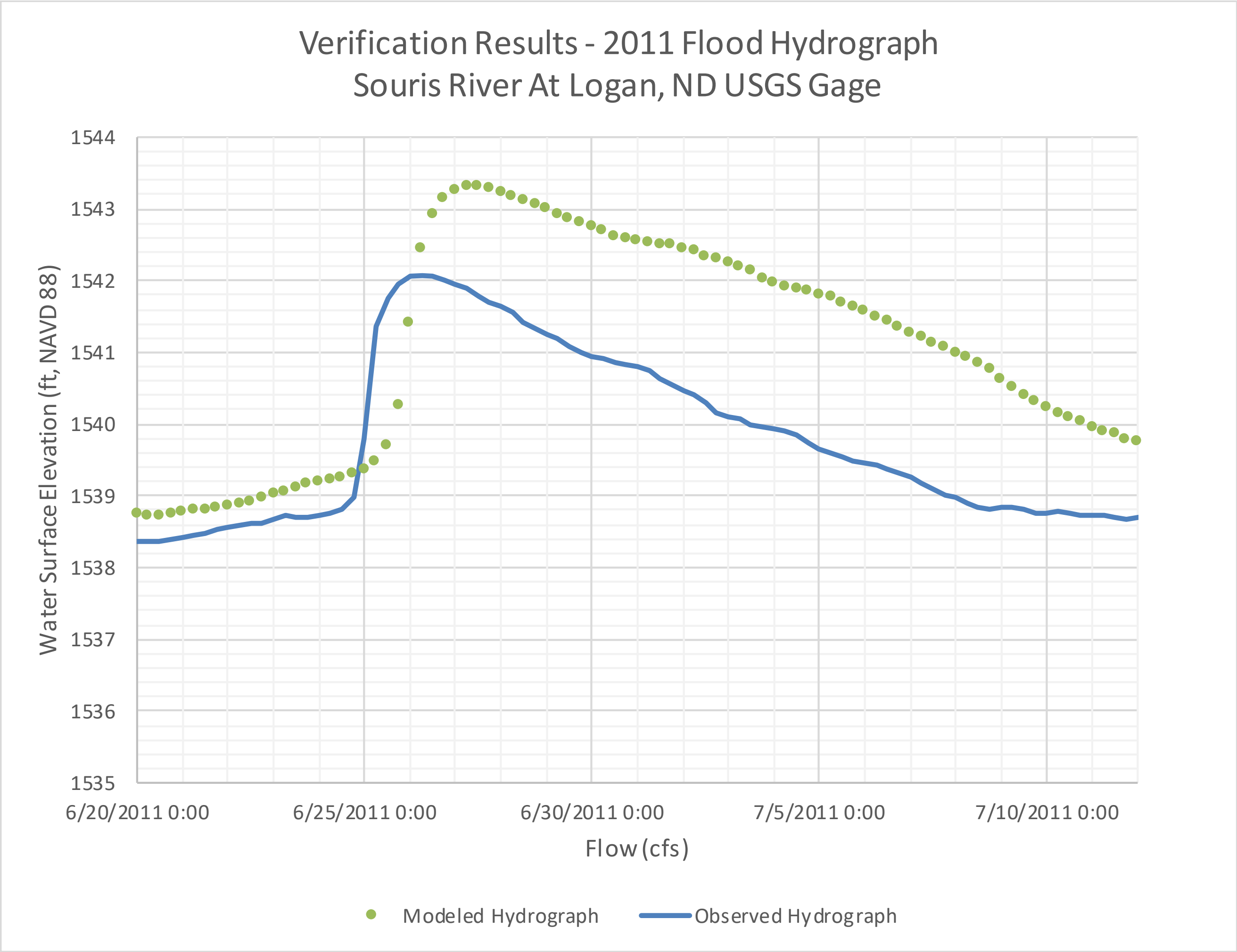

Figure 8-20. Verification - 2011 Flood Souris River At Logan (USGS 480911101090200)

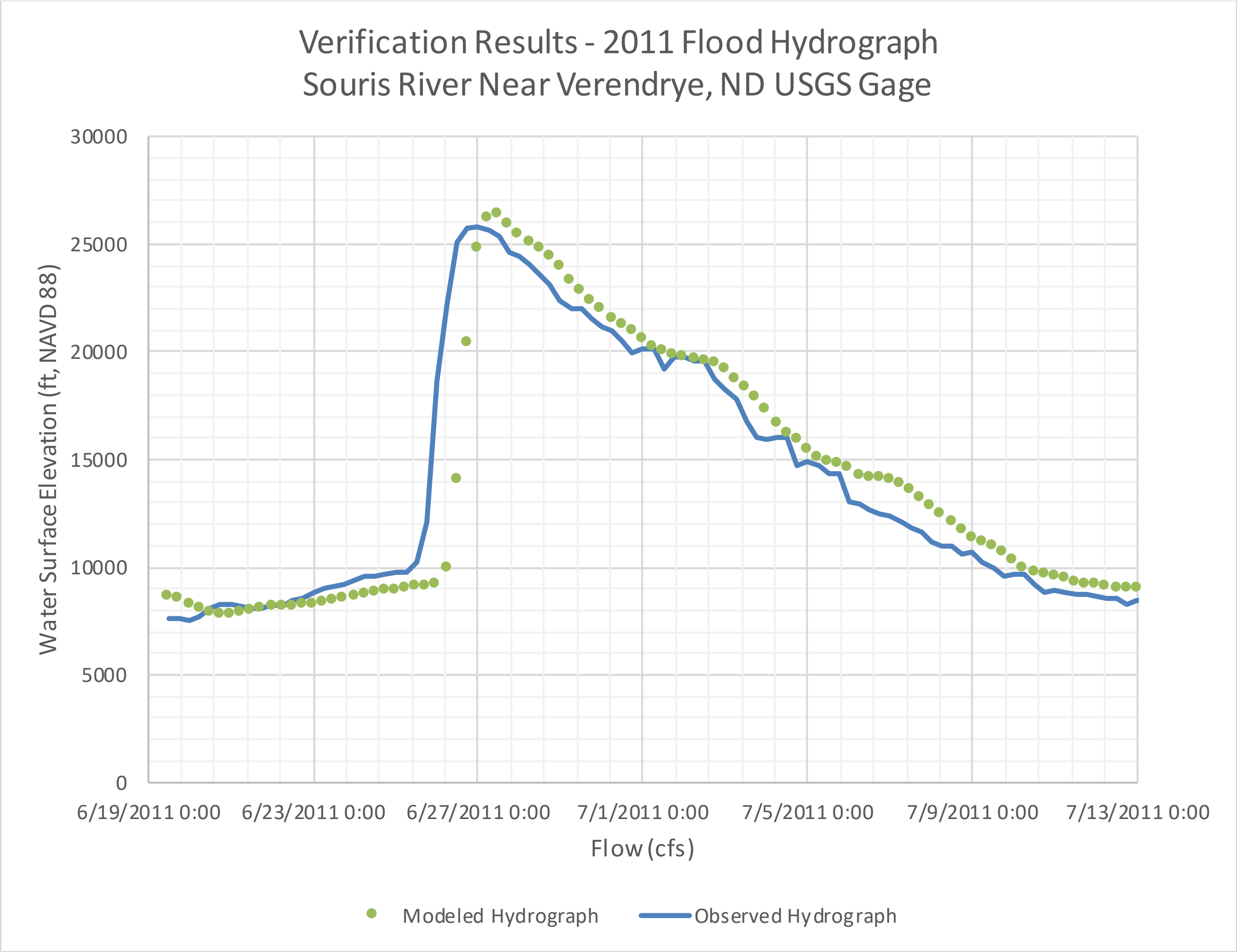

Figure 8-21. Verification - 2011 Flood Hydrograph Souris River Near Verendrye (USGS 05120000)

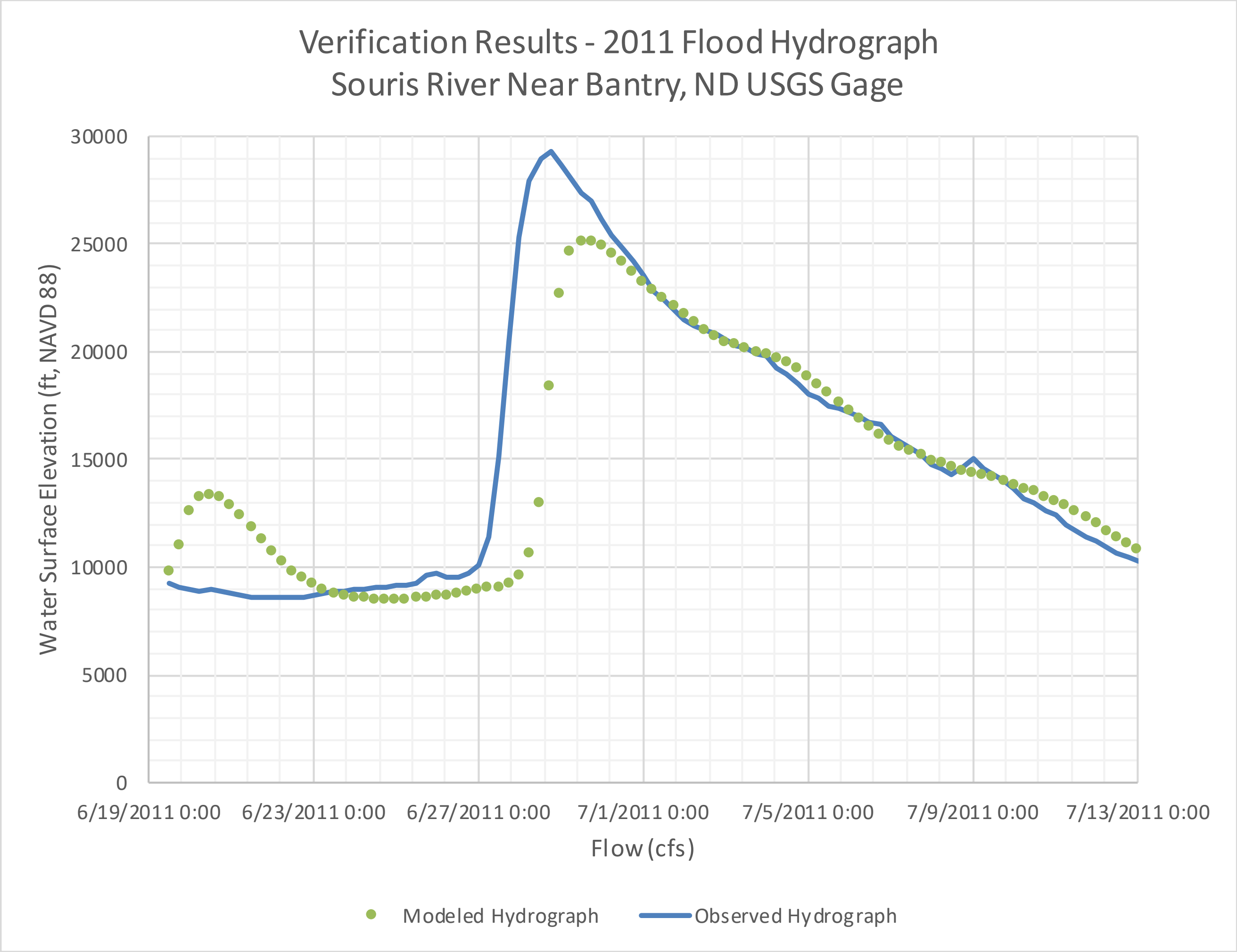

Figure 8-22. Verification - 2011 Flood Hydrograph Souris River Near Bantry (USGS 05122000)

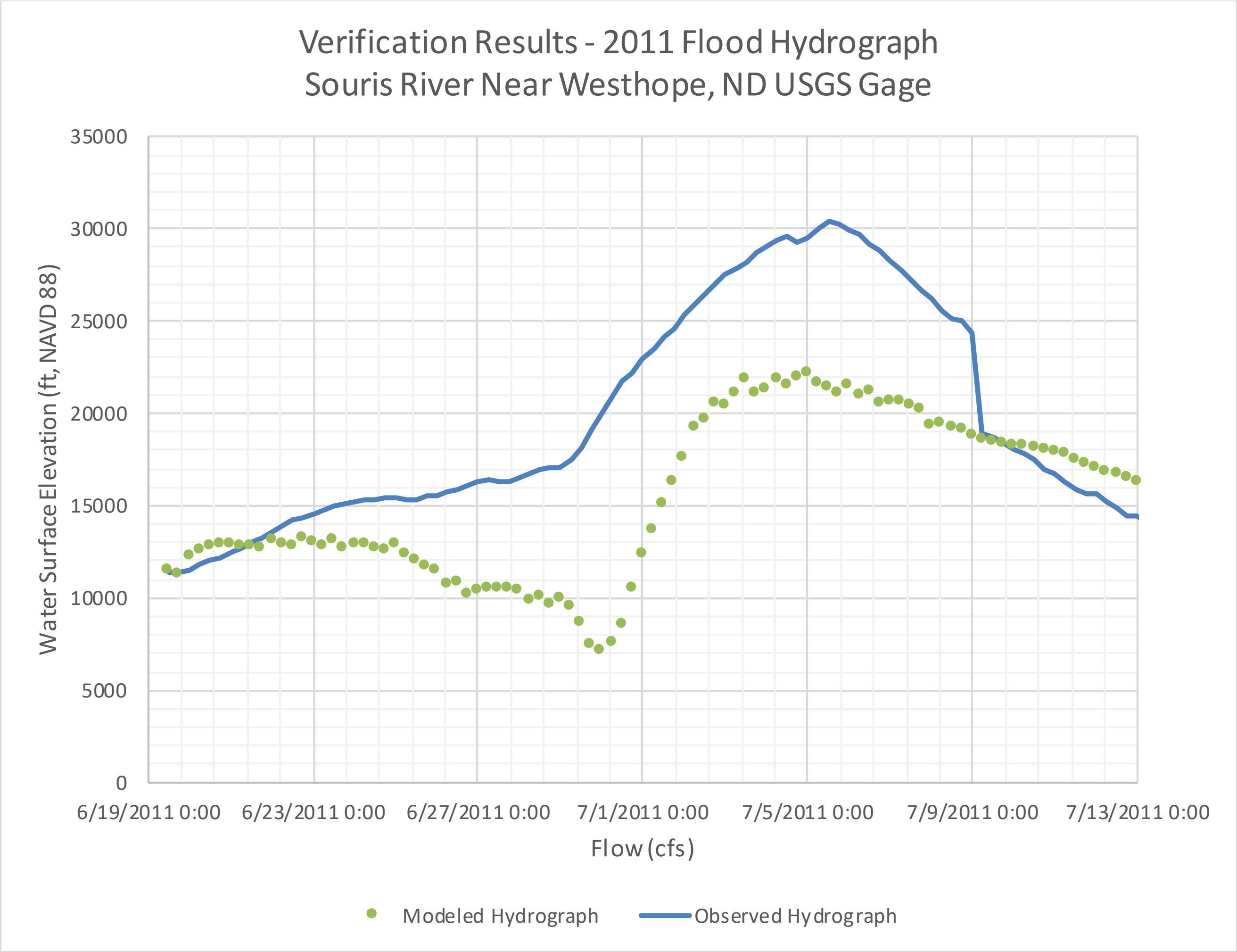

Figure 8-23. Verification - 2011 Flood Hydrograph Souris River Near Westhope (USGS 05124000)

8.7 RECOMMENDATIONS FOR HYDRAULIC ENGINEERING CENTER-RIVER ANALYSIS SYSTEM MODEL USE

Based on the calibration and verification results, the HEC-RAS model for the [Watershed] Basin can be used on a regular basis for water management forecasting purposes. A wide range of flows were run and the model proved to be stable for both low and high flows. Inundation maps can also be generated from the HEC-RAS model during times of high water. Further calibration of the HEC-RAS model is recommended before using the model for other purposes such as design of flood risk management projects.

8.8 UNRESOLVED ISSUES WITH HYDROLOGIC ENGINEERING CENTER-RIVER ANALYSIS SYSTEM MODEL

There are areas where the district can continue to improve the HEC-RAS model. The flowing areas are areas where further model development would be required to increase model results accuracy.

The reach of the model downstream of Verendrye, specifically in the area of the Eaton Irrigation District would benefit from obtaining better data in terms of channel geometry data and series of discharge measurements at a range of flows in reaches where no stream gages exist. The location, dimensions and inverts of all culverts and gates through lateral structures (levees, dikes, roads, and high ground) should be identified and included in the model. Better knowledge of the operating procedures for the hydraulic structures in the J. Clark Salyer National Wildlife Refuge between the Near Bantry and Near Westhope gages would be helpful for calibrating the model further and improving the routing of flows through this area so that the modeled hydrographs better reflect the observed hydrographs.

In the Saskatchewan reach of the model the need for a series of discharge measurements at a range of flows (including a water surface elevation at the same time) is important to calibration especially since there are over 130 river miles without streamflow data. There were some channel surveys done in Saskatchewan near Estevan and Roche Percee in 2012 and 2018 but, the majority of the channel between Roche Percee and Sherwood was taken from older data, some of which was from 1940 surveys. If there was channel scouring during the 2011 flood event, channel survey collected before then would reflect a higher water surface profile in the HEC-RAS model. The location, dimensions and inverts of all culverts and gates through lateral structures (levees, dikes, roads, and high ground) should be identified and included in the model. It is likely that many of these are missing from the model especially in Saskatchewan.

The HEC-RAS model includes 80 river miles of the Des Lacs River, which enters the Souris River between Lake Darling Dam and the City of Minot. Calibration of the Des Lacs River reach of the model was not performed because another project is starting in July 2020 focused on the Des Lacs River Inundation Mapping through another program. All of the model geometry edits and calibration will be performed in detail by that project and will need to be incorporated into the CWMS model upon project completion.

While the remainder of the model calibrated reasonably well to the fictitious flows, additional calibration should be conducted with the use of real-time HEC-ResSim and HEC-HMS flows. The fictitious flows provided a wide spectrum of flows to calibrate to, but they did not take into consideration that the local inflows might shift cause shifts in the rating curves. Calibrating to real time data would provide a more accurate calibration.

PAGES 118-129 have been removed from this version of the report as they do not pertain to the Souris River Watershed Corps Water Management System HEC-RAS model development.

References and Resources

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List of Acronyms and Abbreviations

CAVI	Control and Visualization Interface
cfs	cubic feet per second
CIKR	Critical Infrastructure and Key Resources
CIPR	Critical Infrastructure Protection and Resilience
COP	Community of Practice
CWMS	Corps Water Management System
DEM	digital elevation model
DSS	Data Storage System
EM	Engineering Manual
ENR	Engineering News Record
FEMA	Federal Emergency Management Agency
FIA	Flood Impact Analysis
GeoHMS	Geospatial Hydrologic Model System Extension
GeoRAS	Geospatial River Analysis System Extension
GIS	Geographic Information Systems
GMT	Greenwich Mean Time
GOES	Geostationary Operational Environmental Satellites
HAZUS-MH	Hazards, U.S. Multi-Hazards
HEC	Hydrologic Engineering Center
DSSVue	Data Storage System Visual Utility Engineer
HEC-FIA	Hydrologic Engineering Center-Flood Impact Analysis
HEC-GeoRAS	Hydrologic Engineering Center-Geospatial River Analysis System Extension
HEC-GeoHMS	Hydrologic Engineering Center-Geospatial Hydrologic Model System Extension
HEC-HMS	Hydrologic Engineering Center-Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center-River Analysis System
HEC-ResSim	Hydrologic Engineering Center-Reservoir System Simulation
HEMP	Hydrologic Engineering Management Plan
HMS	Hydrologic Modeling System

IRT	Impact Response Table
LiDAR	Light (Laser) Detection and Range
LOC	local
MFP	Meteorological Forecast Processor
MMC	Modeling, Mapping and Consequence
NAD 83	North American Datum of 1983
NAVD 88	North American Vertical Datum of 1988
NASS	National Agricultural Statistics Service
NCDC	National Climatic Data Center
NED	National Elevation Dataset
NGVD 29	National Geodetic Vertical Datum of 1929
NID	National Inventory of Dams
NLD	National Levee Database
NMAS	National Map Accuracy Standards
NRCS	Natural Resources Conservation Service
NWS	National Weather Service
QPF	Quantitative Precipitation Forecast
RAS	River Analysis System
ResSim	Reservoir System Simulation
SCS	Soil Conservation Service
SHG	Standard Hydrologic Grid
SI	structure inventory
SSURGO	Soil Survey Geographic Database
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WCM	water control manual