

Provision of Hydrodynamic Modelling Study for the Assiniboine River from Shellmouth Dam to Brandon

Manitoba Transportation and Infrastructure

60717754

January 2025

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January 8, 2025

Project #
60717754

Subject: Provision of Hydrodynamic Modelling Study for the Assiniboine River from Shellmouth Dam to Brandon

Dear Dr. Assefa,

We are pleased to submit the final Provision of Hydrodynamic Modelling Study for the Assiniboine River from Shellmouth Dam to Brandon

We thank you for the opportunity to work on this very challenging assignment.

Sincerely,
AECOM Canada ULC



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Encl.

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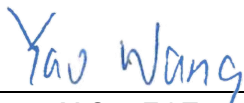
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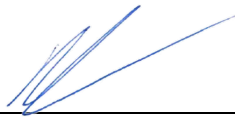
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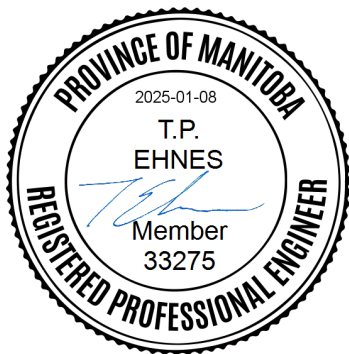


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Revision History

Rev #	Revision Date	Revised By:	Revision Description
0	September 2024	Y. Wang/M. Gaudreau	DRAFT
1	November 2024	Y. Wang/M. Gaudreau	DRAFT REV. 1
3	January 2025	Y. Wang/M. Gaudreau	FINAL

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1. Introduction

AECOM has been contracted by Manitoba Transportation and Infrastructure (MTI) to complete the hydrodynamic modelling study for the Assiniboine River from Shellmouth Dam to Brandon, which includes development of a two-dimensional (2D) model representing various flood scenarios. This study was co-funded by the Government of Manitoba and the Government of Canada through the federal Flood Hazard Identification and Mapping Program.

The Assiniboine River is a major watercourse located in western Manitoba which extends from eastern Saskatchewan and flows eastwards across southern Manitoba, passing through major urban centres such as Brandon, Portage la Prairie, and Winnipeg. The Assiniboine River has received significant attention and regulation in an effort to protect the population centre of Manitoba. The first line of regulation within the Manitoba border is Shellmouth Dam. Shellmouth Dam manages storage within the Lake of the Prairies, a large reservoir used to mitigate peak flows along the Assiniboine River. Almost immediately downstream of Shellmouth Dam, the Assiniboine River is joined by the Qu'Appelle River, another regulated river with inflow from Qu'Appelle Dam and Lake Diefenbaker. Beyond this point, the Assiniboine River collects local tributary flows from along the reach of Shellmouth Dam to Brandon. The most significant additional tributary comes from the Little Saskatchewan River. Other notable tributaries include the Oak River, Gopher Creek, and Birdtail Creek.

The City of Brandon is exposed to significant potential flooding as a result of the Assiniboine River flows. The City of Brandon has constructed a series of dikes along the river to protect the community. The 2011 flood prompted the city to increase the elevation of the flood protection dikes with assistance from the Province of Manitoba. There are many other small communities along or adjacent to the Assiniboine River, including Deerboine Colony, Sioux Valley, Griswold, Oak Lake, Virden, Miniota, Birdtail Sioux, St. Lazare, and Shellmouth.

A significant amount of hydrotechnical modelling has been performed along the Assiniboine River, with the focus on the lower Assiniboine River from Brandon to the City of Winnipeg. It is within this reach that overland flooding could extend well beyond the natural Assiniboine River Valley and has the potential to spread across the flat gradient of the Red River Valley, causing a vast amount of residential and agricultural damage. The proposed domain from Shellmouth Dam to Brandon is opposite in the fact that the river is largely contained within the natural floodplain as the river flows through the Manitoba Escarpment.

The Assiniboine River watershed and proposed model domain is shown in Figure 1.1 on the following page. The model domain will include the Assiniboine River from Shellmouth Dam through to the eastern rail bridge downstream of Brandon. This will allow the model to properly represent the hydraulic conditions through Brandon and allow for a flood map within Brandon to be created. A small segment of the Qu'Appelle River will be included within the model domain to allow for the backwater affect of the Assiniboine River to be reflected on the short reach of the Qu'Appelle River to the Manitoba and Saskatchewan border. The catchment area of the Assiniboine River is shown in light blue in Figure 1.1. This figure also demonstrates the scale of the Qu'Appelle River within the darker blue catchment. An overview map showing the model boundary, hydrometric gauge locations, main settlements, and modelled bridges is shown in Figure 1.2.

AECOM developed a 2D HEC-RAS model of the river and simulated both historic and predicted frequency flows to establish the estimated extent of flooding. This model was calibrated to the 1995, 2011, and 2017 events and verified against the 1976, 2005, and 2014 events. Six (6) Assiniboine River dominant frequency flow events from 1 in 20-year (5%) up to 1 in 500-year (0.2%) frequency and one (1) Qu'Appelle River dominant 200-year (0.5%) frequency flow event were simulated, and 1 in 200-year (0.5%) frequency event flood maps under the Assiniboine River and Qu'Appelle River dominant conditions were produced.

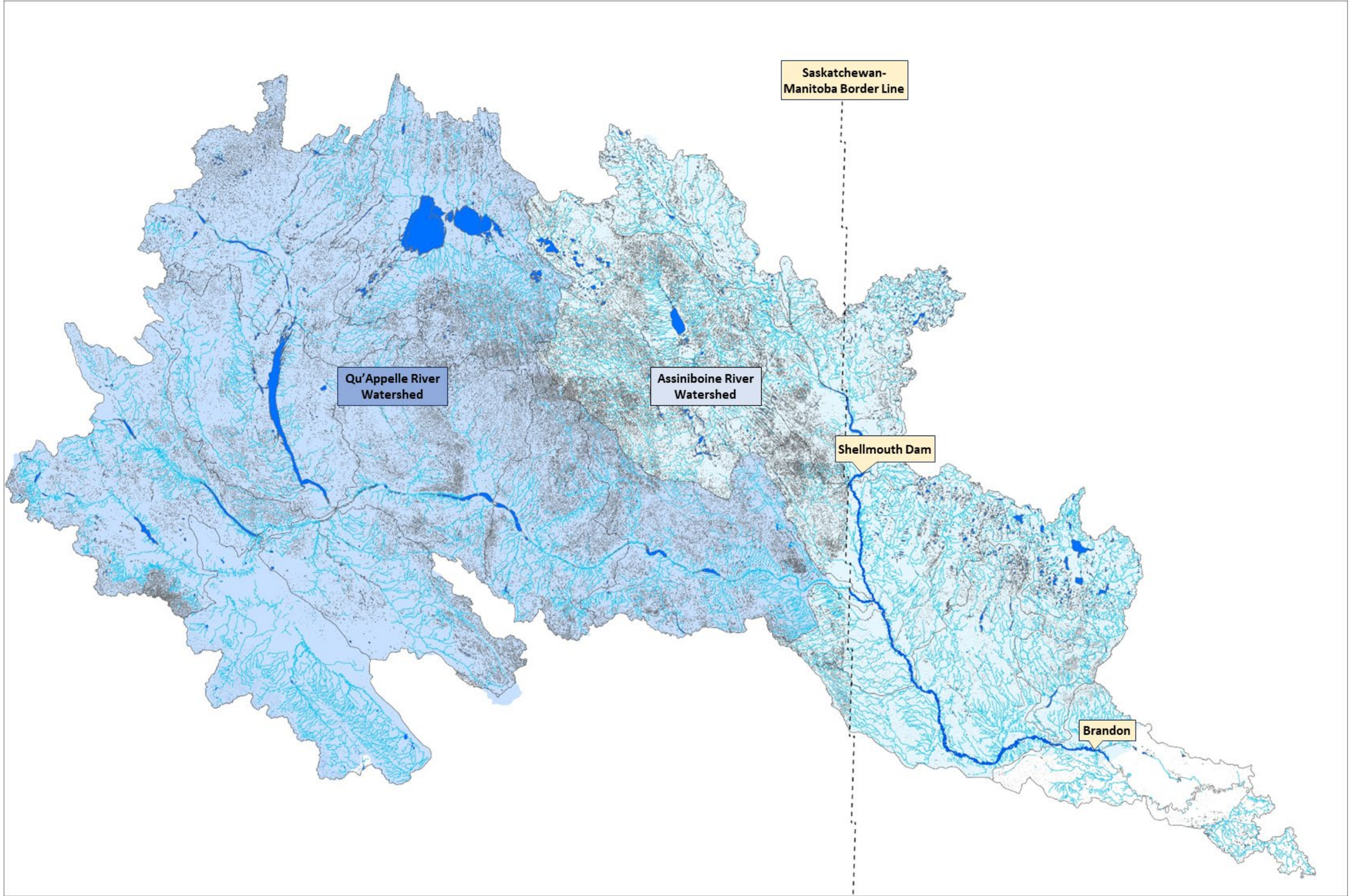


Figure 1.1 - Catchment of the Assiniboine River



Figure 1.2 – Overview of the Assiniboine River Model

2. Hydraulic Model Development

2.1 2D Model Domain

A two-dimensional (2D) model domain was established within HEC-RAS version 6.4. The 2D model domain is based on data from four (4) sources, as shown in Table 2.1.

The Manitoba Land Initiative (MLI) LiDAR data covers the Assiniboine River from Shellmouth Dam to downstream of the City of Brandon, the Qu'Appelle River from eastern Saskatchewan to St. Lazare, and Birdtail Creek. This data was captured within a 1.5 km buffer of the Assiniboine River in May 2007 and re-captured with a 175 m buffer of the river in October 2008.

The LiDAR captured by Aquatics ESI covers the Assiniboine River from Shellmouth Dam to downstream of the City of Brandon and the Qu'Appelle River from eastern Saskatchewan to St. Lazare. This data was captured in 2023 with a 130 m buffer of both rivers. The digital elevation model (DEM) was used as provided by MTI.

The Aquatics ESI bathymetry data covers the Assiniboine River from Shellmouth Dam to downstream of the City of Brandon and the Qu'Appelle River from eastern Saskatchewan to St. Lazare. This data was captured in 2023 and represents full coverage of the river bottom within the bank width.

The City of Brandon LiDAR data covers the City of Brandon area. This data was captured in 2022 during a period of minor flooding. As a result, low lying areas within the floodplain did not represent the natural ground.

Table 2.1 - Four Sources of Data that Combined 2D Domain.

	MLI LiDAR	Aquatics ESI LiDAR	Aquatics ESI Bathymetry	City of Brandon LiDAR
Date	May 2007 / Oct 2008	2023	2023	2022
Width	1.5 km / 175 m buffer	130 m buffer	Bank width	-
Resolution	1 m grid cell	0.25 - 1.00 m grid cell	0.25 m grid cell	1 m grid cell
Horizontal Coordinate System	NAD83	NAD83	NAD83	NAD83
Vertical Coordinate System	CGVD28	CGVD28	CGVD28	CGVD28
Coverage	Assiniboine River Qu'Appelle River Birdtail Creek	Assiniboine River Qu'Appelle River	Assiniboine River Qu'Appelle River	City of Brandon Area

All four (4) data sources were combined into one (1) seamless raster with 1 m grid cells across all areas. The Birdtail Creek section was excluded as it is outside of scope. Elevations matched well at the boundaries of the four (4) data sources, as shown in Figure 2.1. Any holes remaining in the oxbows within the model were filled using the corresponding nearby depth in the LiDAR raster.

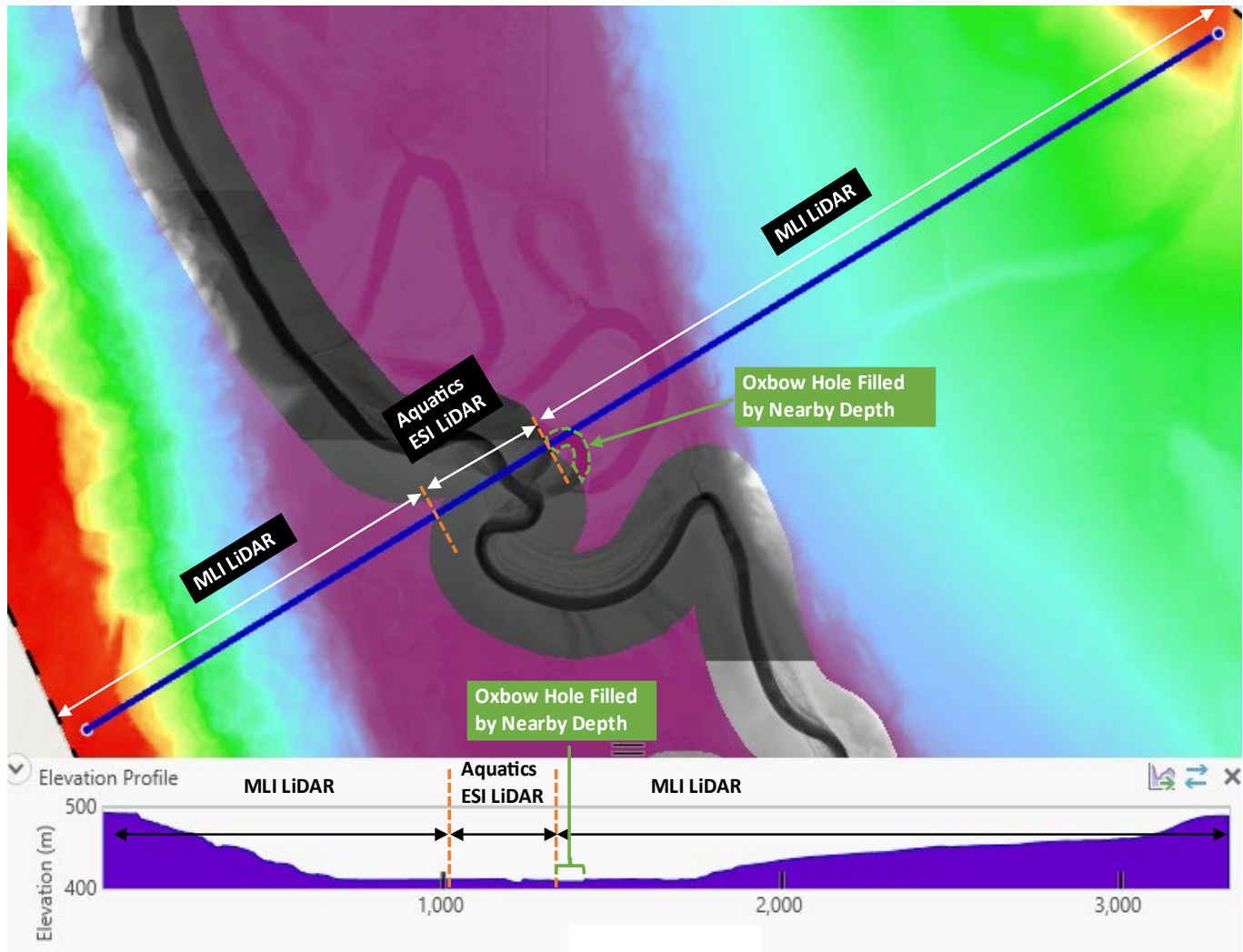


Figure 2.1 - Elevations Matched Well at Different Source Boundaries

The City of Brandon LiDAR data, which shows the bare earth surface outside of the floodplain, was used to represent updated road and dike elevations compared to the MLI LiDAR data. Since this data within the floodplain is affected by minor flooding at the time of the survey, these areas continue to use the MLI and Aquatics ESI LiDAR data. Figure 2.2 shows the data source boundaries in the City of Brandon area.

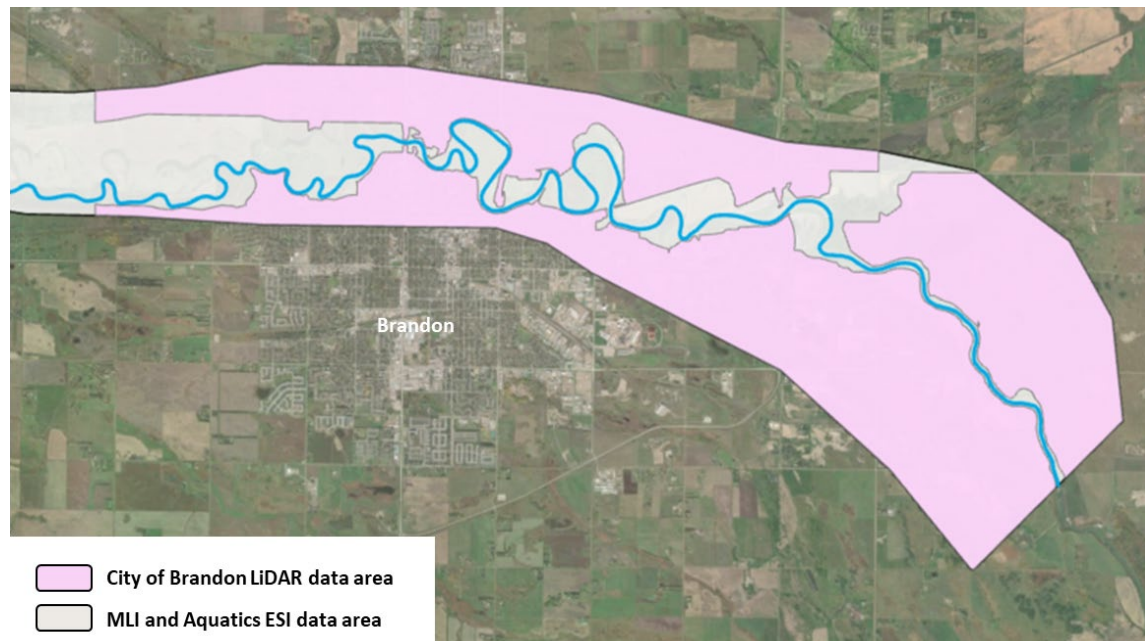


Figure 2.2 - Data Source Boundaries in the City of Brandon Area

Three (3) closure points were identified at the north and south of the Brandon dike. The City of Brandon confirmed they will take action by constructing the closure points during flood events. Therefore, for better flood mapping purposes, the DEM at these closure points were reconstructed to align with the adjacent existing dikes.



Figure 2.3 – Closure Points in Brandon

Slight adjustments were made at PTH 16 to align the old MLI LiDAR raster with the new Aquatics ESI overbank LiDAR raster. Bridges over small tributaries were opened by interpolating the upstream and downstream depths to let the river flow through. An overflow weir has been added west of the PTH 1A on the Assiniboine River near Brandon to better represent the terrain, as shown in Figure 2.4.

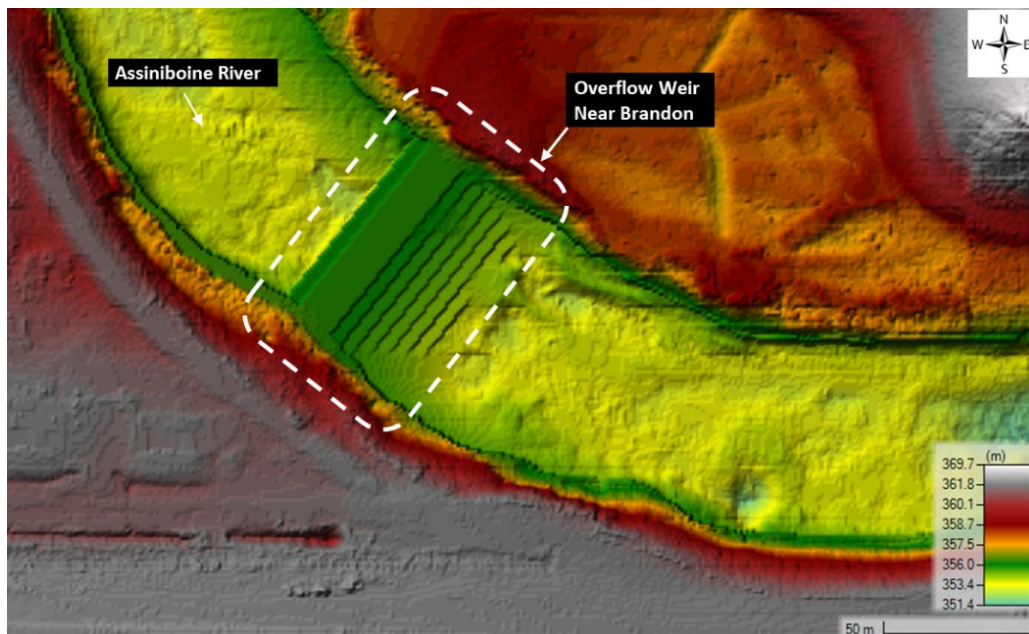


Figure 2.4 - Overflow Weir Near Brandon

A comparative assessment was conducted to compare the elevation of the 2007 Upper Assiniboine River West LiDAR with that of the 2017 Souris River Basin and Arrow-Oak Watershed captures. The result did not show any major changes in elevation across the model domain.

Since no major changes in elevation were observed in the Upper Assiniboine River watershed in 10 years' time between 2007 and 2017, the following technical remarks that are key to the validity of the hydrotechnical/flood mapping study were made:

- No major topographical elevation changes would be expected to happen in the seven (7) years' time between 2017 and 2024.
- Given the fact that the bathymetric data plus 100 m offshore LiDAR were captured in 2022, any changes that matter for the hydrodynamic assessment have already been accounted for in the current study.
- The hydrologic analyses about flows from the watershed were completed primarily based on recorded data, so any natural changes in the watershed other than topographical changes and if any, were reflected in the following recorded flow data.
 - Gauge 05ME007 (Smith Creek near Marchwell) with data for years 1976, 1995, 2005, 2011, 2014, and 2017.
 - Gauge 05ME005 (Conjuring Creek near Russell) with data for years 1976, 1995, 2005, 2011, 2014, and 2017.
 - Gauge 05ME003 (Birdtail Creek near Birtle) with data for years 1976, 1995, 2005, 2011, 2014, and 2017.
 - Gauge 05MG001 (Arrow River near Arrow River) with data for years 1976, 1995, 2005, 2011, 2014, and 2017.

- Gauge 05MG003 (Gopher Creek near Virden) with data for years 1976, 1995, 2005, 2011, 2014, and 2017.
- Gauge 05MG004 (Oak River near Rivers) with data for years 1976, 1995, 2005, 2011, 2014, and 2017.
- Gauge 05MF018 (Little Saskatchewan River near Rivers) with data for years 1976, 1995, 2014, and 2017.
- Gauge 05MH011 (Willow Creek near Chater) with data for the year 1976.
- Gauge 05ME009 (Scissor Creek near McAuley) with data for years 1995, 2005, 2011, 2014, and 2017.
- Gauge 05ME010 (Silver Creek near Binscarth) with data for years 2011, 2014, and 2017.
- Gauge 05MG015 (Baileys Creek near Oak River) with data for years 2014 and 2017.

2.2 Boundary Conditions

The model boundary was established based on the MLI LiDAR data extent, capturing the full floodplain of the Assiniboine River from Shellmouth Dam to downstream of the City of Brandon and the Qu'Appelle River from the Saskatchewan-Manitoba border to St. Lazare, as shown in Figure 2.5.

The upstream inflow boundary of the Assiniboine River was located at Shellmouth Dam and the upstream inflow boundary of the Qu'Appelle River was located at the Saskatchewan-Manitoba border. For the other thirty-one (31) tributaries, flow input locations were snapped to the intersection of creeks/rivers with the model boundary. The development of inflow hydrographs is presented in Section 3. The energy slopes for distributing flow along boundary condition lines are determined by the terrain slopes at boundary locations.

The downstream boundary of the model is located downstream of the City of Brandon, which covers the Eastern Rail Bridge located approximately 7 km east of PTH 110. The downstream boundary was set to a friction slope of 0.0007 m/m, matching the natural slope of the river at this location.



Figure 2.5 - Model Boundary

2.3 Mesh Generation

A gridded mesh with fifty meters by fifty meters (50 m x 50 m) spacing was generated within the 2D model domain, as shown in Figure 2.6.

An immediate overbank refinement region was enforced within the 2D flow area, changing the cell point spacing to twenty-five meters by twenty-five meters (25 m x 25 m), to control the transition from the riverbank to larger cells. The overbank refinement region is an envelope that captures the primary overbank region between meanders of the river, created by buffering the riverbank polygon out by 1000 m and then back in 950 m. The refinement region was expanded to nearby roads, dikes, or places with large terrain changes in key areas, such as the communities of St. Lazare and Brandon.

River centerlines were enforced along the Assiniboine River and the Qu'Appelle River to improve the mesh alignment with the flow. The river centerlines were added with three (3) repeat points and ten meters by ten meters (10 m x 10 m) cell point spacing. River centerlines were broken where bridges or culverts cross rivers to ensure mesh alignment with the bridge structures.

Breaklines are used to align cell faces to certain features in the geometry. Breaklines were enforced along major roadways, railways, and dikes, especially for areas close to the Assiniboine River and areas with large terrain changes. One (1) repeat point and ten meters by ten meters (10 m x 10 m) cell point spacing was enforced. Not all roads were set as breaklines. For roads that do not appear to be affected by floods, they were not added.

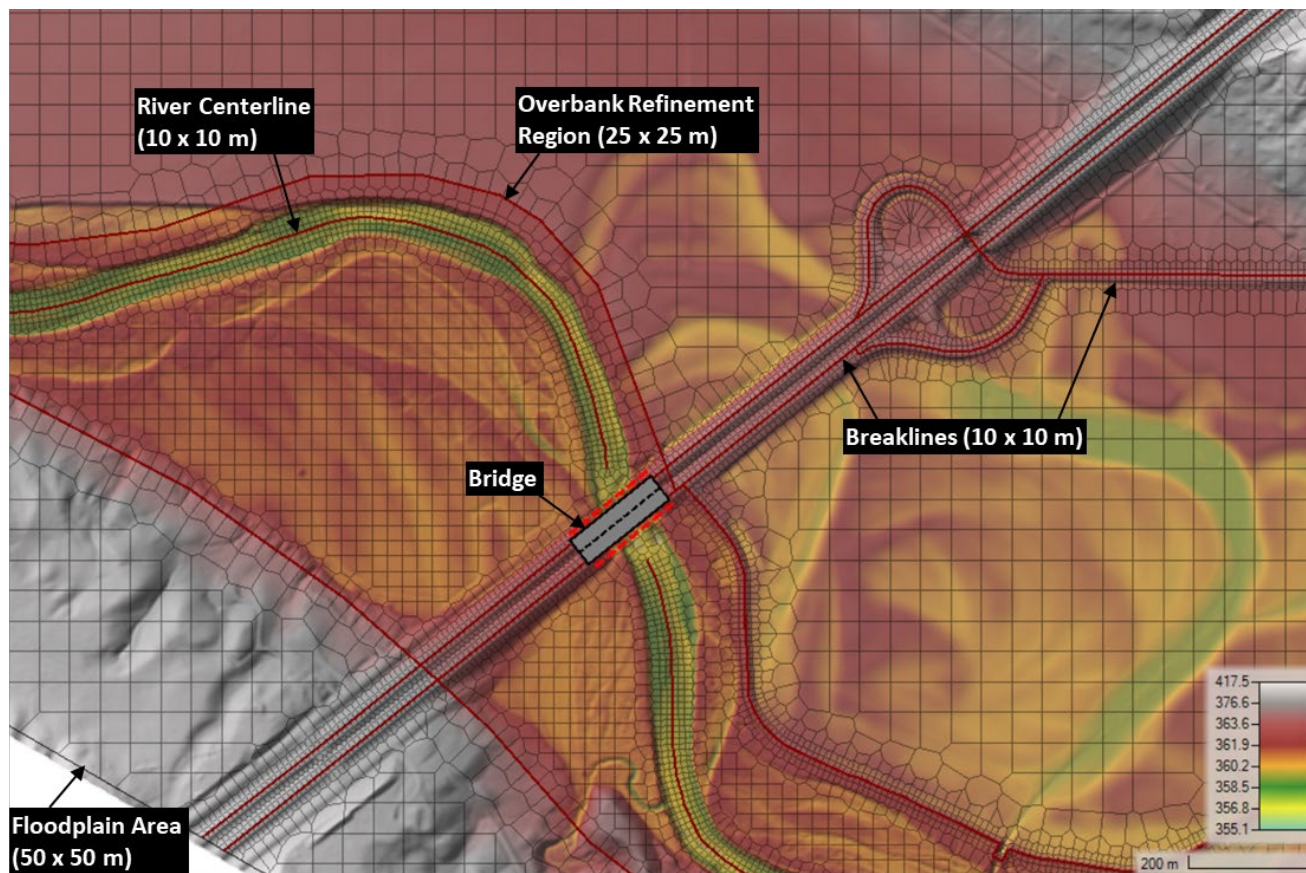


Figure 2.6 - Model Boundary, Refinement Region, Breaklines and Bridge

2.4 Hydraulic Structures

Twenty-seven (27) structures have been added to the model, including:

- Seventeen (17) bridges on provincial roads.
- Four (4) bridges on municipal roads.
- Five (5) railway bridges.
- One (1) culvert crossing on a provincial road.

The information of seventeen (17) provincial road bridges, one (1) municipal road bridge on Road 78 N, and one (1) culvert on a provincial road was obtained from MTI. AECOM contacted the municipalities for information regarding the three (3) additional municipal road bridges; however, the municipalities did not have additional information to provide. Three (3) through truss bridges on municipal Road 121 N, Montagne a la Bosse Road, and Harrison Bridge Road, along with five (5) through truss railway bridges on CP Bredenbury, CN Rivers, CP Carberry, and CN Carberry subdivisions, were added to the model based on information from Google Maps.

Figure 2.7 shows a provincial road bridge 2844 in floodplain area and its cross-section profile.

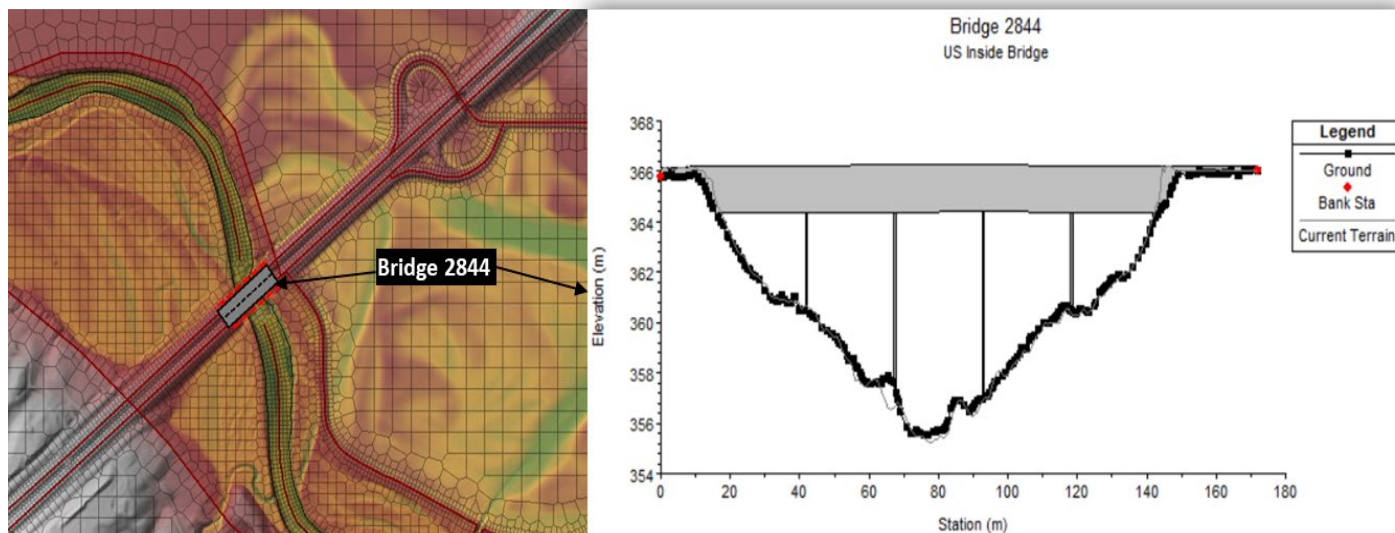


Figure 2.7 - Bridge 2844 in Floodplain Area and its Cross-section Profile

2.5 Initial Conditions

Low flow simulations were conducted to provide hot start initial condition files for each of the flood simulations, as shown in Table 2.2. The initial hot start files were developed to simulate various steady state flows using a fixed time step of 20 seconds. The flow rate in the hot start files were set to the first ordinate of the inflow hydrographs used for each individual model. The use of a hot start file reduces the initial instability associated with initial wetting of flow cells.

Table 2.2 - Flow Rate of Hot Start Files for Calibration and Verification Events

	1976 Event Hot Start File Flow Rate (m ³ /s)	1995 Event Hot Start File Flow Rate (m ³ /s)	2005 Event Hot Start File Flow Rate (m ³ /s)	2011 Event Hot Start File Flow Rate (m ³ /s)	2014 Event Hot Start File Flow Rate (m ³ /s)	2017 Event Hot Start File Flow Rate (m ³ /s)
Shellmouth Reservoir	6.970	10.744	10.826	11.400	2.821	6.959
Qu'Appelle River	6.680	22.200	4.240	14.200	6.260	9.700
Little Saskatchewan	2.288	1.933	0.002	0.033	1.379	3.009

3. Calibration and Verification

3.1 Hydraulic Calibration

The Assiniboine River hydraulic model was calibrated to reproduce the published rating curves at the three (3) compliance locations. Calibration was accomplished by modifying the Manning's roughness assigned to each land use category. It was found through the calibration process that minor adjustments to each individual land use category were not beneficial. Rather, broad categories were used to group similar land use types together and minimize the spatial variability of Manning's roughness. The three (3) compliance locations are shown in Table 3.1.

Table 3.1 - Compliance Locations and Used Rating Curve for Comparison

Compliance Location	Gauge Number	Used Rating Curve for Comparison
Assiniboine River near Russell	05ME001	2017 rating curve
Assiniboine River near Miniota	05ME006	2017 rating curve
Assiniboine River at Brandon	05MH001	2023 rating curve

The Manning's roughness assigned to each of the land use categories is as follows:

Table 3.2 - Manning's Roughness by Land Use Category

Category ID	Category Name	Manning's n
1	Coniferous Forest	0.100
5	Deciduous Forest	
6	Mixed Forest	
8	Shrubland	0.060
10	Grassland	
14	Wetland	
15	Cropland	
16	Barren Lands	
17	Urban	
18	Water	
Override – River Channel		0.032

The category for "Water" is found within the river, within historic oxbows of the river, and other wet areas with significant depth. Considering that the land use raster is provided on a 30 m x 30 m grid, the river is not well represented by the land use category for "Water". A Manning's roughness override was established within the river channel as defined by the extend of the bathymetric survey data. The land use category for "Water" was subsequently joined with the other land use categories considering they are not hydraulically effective.

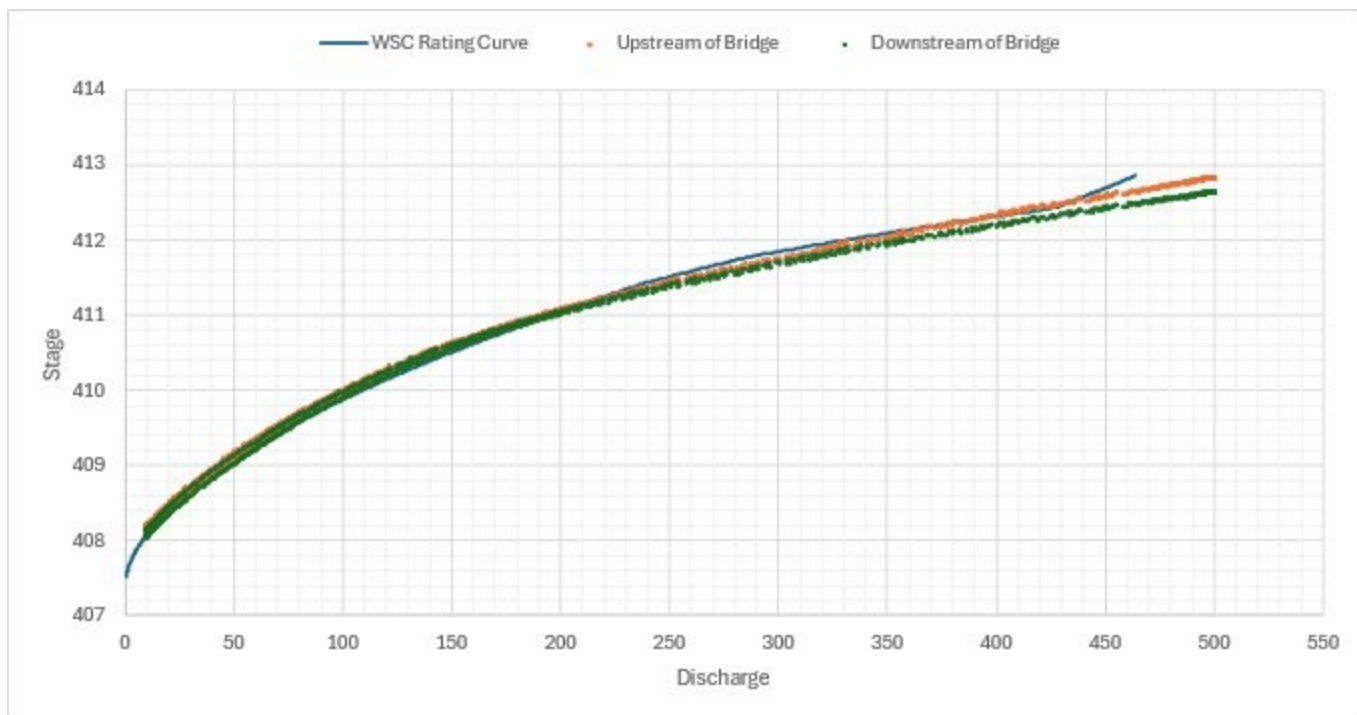


Figure 3.1 - Published and Modelled Rating Curve along the Assiniboine River near Russell (05ME001)

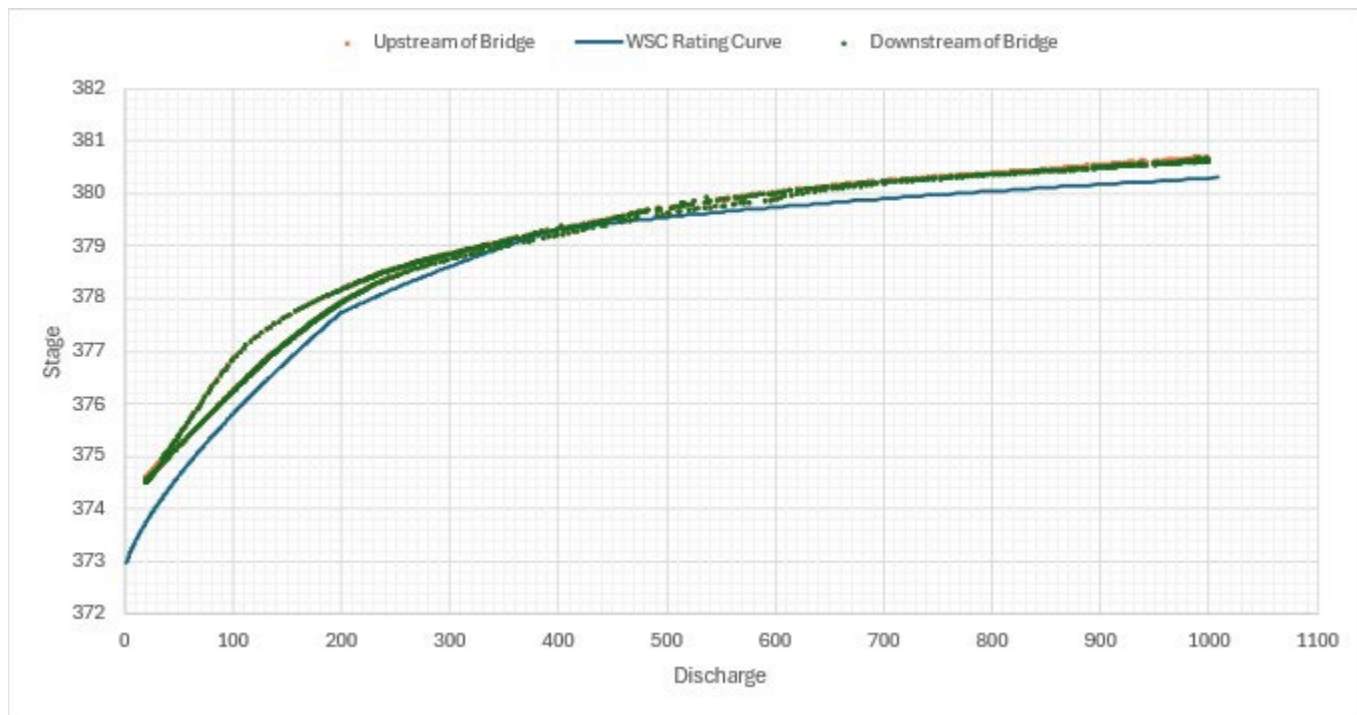


Figure 3.2 - Published and Modelled Rating Curve along the Assiniboine River near Miniota (05ME006)

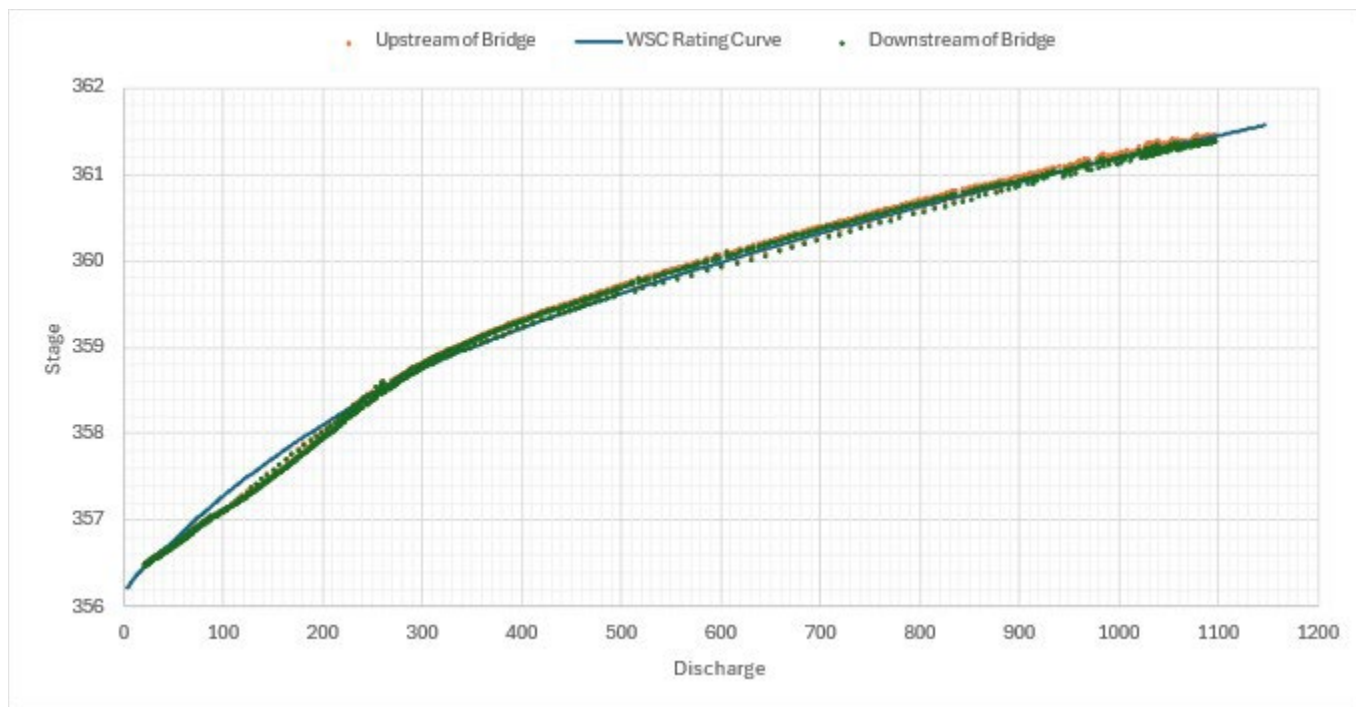


Figure 3.3 - Published and Modelled Rating Curve along the Assiniboine River at Brandon (05MH001)

The modelled rating curve at Russell and Brandon were both found to match the published rating curve particularly well. The curve at Miniota did not provide as good of a match. Low flows may be affected by changes within the river channel itself, potentially through riverbed erosion since the rating curve was developed in 2017. High flows may be affected by changes within the floodplain, such as new or modified dikes or roads. It was found that a low elevation dike downstream of Miniota was modified between 2017 and 2023, which has the potential to create a change in rating curve from 2017 to 2023. The comparison of published and modelled rating curve shows that the HEC-RAS model is hydraulically calibrated.

3.2 Development of Calibration Event Hydrographs

Each subcatchment within the Assiniboine River model requires an input hydrograph for the model to run. Not all subcatchments contain a Water Survey of Canada gauge and therefore recorded data. Further, not all Water Survey of Canada gauges are located exactly at the confluence with the Assiniboine River. AECOM used three (3) approaches to develop inflow hydrographs.

The first approach is applied to the two (2) upstream inflow catchments. These are the Shellmouth Reservoir discharge, and the Qu'Appelle River recorded flow at Welby. These two (2) inflows locations can be considered as upstream inflow boundaries. The recorded discharge from Shellmouth Reservoir was provided by MTI while the recorded discharge of the Qu'Appelle River at Welby was downloaded from the Water Survey of Canada.

The second approach is applied to the eleven (11) catchments with a Water Survey of Canada gauge somewhere within the catchment. In this approach, the recorded discharge, downloaded from the Water Survey of Canada, is scaled by area to the edge of the Assiniboine River model. The discharge is input to the model as a lateral inflow at the top of the Assiniboine River valley and allowed to naturally flow into the Assiniboine River proper.

The scaling by area uses the same Regional Method equation for estimating frequency flows and the coefficient for this area of Manitoba (0.679). Each ordinate of the recorded data is scaled by the following equation:

$$Q_{\text{inflow}} = Q_{\text{gauge}} * A_{\text{inflow}}^{0.679} / A_{\text{gauge}}^{0.679}$$

The third method is applied to all other catchments (i.e., all catchments with no recorded data). The same method described above is applied; however, the inflow hydrograph is taken from a reference catchment. The reference catchment for each catchment was initially established based on an analysis of land use characteristics, soil properties, effective drainage area, and proportion of water/wetland. Then reference catchments were adjusted for each event to better reflect the actual event. This was completed through an iterative process until AECOM was satisfied that the calibration results are adequate to proceed. The results of each calibration event are described in the following sections.

The reference catchments used for each subcatchment, for each event, are shown in Table 3.3. The available gauge locations and reference catchments for six historical events are also shown in maps in Appendix G.

Table 3.3 - Reference Catchment used for Development of Calibration Event Hydrographs

Catchment Number	Catchment Name	Used Reference					
		1976	1995	2005	2011	2014	2017
1	Shellmouth Reservoir	Shellmouth Reservoir	Shellmouth Reservoir	Shellmouth Reservoir	Shellmouth Reservoir	Shellmouth Reservoir	Shellmouth Reservoir
2	Unnamed Creek	Smith Creek	Smith Creek	Smith Creek	Smith Creek	Conjuring Creek	Smith Creek
3	Thunder Creek	Smith Creek	Smith Creek	Smith Creek	Smith Creek	Conjuring Creek	Smith Creek
4	Smith Creek	Smith Creek	Smith Creek	Smith Creek	Smith Creek	Smith Creek	Smith Creek
5	Conjuring Creek	Conjuring Creek	Conjuring Creek	Conjuring Creek	Conjuring Creek	Conjuring Creek	Conjuring Creek
6	Unnamed Creek	Smith Creek	Smith Creek	Smith Creek	Smith Creek	Smith Creek	Smith Creek
7	Silver Creek	Smith Creek	Smith Creek	Birdtail Creek	Silver Creek	Silver Creek	Silver Creek
8	Deerhorn Creek	Smith Creek	Smith Creek	Smith Creek	Smith Creek	Smith Creek	Smith Creek
9	Qu'Appelle River	Qu'Appelle River	Qu'Appelle River	Qu'Appelle River	Qu'Appelle River	Qu'Appelle River	Qu'Appelle River
10	Beaver Creek	Birdtail Creek	Gopher Creek	Gopher Creek	Gopher Creek	Birdtail Creek	Birdtail Creek
11	Snake Creek	Birdtail Creek	Smith Creek	Birdtail Creek	Smith Creek	Birdtail Creek	Birdtail Creek
12	Scissor Creek	Gopher Creek	Scissor Creek	Scissor Creek	Scissor Creek	Scissor Creek	Scissor Creek
13	Brennand Creek	Gopher Creek	Gopher Creek	Gopher Creek	Gopher Creek	Gopher Creek	Gopher Creek
14	Birdtail Creek	Birdtail Creek	Birdtail Creek	Birdtail Creek	Birdtail Creek	Birdtail Creek	Birdtail Creek
15	Minnewasta Creek	Birdtail Creek	Arrow River	Birdtail Creek	Birdtail Creek	Birdtail Creek	Birdtail Creek
16	Unnamed Creek	Birdtail Creek	Gopher Creek	Gopher Creek	Gopher Creek	Birdtail Creek	Birdtail Creek
17	Unnamed Creek	Birdtail Creek	Gopher Creek	Gopher Creek	Gopher Creek	Birdtail Creek	Birdtail Creek
18	Wythes Creek	Birdtail Creek	Gopher Creek	Gopher Creek	Gopher Creek	Birdtail Creek	Birdtail Creek
19	Niso Creek	Gopher Creek	Gopher Creek	Gopher Creek	Gopher Creek	Gopher Creek	Gopher Creek
20	Arrow Marsh Drain	Arrow River	Arrow River	Arrow River	Arrow River	Arrow River	Arrow River
21	Arrow River	Arrow River	Arrow River	Arrow River	Arrow River	Arrow River	Arrow River
22	Unnamed Creek	Arrow River	Arrow River	Arrow River	Arrow River	Arrow River	Arrow River
23	Unnamed Creek	Arrow River	Arrow River	Arrow River	Arrow River	Arrow River	Arrow River
24	Unnamed Creek	Gopher Creek	Gopher Creek	Gopher Creek	Arrow River	Arrow River	Arrow River
25	Unnamed Creek	Gopher Creek	Gopher Creek	Gopher Creek	Arrow River	Arrow River	Arrow River

Catchment Number	Catchment Name	Used Reference					
		1976	1995	2005	2011	2014	2017
26	Unnamed Creek	Gopher Creek	Gopher Creek	Gopher Creek	Arrow River	Arrow River	Arrow River
27	Gopher Creek	Gopher Creek	Gopher Creek	Gopher Creek	Gopher Creek	Gopher Creek	Gopher Creek
28	Baileys Creek	Arrow River	Arrow River	Arrow River	Arrow River	Baileys Creek	Baileys Creek
29	Hales Creek	Arrow River	Arrow River	Arrow River	Arrow River	Arrow River	Arrow River
30	Oak River	Oak River	Oak River	Oak River	Oak River	Oak River	Oak River
31	Sibbald Creek	Arrow River	Arrow River	Arrow River	Arrow River	Arrow River	Arrow River
32	Little Saskatchewan River	Little Saskatchewan River	Little Saskatchewan River	Oak River	Oak River	Little Saskatchewan River	Little Saskatchewan River
33	Willow Creek	Willow Creek	Arrow River	Arrow River	Arrow River	Arrow River	Arrow River
50	PR 549	Smith Creek	Smith Creek	Smith Creek	Smith Creek	Conjuring Creek	Smith Creek
51	d/s of Thunder Creek	Smith Creek	Smith Creek	Smith Creek	Smith Creek	Conjuring Creek	Smith Creek
52	Municipal Road	Smith Creek	Smith Creek	Smith Creek	Smith Creek	Conjuring Creek	Smith Creek
53	PTH 16	Smith Creek	Gopher Creek	Birdtail Creek	Arrow River	Birdtail Creek	Birdtail Creek
54	CPR Bredenbury	Smith Creek	Gopher Creek	Birdtail Creek	Arrow River	Birdtail Creek	Birdtail Creek
55	PR 579	Smith Creek	Gopher Creek	Birdtail Creek	Arrow River	Birdtail Creek	Birdtail Creek
56	PR 478	Smith Creek	Gopher Creek	Birdtail Creek	Arrow River	Birdtail Creek	Birdtail Creek
57	d/s of Silver Creek	Smith Creek	Gopher Creek	Birdtail Creek	Arrow River	Birdtail Creek	Birdtail Creek
58	d/s of Deerhorn Creek	Smith Creek	Gopher Creek	Birdtail Creek	Arrow River	Birdtail Creek	Birdtail Creek
59	CN Rivers - Assiniboine	Smith Creek	Gopher Creek	Gopher Creek	Arrow River	Gopher Creek	Birdtail Creek
60	CN Rivers - Qu'Appelle	Smith Creek	Gopher Creek	Gopher Creek	Arrow River	Gopher Creek	Birdtail Creek
61	Municipal Road	Smith Creek	Gopher Creek	Gopher Creek	Arrow River	Gopher Creek	Birdtail Creek
62	PTH 41	Smith Creek	Gopher Creek	Gopher Creek	Arrow River	Gopher Creek	Birdtail Creek
63	d/s of Snake Creek	Smith Creek	Gopher Creek	Gopher Creek	Arrow River	Gopher Creek	Birdtail Creek
64	d/s of Scissor Creek	Smith Creek	Gopher Creek	Gopher Creek	Arrow River	Gopher Creek	Birdtail Creek
65	d/s of Birdtail Creek	Smith Creek	Gopher Creek	Gopher Creek	Arrow River	Gopher Creek	Birdtail Creek
66	d/s of Minnewasta Creek	Smith Creek	Gopher Creek	Gopher Creek	Arrow River	Gopher Creek	Birdtail Creek
67	PTH 83	Gopher Creek	Gopher Creek	Gopher Creek	Arrow River	Gopher Creek	Birdtail Creek

Catchment Number	Catchment Name	Used Reference					
		1976	1995	2005	2011	2014	2017
67	PTH 83	Gopher Creek	Gopher Creek	Gopher Creek	Arrow River	Gopher Creek	Birdtail Creek
68	d/s of Arrow River	Gopher Creek	Gopher Creek	Gopher Creek	Arrow River	Arrow River	Arrow River
69	d/s of Unnamed Creeks	Gopher Creek	Gopher Creek	Gopher Creek	Arrow River	Arrow River	Arrow River
70	PR 259	Gopher Creek	Gopher Creek	Gopher Creek	Arrow River	Arrow River	Arrow River
71	Municipal Road	Arrow River	Arrow River	Arrow River	Arrow River	Arrow River	Arrow River
72	PR 254	Arrow River	Arrow River	Arrow River	Arrow River	Arrow River	Arrow River
73	Municipal Road	Arrow River	Arrow River	Arrow River	Arrow River	Baileys Creek	Arrow River
74	d/s of Oak River	Arrow River	Arrow River	Arrow River	Arrow River	Baileys Creek	Arrow River
75	PTH 21	Arrow River	Arrow River	Arrow River	Arrow River	Baileys Creek	Arrow River
76	PR 250	Arrow River	Arrow River	Arrow River	Arrow River	Baileys Creek	Arrow River
77	PTH 1	Arrow River	Arrow River	Arrow River	Arrow River	Baileys Creek	Arrow River
78	PTH 10	Arrow River	Arrow River	Arrow River	Arrow River	Baileys Creek	Arrow River
79	PTH 1	Arrow River	Arrow River	Arrow River	Arrow River	Baileys Creek	Arrow River
80	End of Model	Arrow River	Arrow River	Arrow River	Arrow River	Baileys Creek	Arrow River

3.3 Calibration and Verification Results

3.3.1 1976

The 1976 event is characterized by a single snowmelt-driven runoff with minimal subsequent rainfall-driven peaks. Recorded flow data is available at the following gauge locations shown in Table 3.4.

Table 3.4 - Gauge Locations - 1976

Location	Gauge Number
Smith Creek near Marchwell	05ME007
Conjuring Creek near Russell	05ME005
Birdtail Creek near Birtle	05ME003
Arrow River near Arrow River	05MG001
Gopher Creek near Virden	05MG003
Oak River near Rivers	05MG004
Little Saskatchewan River near Rivers	05MF018
Willow Creek near Chater	05MH011

Normalized recorded flow is provided in Figure 3.4 and Figure 3.5 as m^3/s per 100 km^2 . The recorded data indicates that Gopher Creek and Willow Creek generated a higher rate of runoff than the other minor inflow catchments. Relative to the minor inflow catchments, the normalized recorded flow out of the Shellmouth Reservoir and the Qu'Appelle River are small, indicative of the size and regulation within these catchments. The peak flow from the Shellmouth Reservoir is $83.6 \text{ m}^3/\text{s}$ and the peak flow from the Qu'Appelle River is $167 \text{ m}^3/\text{s}$. The Qu'Appelle River is shown to have peaked earlier than the peak discharge from the Shellmouth Reservoir.

Recorded and modelled flow and water level results are shown in Figure 3.6 through Figure 3.10. A summary of the results is presented in Table 3.5. The results are shown to be within the required 0.15 m for water level and 5% for flow at each of the three (3) compliance locations.

Table 3.5 - Recorded and Modelled Results of Discharge and Water Level - 1976

	Russell	Miniota	Brandon
Discharge (m^3/s)			
Recorded	82.1 (April 26)	447.0 (April 12)	617.0 (April 18)
Modelled	85.8 (April 30)	434.0 (April 13)	595.2 (April 17)
Difference	+ 3.7 (4.5%)	- 13.0 (2.9%)	- 21.8 (3.5%)
Water Level (m)			
Recorded	409.61 (April 26)	379.43 (April 12)	-
Modelled	409.69 (April 30)	379.54 (April 12)	363.06 (April 17)
Difference	+ 0.08	+ 0.11	n/a

Modelled flow at each compliance location matches well to the recorded data. Modelled water level at Miniota indicates that the existing terrain surface within the Assiniboine River channel may not represent the conditions in 1976. The base flow water level at the beginning and end of the hydrograph does not match well; however, this appears to have little effect on the peak water level.

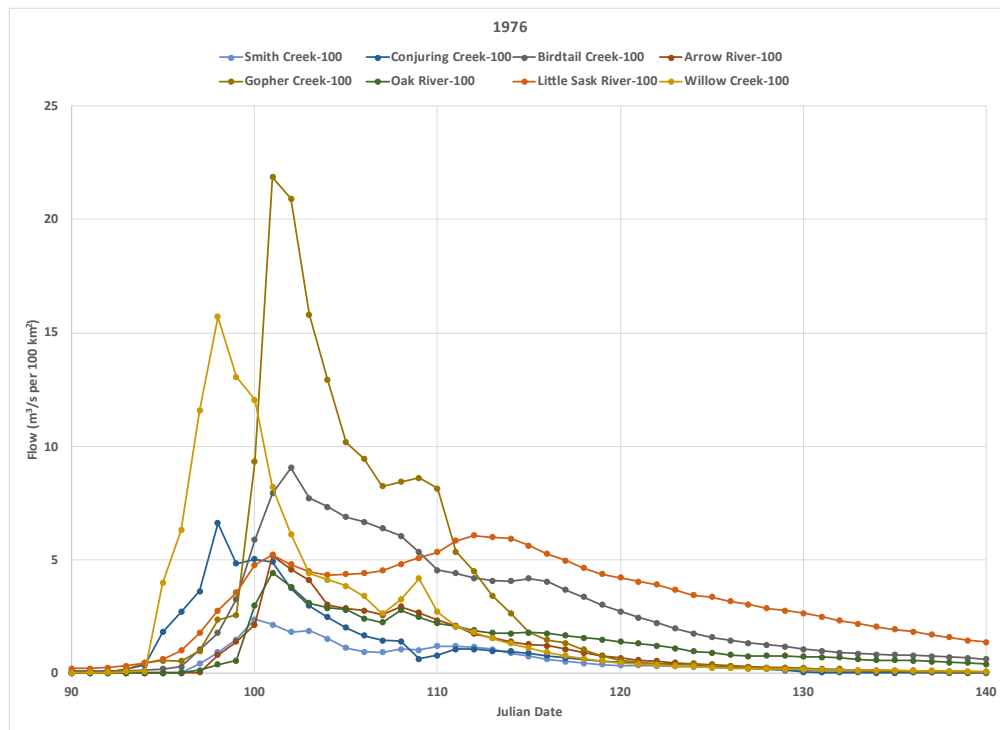


Figure 3.4 - Recorded Tributary Catchment Inflow – 1976 Normalized

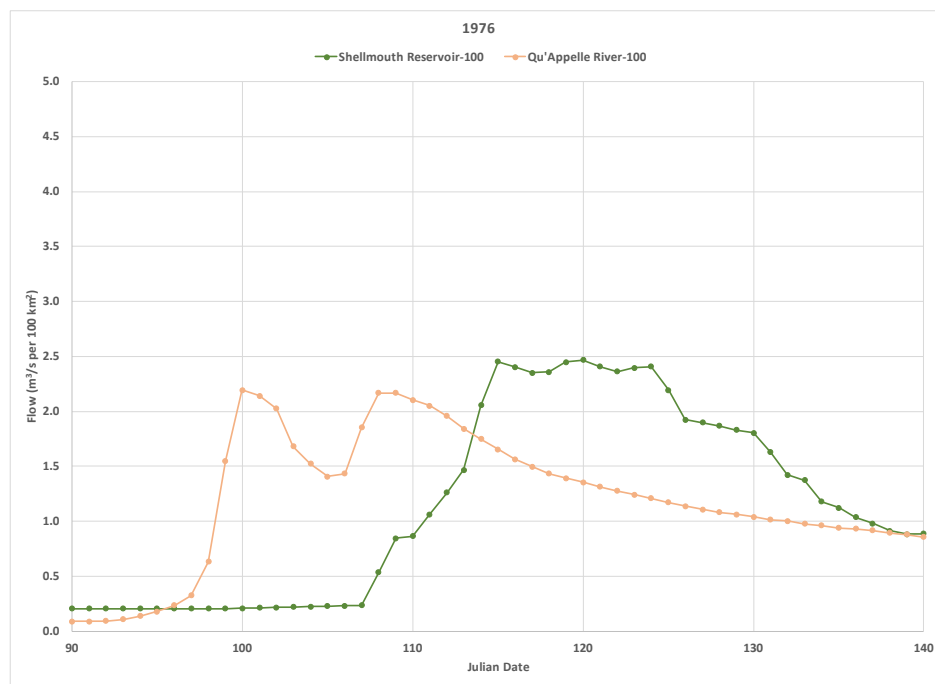


Figure 3.5 - Recorded Major Catchment Inflow – 1976 Normalized

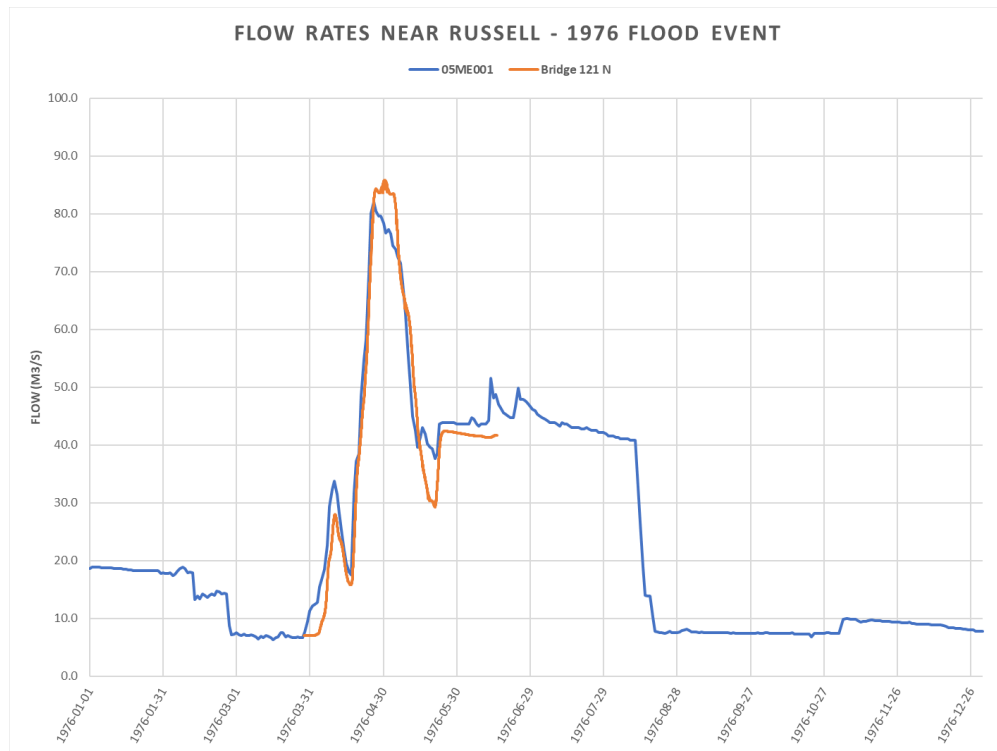


Figure 3.6 - Recorded and Modelled Flow near Russell – 1976

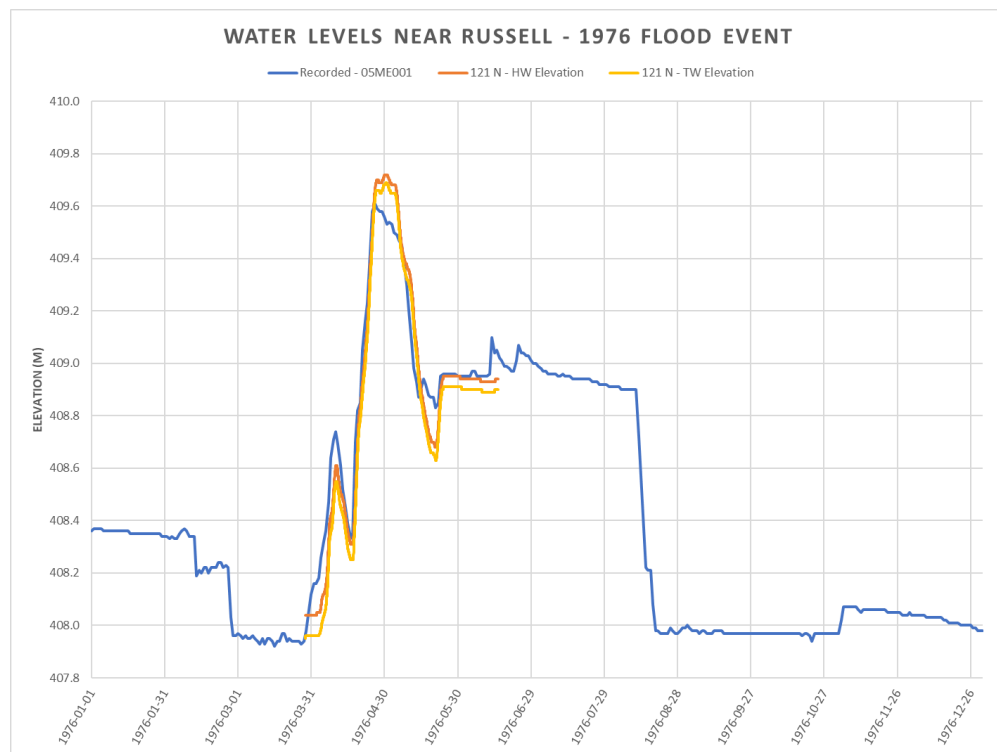


Figure 3.7 - Recorded and Modelled Water Level near Russell - 1976

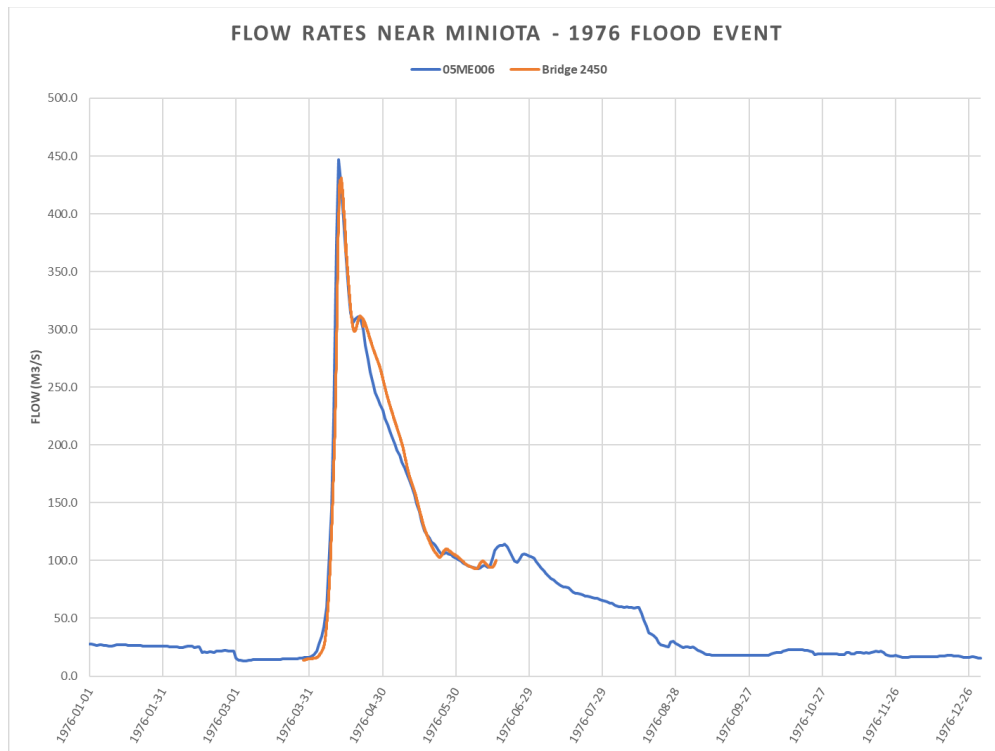


Figure 3.8 - Recorded and Modelled Flow near Miniota - 1976

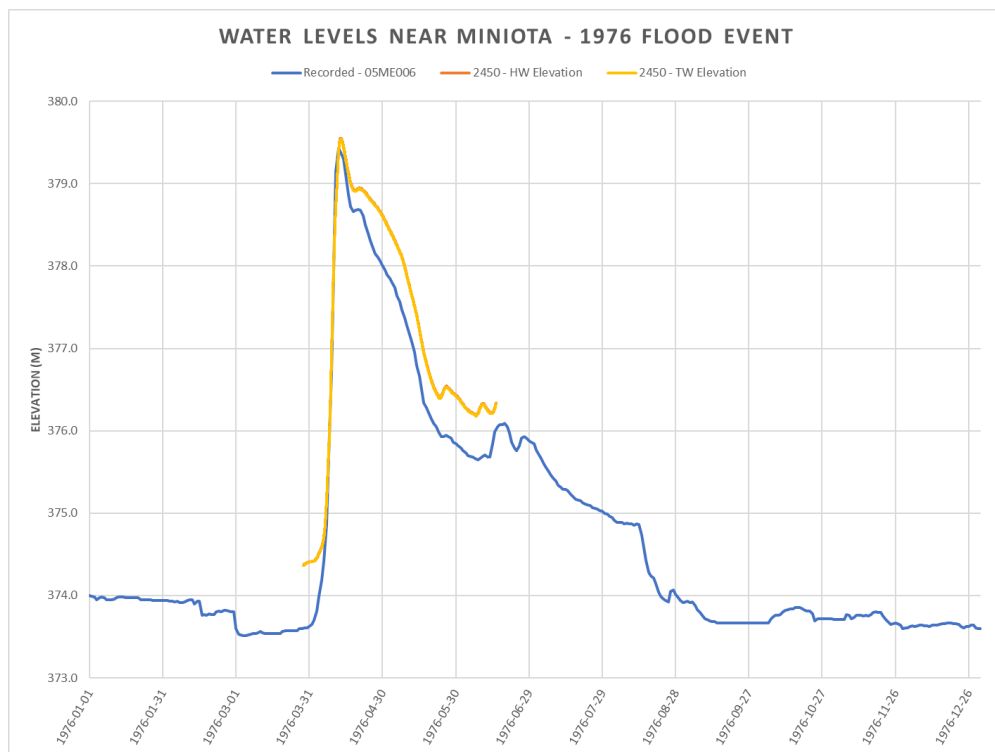


Figure 3.9 - Recorded and Modelled Water Level near Miniota - 1976

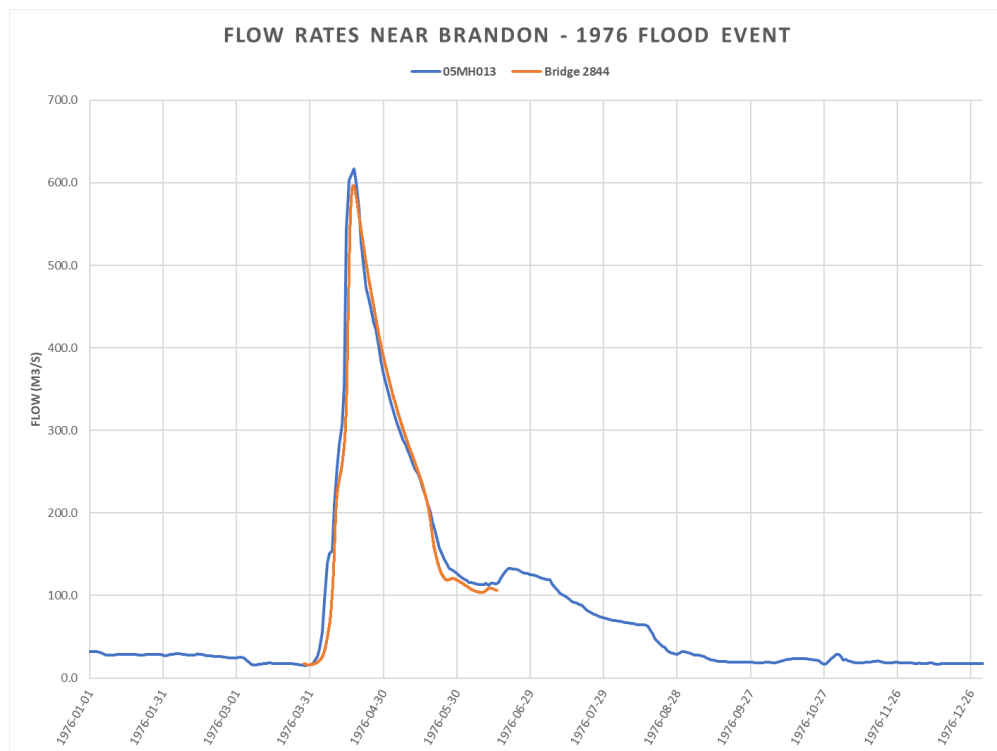


Figure 3.10 - Recorded and Modelled Flow near Brandon – 1976

3.3.2 1995

The 1995 event is characterized by a single snowmelt-driven runoff with a distinctive double peak. The double peak is recorded as having a similar peak flow and water level during both peaks, separated by approximately 12 days from each other. Recorded flow data is available at the following gauge locations shown in Table 3.6.

Table 3.6 - Gauge Locations - 1995

Location	Gauge Number
Smith Creek near Marchwell	05ME007
Conjuring Creek near Russell	05ME005
Scissor Creek near McAuley	05ME009
Birdtail Creek near Birtle	05ME003
Arrow River near Arrow River	05MG001
Gopher Creek near Virden	05MG003
Oak River near Rivers	05MG004
Little Saskatchewan River near Rivers	05MF018

Normalized recorded flow is provided in Figure 3.11 and Figure 3.12 as m^3/s per 100 km^2 . The recorded data indicates that Gopher Creek and Scissor Creek peaked earlier than the other minor inflow catchments. Conjuring Creek and Oak River generated the highest rate of runoff, while Oak River also produced a significant second

peak. Shellmouth Reservoir is shown to have produced a similar rate of runoff compared to the minor inflow catchments. The Qu'Appelle River rate of runoff is small. The peak flow from the Shellmouth Reservoir is 343.3 m³/s and the peak flow from the Qu'Appelle River is 130 m³/s. The Qu'Appelle River is shown to have peaked earlier than the peak discharge from the Shellmouth Reservoir.

Recorded and modelled flow and water level results are shown in Figure 3.13 through Figure 3.17. A summary of the results is presented in Table 3.7. The modelled results at Russell are shown to be within the required 0.15 m for water level and 5% for flow, while the modelled results at Miniota and Brandon are both higher than the recorded data.

Table 3.7 - Recorded and Modelled Results of Discharge and Water Level - 1995

	Russell	Miniota	Brandon
Discharge (m³/s)			
Recorded	360.0 (May 3)	463.0 (May 7)	580.0 (May 9)
Modelled	372.0 (May 3)	521.1 (May 2)	636.7 (May 5)
Difference	+ 12.0 (3.3%)	+ 58.1 (12.5%)	+ 56.7 (9.8%)
Water Level (m)			
Recorded	412.14 (May 3)	379.47 (May 7)	-
Modelled	412.06 (May 3)	379.76 (May 2)	363.15 (May 5)
Difference	- 0.08	+ 0.29	n/a

The modelled results are close to the recorded data; however, they show a lower flow on the first peak and a higher flow on the second peak. Overall, the volume of runoff appears to be correct with only the timing of the two (2) peaks not represented well. Nevertheless, the hydraulic model appears to be functioning well. With significant timing variability between the gauged catchments, it is likely that the current catchment assignment does not reflect the true timing of all ungauged catchments. It is our opinion that these results show that the model is calibrated and could be made to match with additional timing adjustments; however, the return on this level of effort is not warranted.

Like the 1976 event, water levels at baseflow for the Miniota location do not match well. This is not of concern but does indicate that the channel has likely changed from 1995 to present.

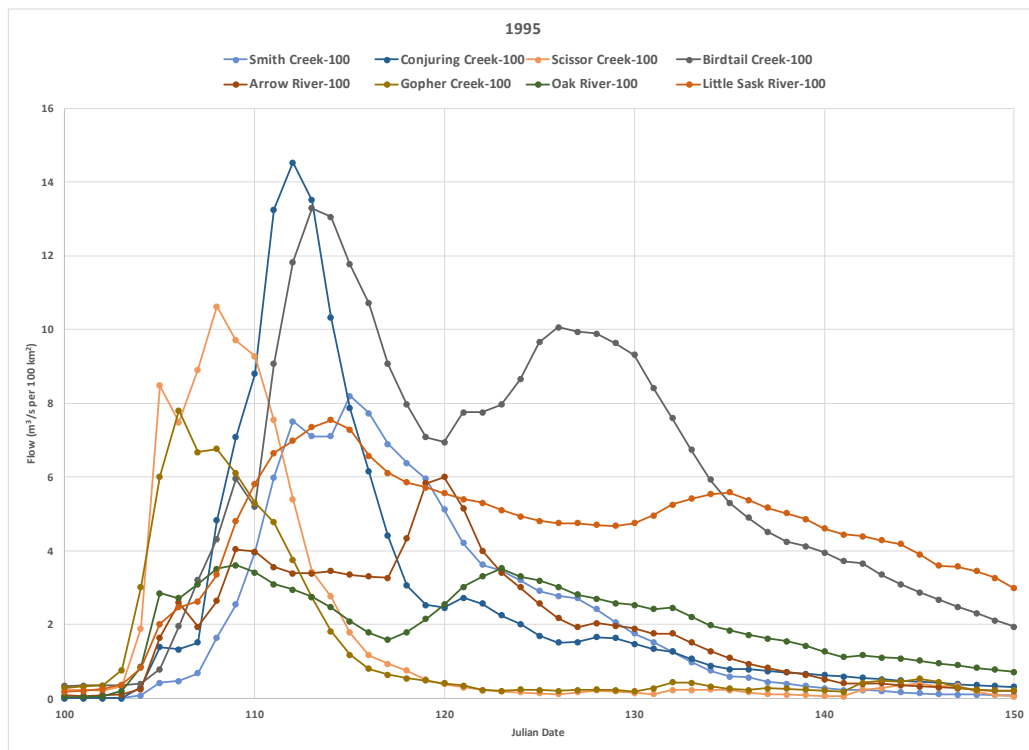


Figure 3.11 - Recorded Tributary Catchment Inflow – 1995 Normalized

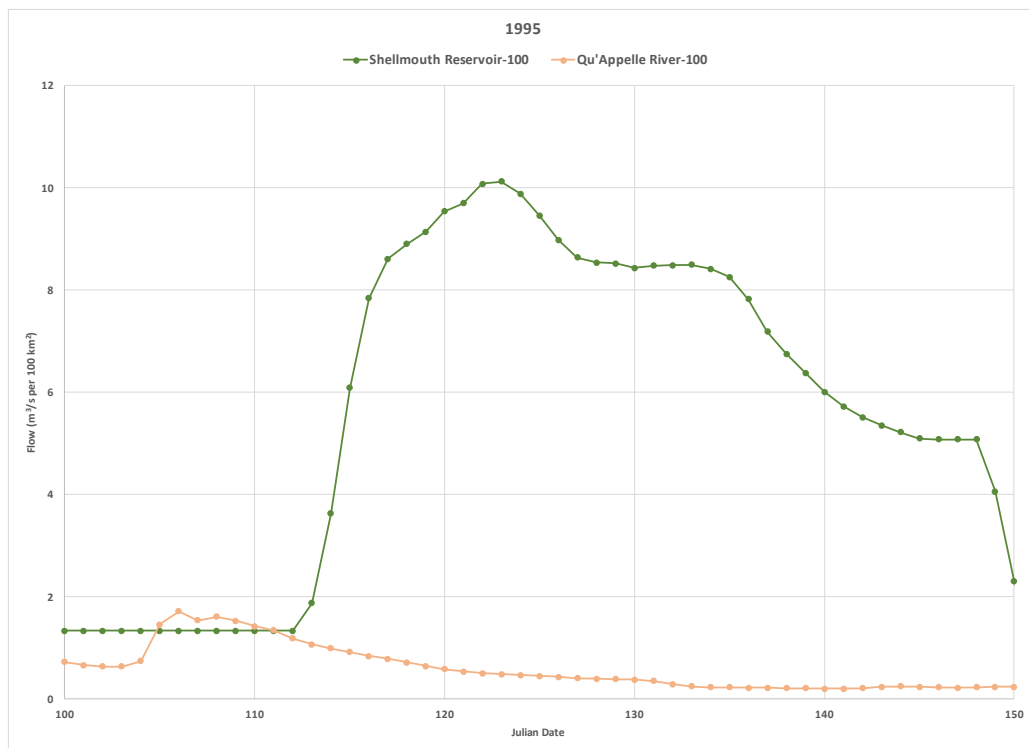


Figure 3.12 - Recorded Major Catchment Inflow – 1995 Normalized

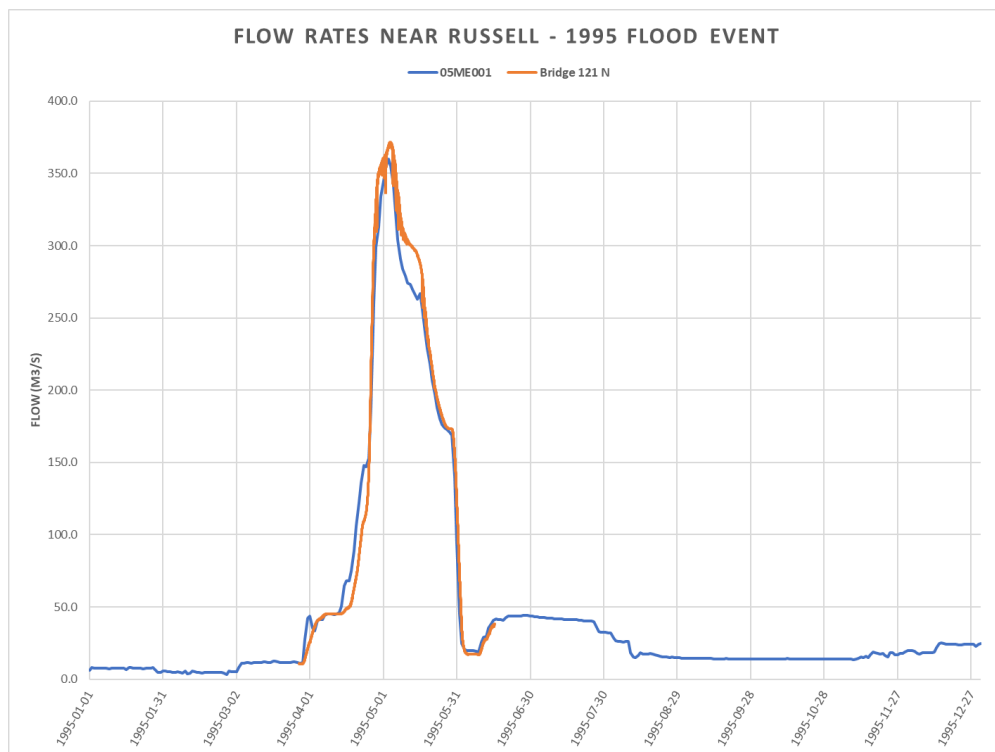


Figure 3.13 - Recorded and Modelled Flow near Russell - 1995

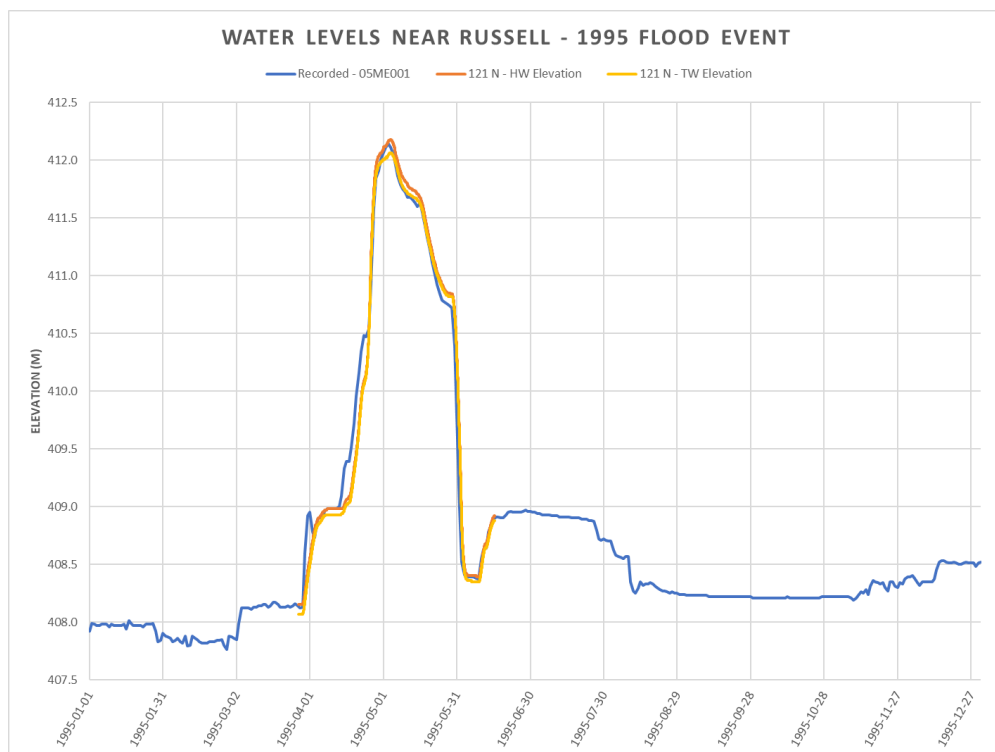


Figure 3.14 - Recorded and Modelled Water Level near Russell - 1995

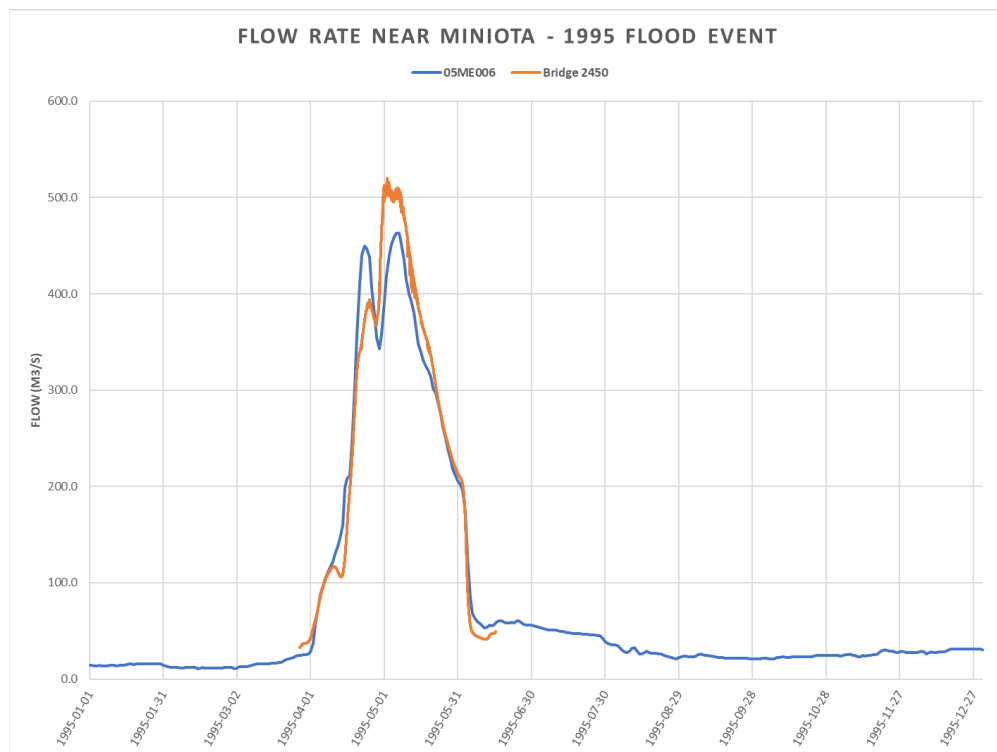


Figure 3.15 - Recorded and Modelled Flow near Miniota - 1995

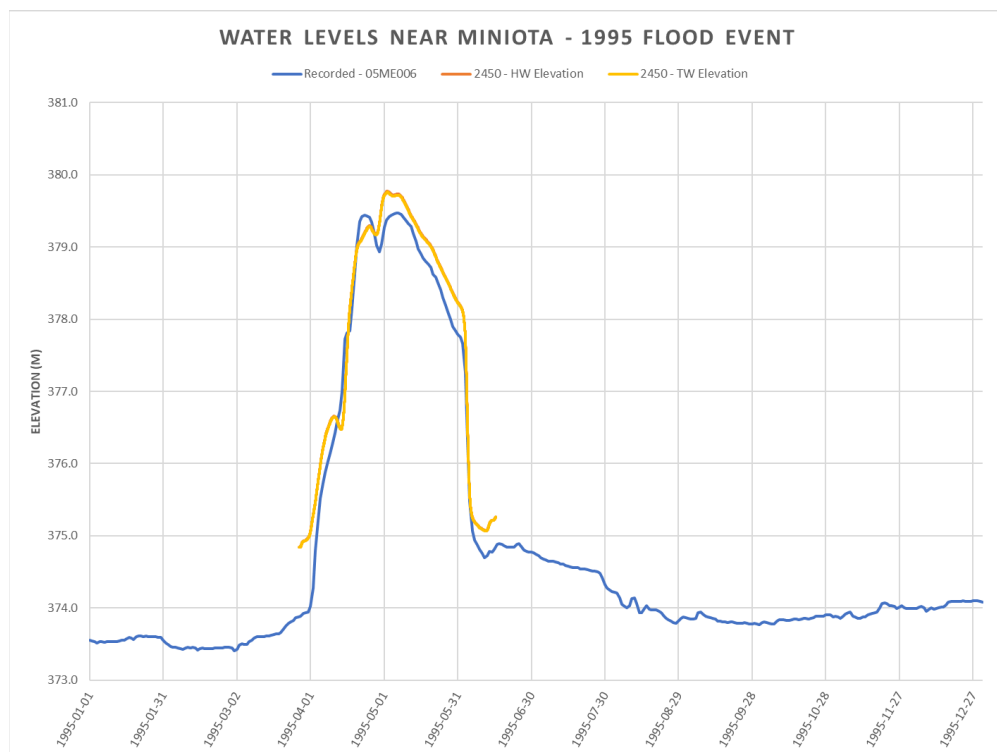


Figure 3.16 - Recorded and Modelled Water Level near Miniota - 1995

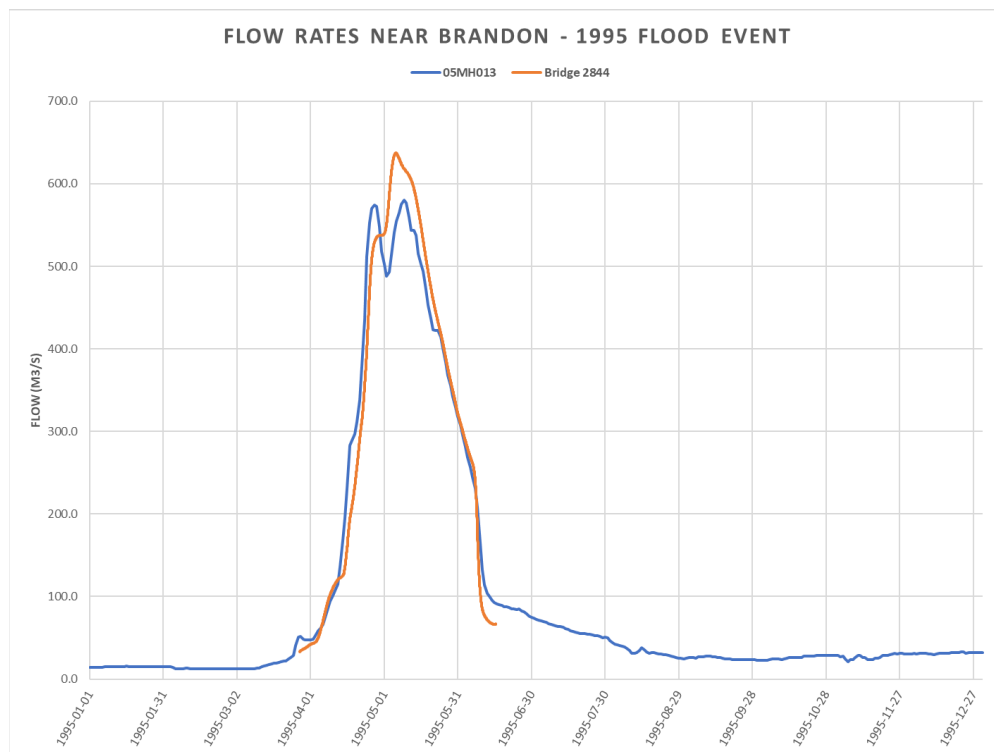


Figure 3.17 - Recorded and Modelled Flow near Brandon – 1995

3.3.3 2005

The 2005 event is characterized by a single snowmelt-driven runoff followed by a substantial summer rainfall peak. The spring peak is predominantly driven by the Qu'Appelle River while the summer peak is a result of rainfall on the minor inflow catchments of the Assiniboine River. Recorded flow data is available at the following gauge locations shown in Table 3.8.

Table 3.8 - Gauge Locations - 2005

Location	Gauge Number
Smith Creek near Marchwell	05ME007
Conjuring Creek near Russell	05ME005
Scissor Creek near McAuley	05ME009
Birdtail Creek near Birtle	05ME003
Arrow River near Arrow River	05MG001
Gopher Creek near Virden	05MG003
Oak River near Rivers	05MG004

It must be noted that there is no recorded data for the Little Saskatchewan River catchment, which is the third largest catchment (after the Shellmouth Reservoir and the Qu'Appelle River). This represents a large unknown inflow that must be estimated based on nearby catchments.

Normalized recorded flow is provided in Figure 3.18 and Figure 3.19 as m^3/s per 100 km^2 . The recorded data indicates that timing of the spring peak was comparable across all minor inflow catchments. Gopher Creek, Scissor Creek, Conjuring Creek, and Birdtail Creek all generated the highest rate of runoff during the spring peak. The summer rainfall peak appears to have been focused to the northeast with a significant rate of runoff coming from Birdtail Creek and Oak River. The Shellmouth Reservoir and the Qu'Appelle River rate of runoff are small. The peak flow from the Shellmouth Reservoir is $40.0 \text{ m}^3/\text{s}$ and the peak flow from the Qu'Appelle River is $77.5 \text{ m}^3/\text{s}$. The Qu'Appelle River is shown to have peaked earlier than the peak discharge from the Shellmouth Reservoir.

Recorded and modelled flow and water level results are shown in Figure 3.20 through Figure 3.25. A summary of the results is presented in Table 3.9. The modelled results at all compliance locations are shown to be within the required 0.15 m for water level, but all miss the 5% for flow.

Table 3.9 - Recorded and Modelled Results of Discharge and Water Level - 2005

	Russell	Miniota	Brandon
Discharge (m^3/s)			
Recorded	66.7 (July 3)	296.0 (April 9)	434.0 (April 14)
Modelled	53.3 (July 1)	252.7 (April 9)	346.1 (April 13)
Difference	- 13.4 (20.1%)	- 43.3 (14.6%)	- 87.9 (20.2%)
Water Level (m)			
Recorded	409.22 (July 3)	378.76 (April 9)	361.92 (April 14)
Modelled	409.10 (July 1)	378.62 (April 9)	362.07 (April 13)
Difference	- 0.12	- 0.14	+ 0.15

The 2005 event is the worst of all six (6) calibration events, likely due to the complexity of the multiple peaks rising and falling to baseflow in quick succession and the most limited gauge data. Only seven (7) gauges were available in 2005 compared to eight to ten (8 - 10) gauges in other calibration events. Since this model represents a very large spatial area and only seven (7) tributaries were covered by gauges, runoff from hundreds of kilometres of ungauged areas was made from the assumption described in 3.2 instead of using recorded data. It is likely that the timing of the estimated local inflows does not reflect the true timing of all ungauged catchments. The late peak time of the local inflow contributes to a later peak instead of an earlier peak that it should be, resulting in a lower peak flow in Russell and Miniota. In addition, the 2005 event does not have gauge data from the Little Saskatchewan River, which is an important tributary that affects Brandon. Estimation of the Little Saskatchewan River also affects Brandon significantly.

Nevertheless, all three (3) compliance locations are within the required 0.15 m for water level. The recorded peak flow at all three (3) compliance locations are the smallest of all calibration events, which makes the results sensitive to small deviation in flow. Calibration of the hydraulic model gives a higher priority to high flows, considering the high flows will be used in the flood maps. It is of little concern that this smallest event of the calibration events does not meet the 5% flow requirement.

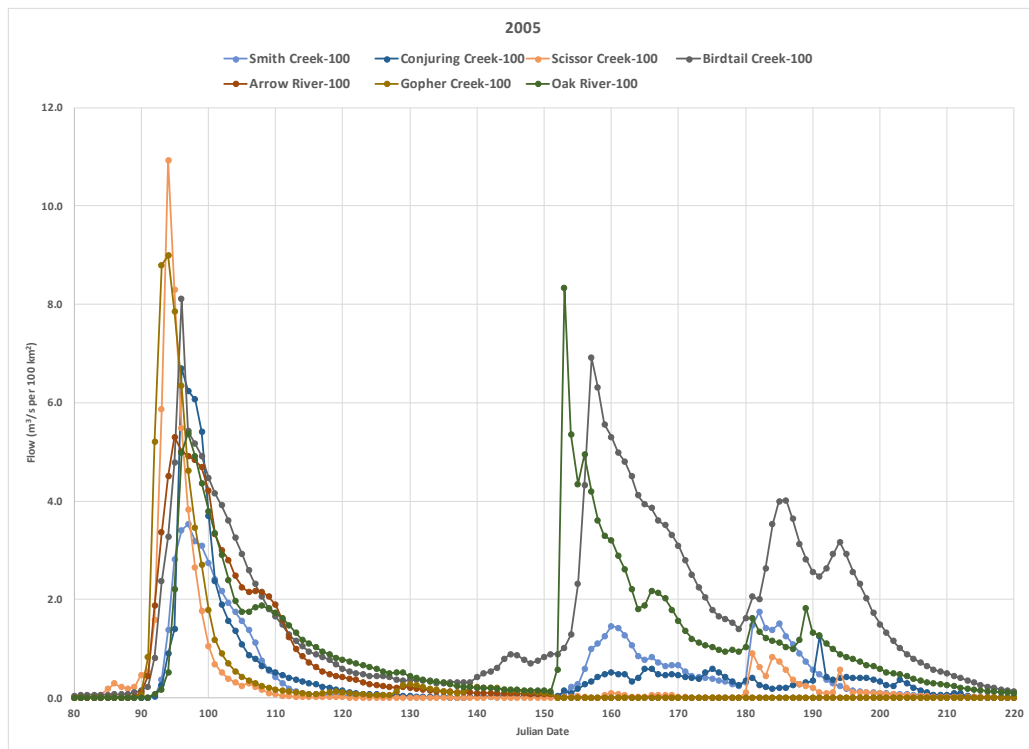


Figure 3.18 - Recorded Tributary Catchment Inflow – 2005 Normalized

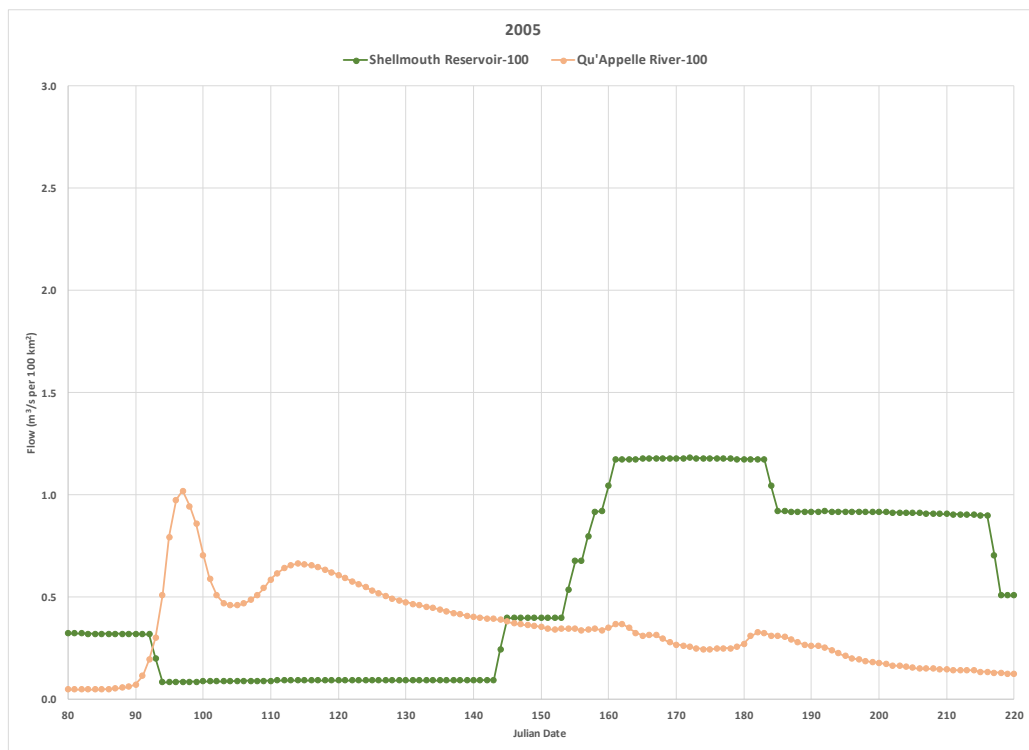


Figure 3.19 - Recorded Major Catchment Inflow – 2005 Normalized

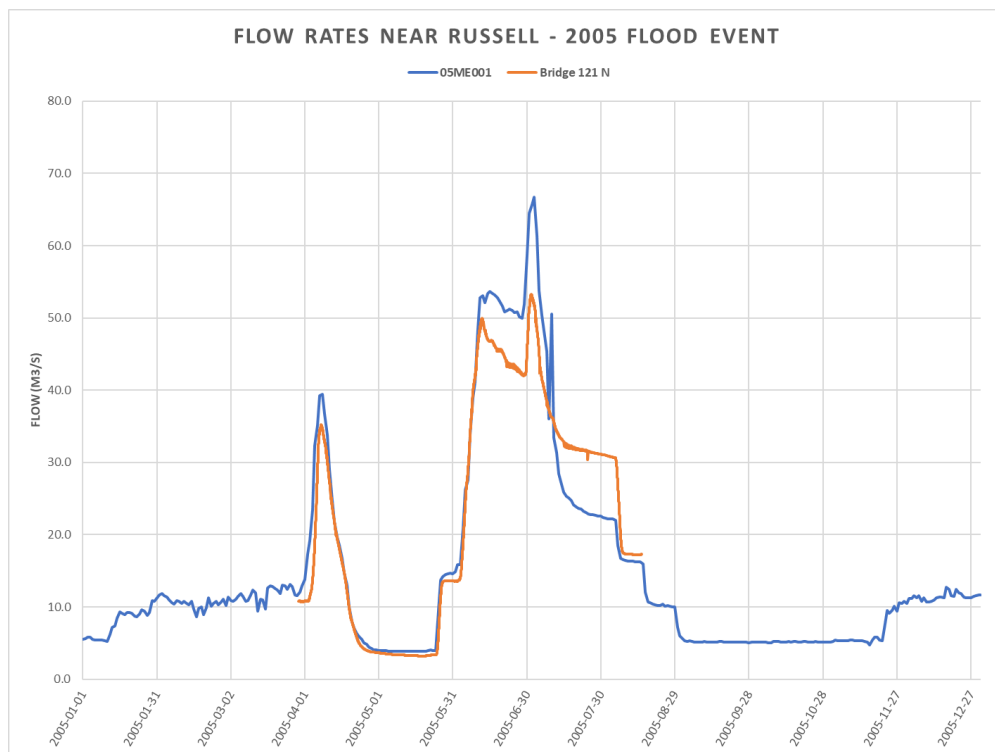


Figure 3.20 - Recorded and Modelled Flow near Russell - 2005

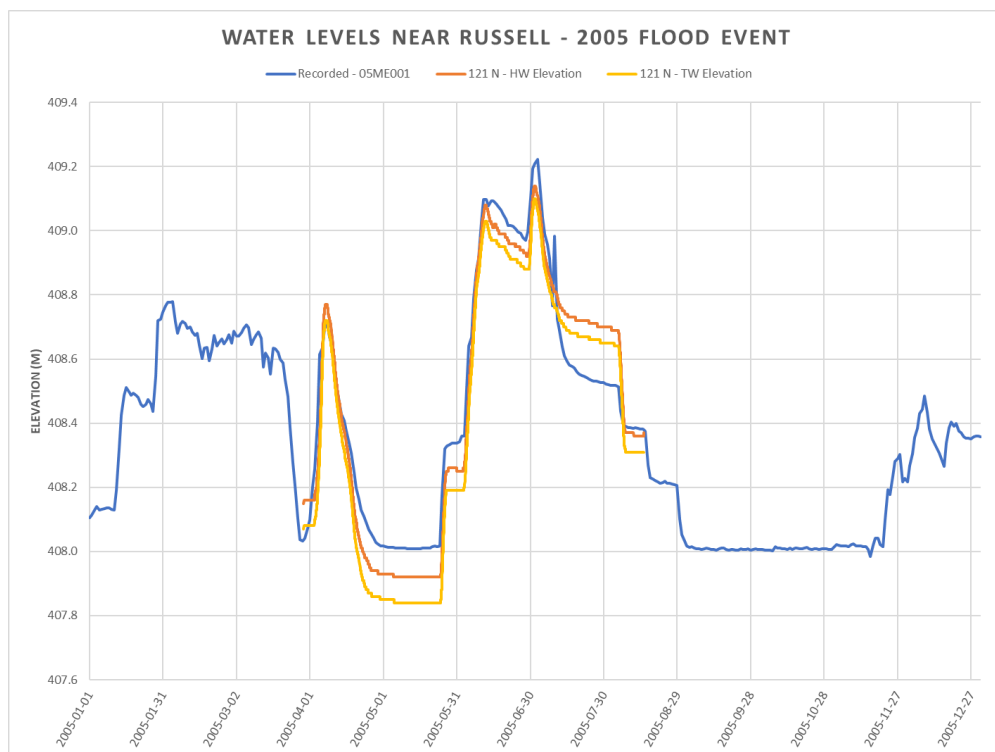


Figure 3.21 - Recorded and Modelled Water Level near Russell - 2005

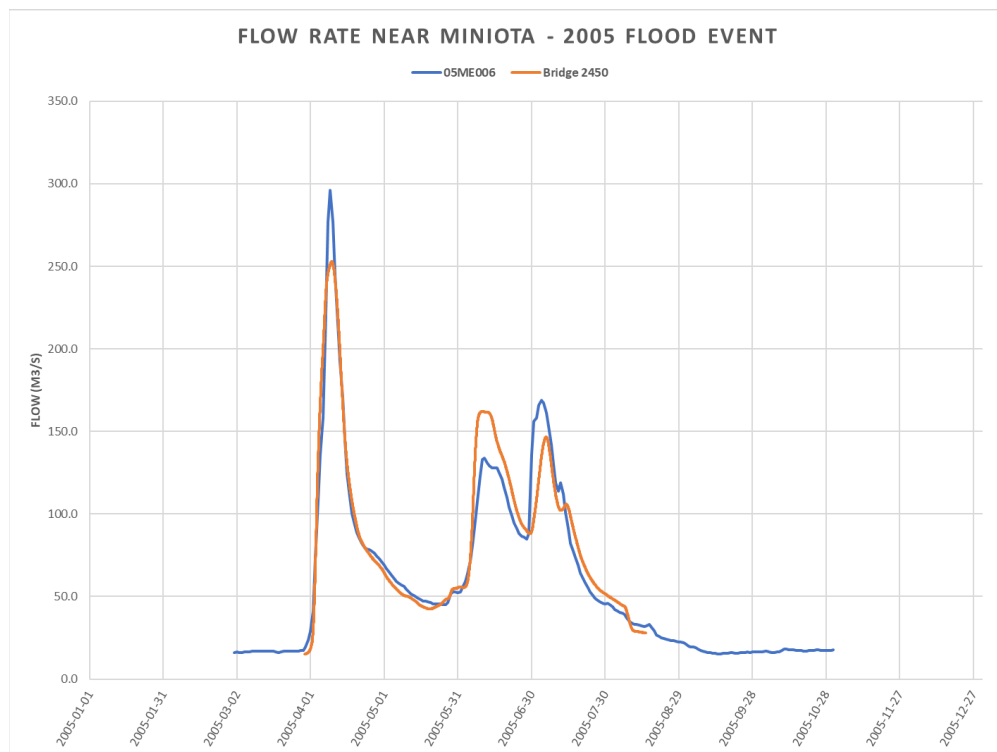


Figure 3.22 - Recorded and Modelled Flow near Miniota - 2005

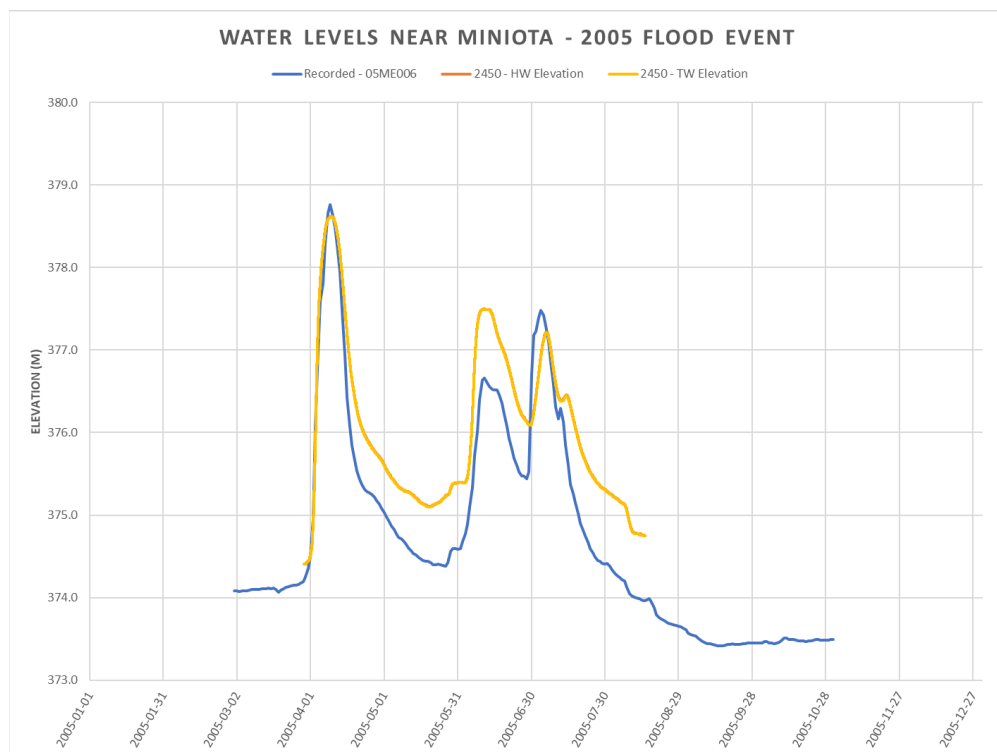


Figure 3.23 - Recorded and Modelled Water Level near Miniota - 2005

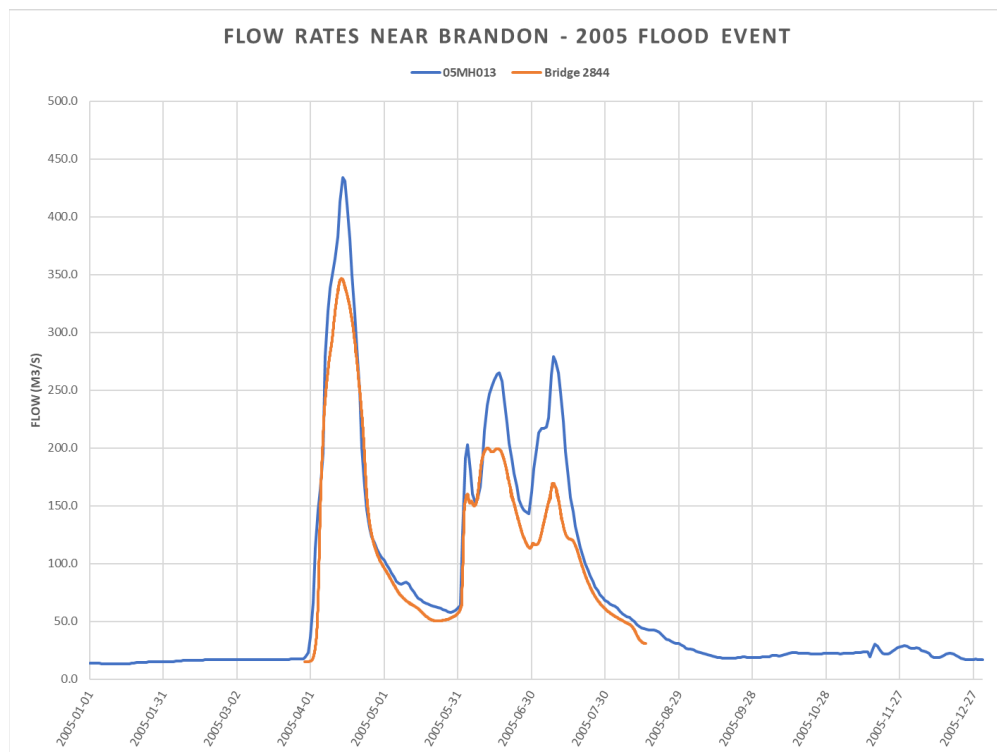


Figure 3.24 - Recorded and Modelled Flow near Brandon - 2005

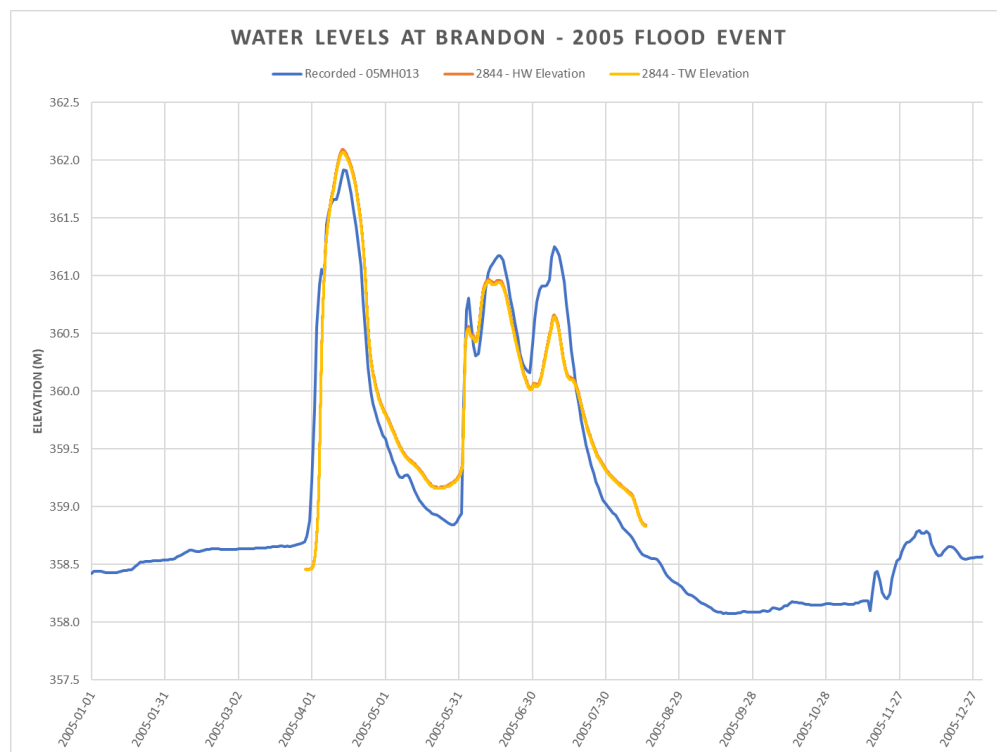


Figure 3.25 - Recorded and Modelled Water Level near Brandon – 2005

3.3.4 2011

The 2011 event is characterized by a snowmelt-driven runoff with frequent rainfall during both the rising and falling limb of the snowmelt hydrograph. This creates a stepped rising limb and a drawn-out falling limb with a large volume. The 2011 and the 2014 events are the largest of the six (6) calibration events. The 2011 event appears to have developed flow from all minor inflow catchments, the Shellmouth Reservoir, and the Qu'Appelle River. Recorded flow data is available at the following gauge locations shown in Table 3.10.

Table 3.10 - Gauge Locations - 2011

Location	Gauge Number
Smith Creek near Marchwell	05ME007
Conjuring Creek near Russell	05ME005
Silver Creek near Binscarth	05ME010
Scissor Creek near McAuley	05ME009
Birdtail Creek near Birtle	05ME003
Arrow River near Arrow River	05MG001
Gopher Creek near Virden	05MG003
Oak River near Rivers	05MG004

It must be noted that there is no recorded data for the Little Saskatchewan River catchment, which is the third largest catchment (after the Shellmouth Reservoir and the Qu'Appelle River). This represents a large unknown inflow that must be estimated based on nearby catchments.

Normalized recorded flow is provided in Figure 3.26 and Figure 3.27 as m^3/s per 100 km^2 . The recorded data indicates that all catchments contributed to the 2011 event, and the continuous rainfall driven runoff lasted until the end of June. Scissor Creek and Birdtail Creek appear to have generated the highest rate of runoff during the event, while both the Shellmouth Reservoir and the Qu'Appelle River provided significant inflow. The peak flow from the Shellmouth Reservoir is $343.3 \text{ m}^3/\text{s}$ and the peak flow from the Qu'Appelle River is $345 \text{ m}^3/\text{s}$. The two (2) major inflow catchments are shown to have similar peak flow timing, and both continue through summer.

Recorded and modelled flow and water level results are shown in Figure 3.28 through Figure 3.33. A summary of the results is presented in Table 3.11. The modelled results at Russell and Brandon are shown to be within or very near to the required 0.15 m for water level and the 5% for flow. Miniota is shown to exceed both flow and level.

Table 3.11 - Recorded and Modelled Results of Discharge and Flow Rate - 2011

	Russell	Miniota	Brandon
Discharge (m^3/s)			
Recorded	398.0 (May 12)	832.0 (May 12)	1040.0 (May 9)
Modelled	395.9 (May 12)	953.9 (May 7)	1060.7 (May 10)
Difference	- 2.1 (0.5%)	+ 121.9 (14.7%)	+ 20.7 (2.0%)
Water Level (m)			
Recorded	412.30 (May 12)	380.20 (May 6)	363.71 (May 9)
Modelled	412.18 (May 12)	380.57 (May 7)	363.87 (May 10)
Difference	- 0.12	+ 0.37	+ 0.16

The hydrographs for 2011 track the recorded data very well across the whole event. The model results at Miniota show a significantly higher water level than the recorded data, but it also shows the baseflow water level to now match the recorded data. Downstream of Miniota there is a low dike that protects a large portion of the floodplain. This dike is seen to overtop at these high flows. By comparing the current LiDAR data to the older MLI LiDAR data, it appears that the dike has been raised after 2017. During the 2011 event, this dike would have been overtopped earlier than the existing condition model indicates, and the water level would have been lower. It is suspected that the change in physical conditions around Miniota and the higher flow may be the cause for the discrepancy. Generally, the modelled results of the 2011 event follow the recorded data very well.

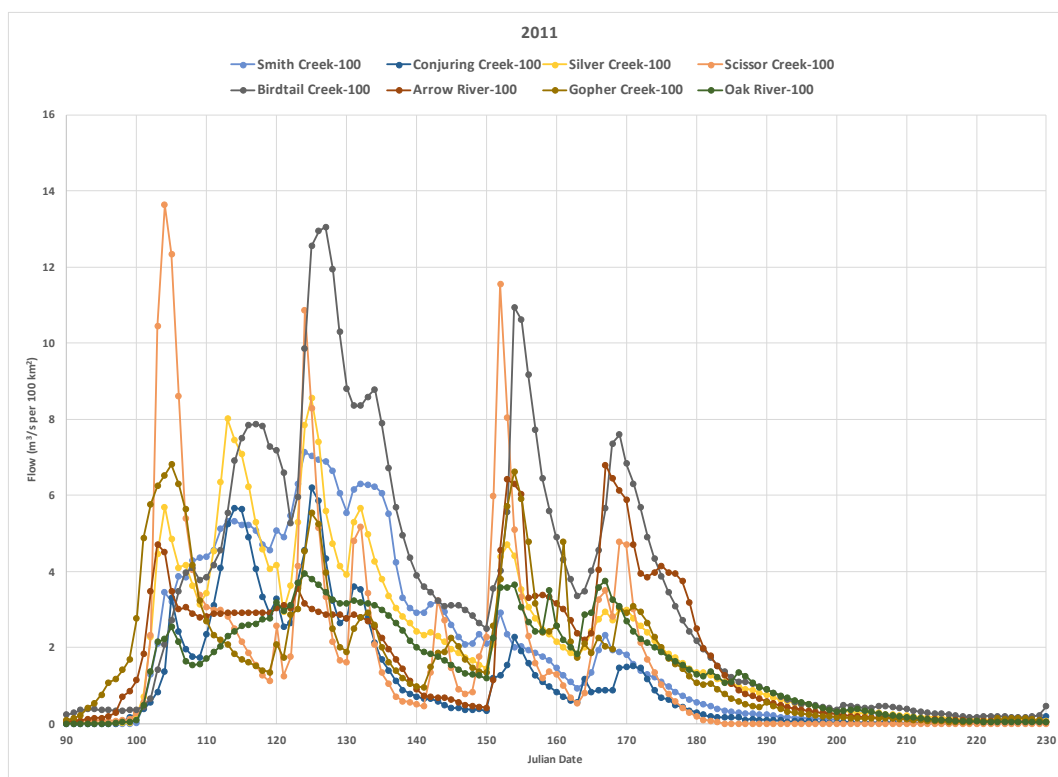


Figure 3.26 - Recorded Tributary Catchment Inflow – 2011 Normalized

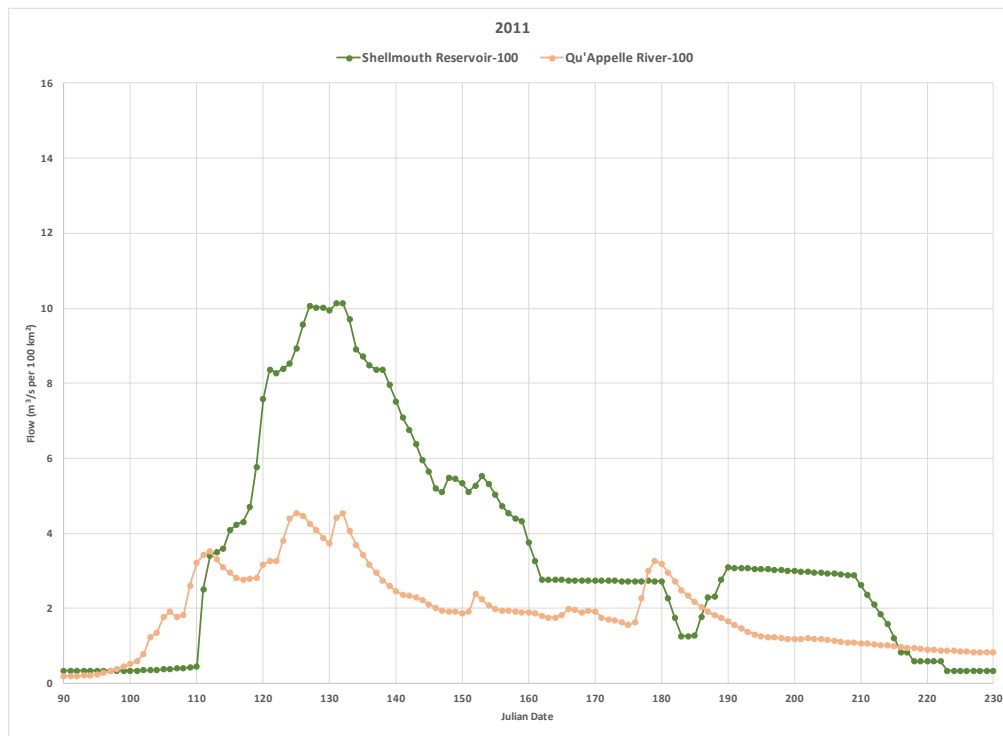


Figure 3.27 - Recorded Major Catchment Inflow – 2011 Normalized

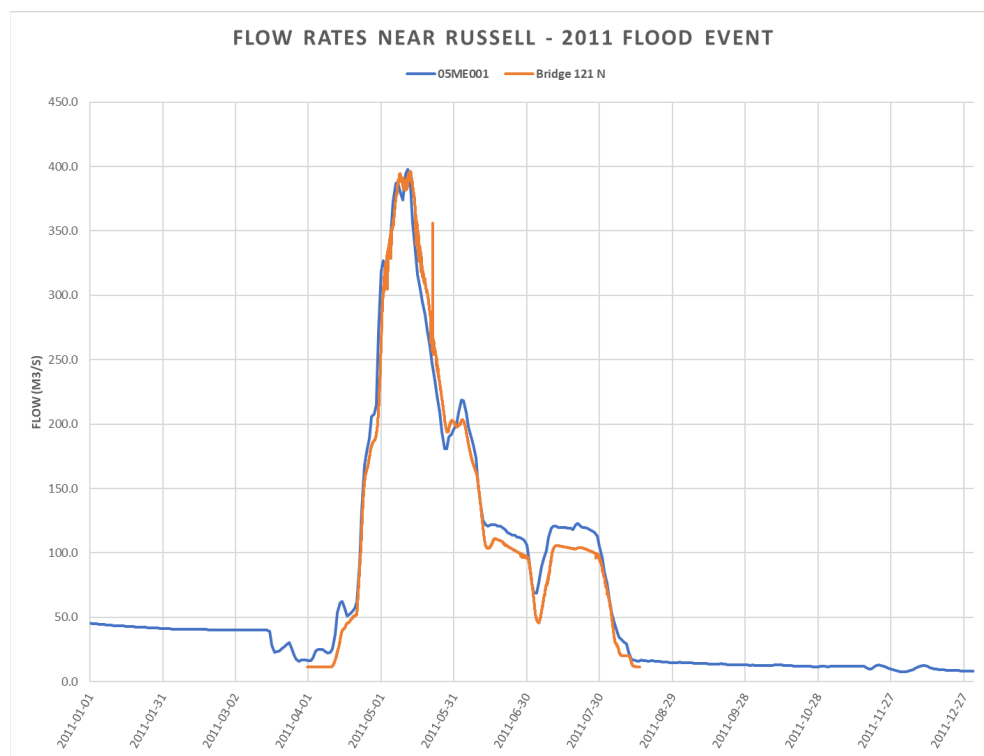


Figure 3.28 - Recorded and Modelled Flow near Russell - 2011

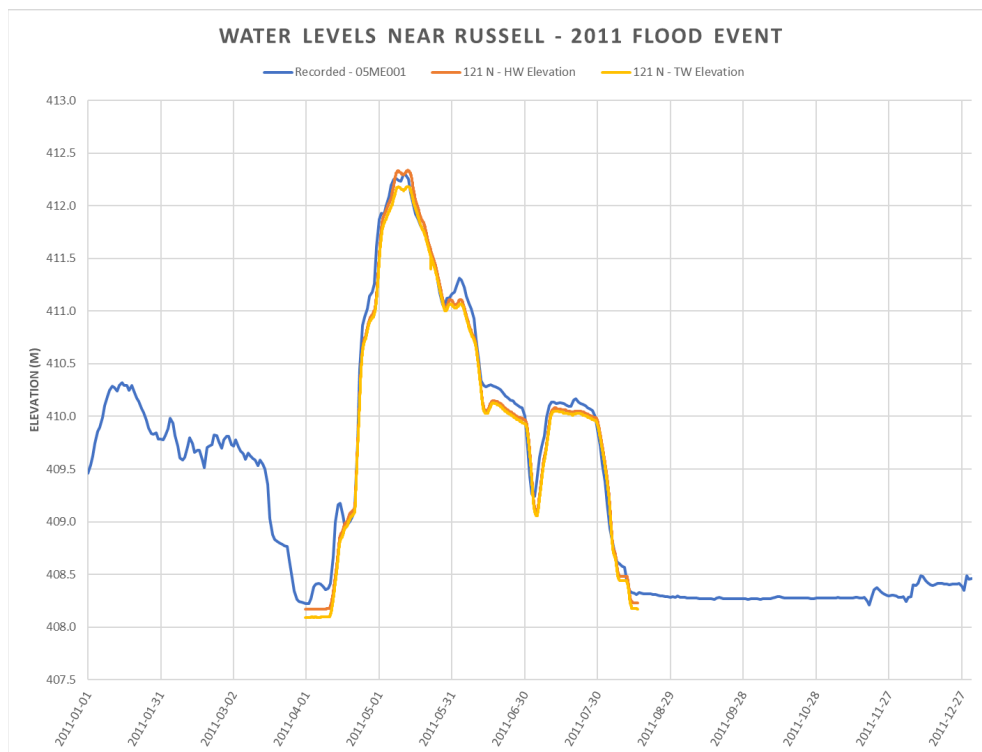


Figure 3.29 - Recorded and Modelled Water Level near Russell - 2011

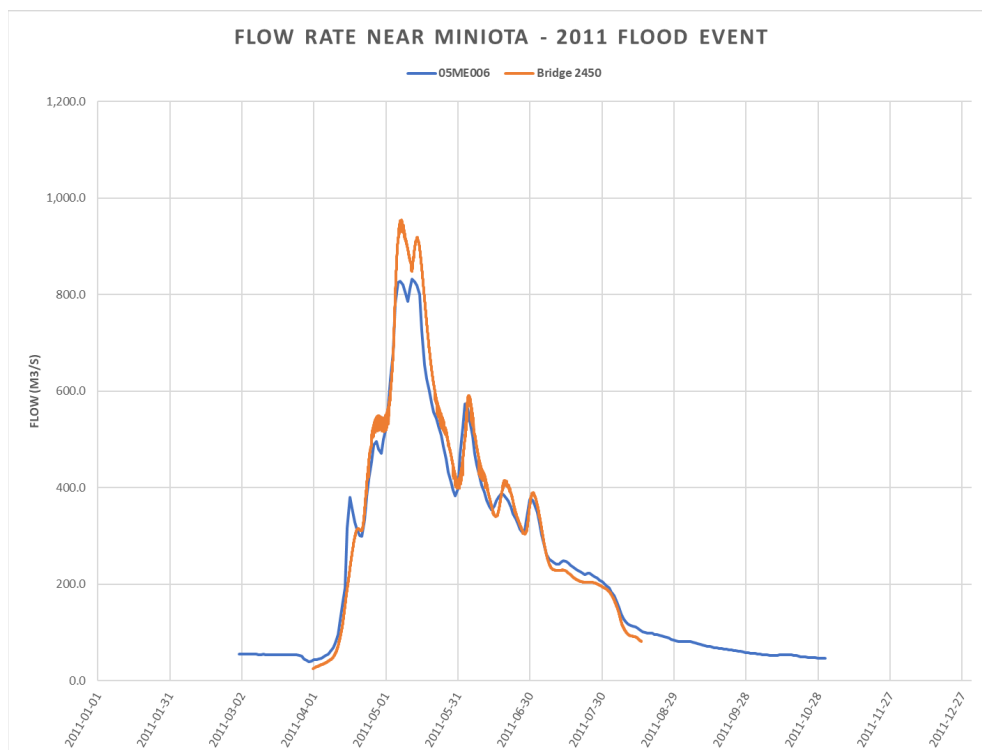


Figure 3.30 - Recorded and Modelled Flow near Miniota - 2011

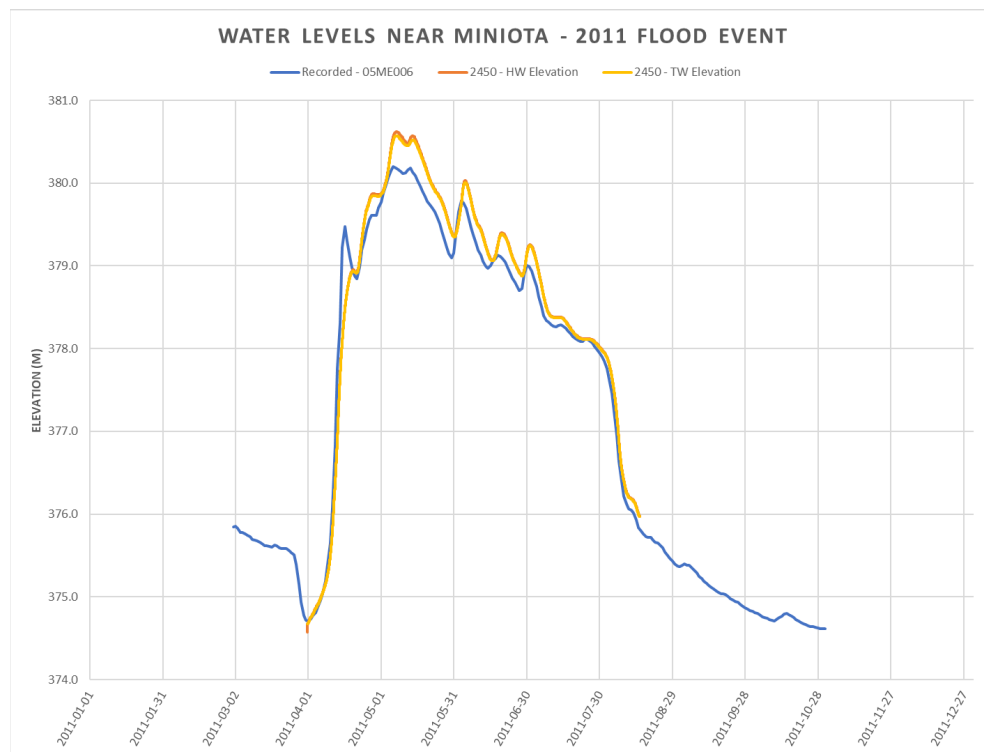


Figure 3.31 - Recorded and Modelled Water Level near Miniota - 2011

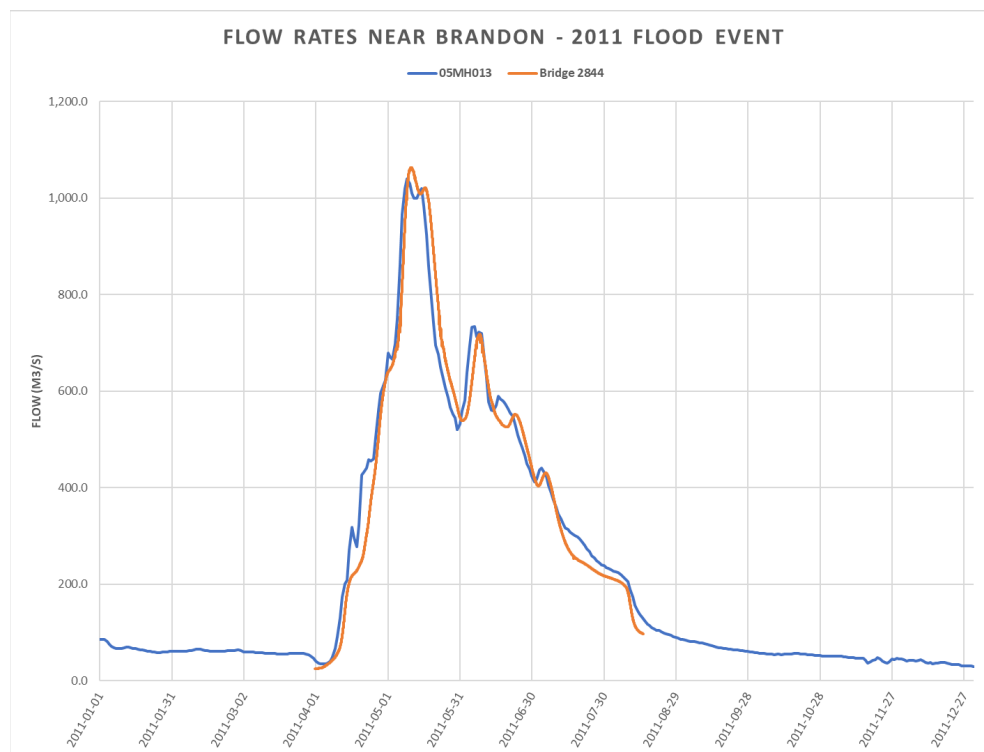


Figure 3.32 - Recorded and Modelled Flow near Brandon - 2011

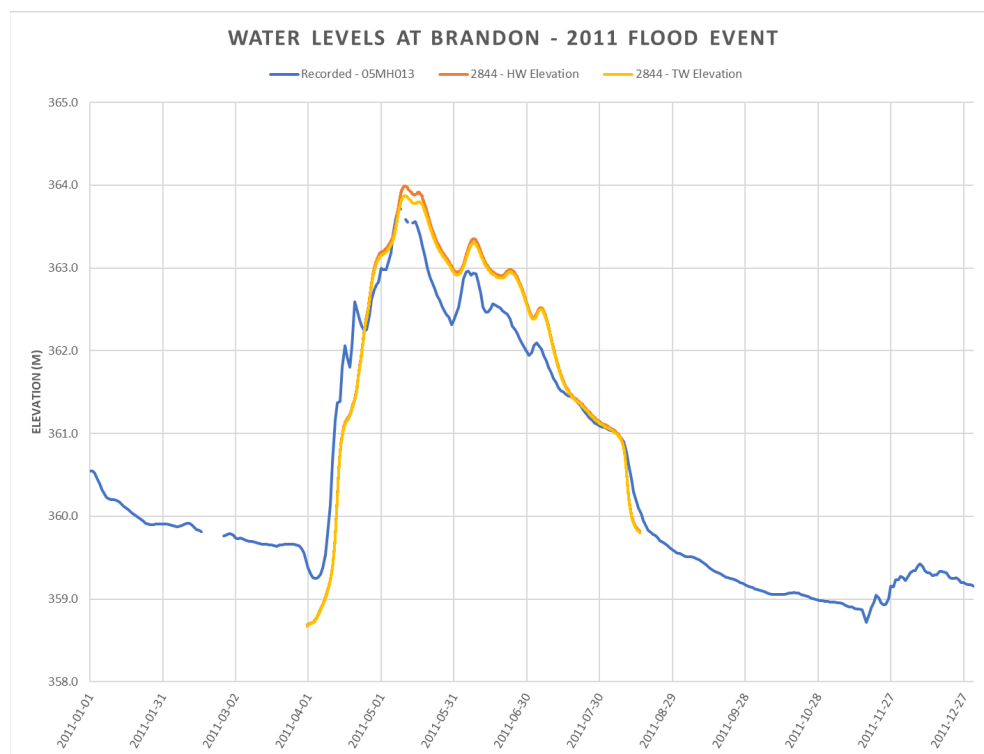


Figure 3.33 - Recorded and Modelled Water Level near Brandon – 2011

3.3.5 2014

The 2014 event is characterized by a spring snowmelt-driven runoff peak followed by a significantly larger summer rainfall-driven peak. The Shellmouth Reservoir and the Qu'Appelle River appear to flow naturally as the control of these events was likely exceeded. Recorded flow data is available at the following gauge locations shown in Table 3.12.

Table 3.12 - Gauge Locations - 2014

Location	Gauge Number
Smith Creek near Marchwell	05ME007
Conjuring Creek near Russell	05ME005
Silver Creek near Binscarth	05ME010
Scissor Creek near McAuley	05ME009
Birdtail Creek near Birtle	05ME003
Arrow River near Arrow River	05MG001
Gopher Creek near Virden	05MG003
Baileys Creek near Oak River	05MG015
Oak River near Rivers	05MG004
Little Saskatchewan River near Rivers	05MF018

Normalized recorded flow is provided in Figure 3.34 and Figure 3.35 as m^3/s per 100 km^2 . The recorded data indicates that all catchments contributed to both the spring and summer peaks of the 2014 event. Gopher Creek and Scissor Creek appear to have generated the highest rate of runoff during the summer event, while both the Shellmouth Reservoir and the Qu'Appelle River provided significant inflow. The peak flow from the Shellmouth Reservoir is $466 \text{ m}^3/\text{s}$ and the peak flow from the Qu'Appelle River is $454 \text{ m}^3/\text{s}$. The two (2) major inflow catchments are shown to have similar peak flow timing during the summer peak.

Recorded and modelled flow and water level results are shown in Figure 3.36 through Figure 3.41. A summary of the results is presented in Table 3.13. Although the flow and water level results at the compliance location don't fall within the criteria, all categories are relatively close.

Table 3.13 - Recorded and Modelled Results of Discharge and Water Level - 2014

	Russell	Miniota	Brandon
Discharge (m^3/s)			
Recorded	458.0 (July 10)	950.0 (July 10)	1040.0 (July 12)
Modelled	480.1 (July 11)	885.6 (July 11)	1011.1 (July 13)
Difference	+ 22.1 (4.8%)	- 64.5 (6.8%)	- 28.9 (2.8%)
Water Level (m)			
Recorded	412.75 (July 10)	380.19 (July 10)	363.58 (July 12)
Modelled	412.56 (July 11)	380.48 (July 11)	363.79 (July 13)
Difference	- 0.19	+ 0.29	+ 0.21

The hydrographs for 2014 track the recorded data very well across the whole event. The model results at Miniota show a significantly higher water level than the recorded data, but it also shows the baseflow water level to now match the recorded data. Downstream of Miniota there is a low dike that protects a large portion of the floodplain. This dike is seen to overtop at these high flows. By comparing the current LiDAR data to the older MLI LiDAR data, it appears that the dike has been raised after 2017. During the 2014 event, this dike would have been overtopped earlier than the existing condition model indicates, and the water level would have been lower. It is suspected that the change in physical conditions around Miniota and the higher flow may be the cause for the discrepancy. Generally, the modelled results of the 2014 event follow the recorded data very well.

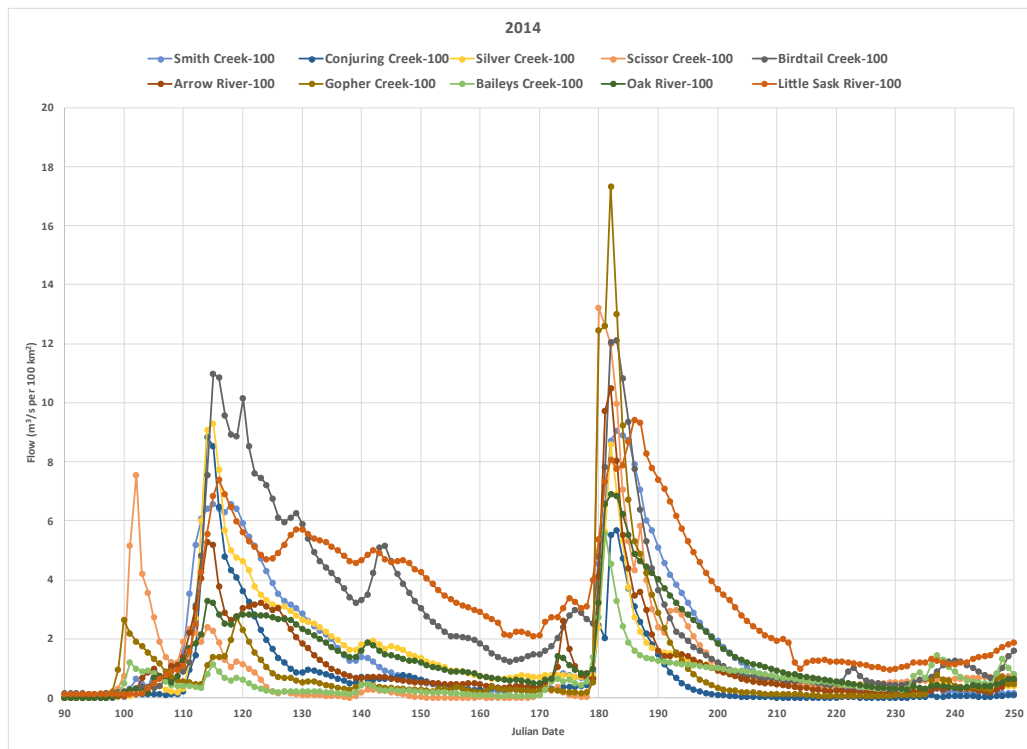


Figure 3.34 - Recorded Tributary Catchment Inflow – 2014 Normalized

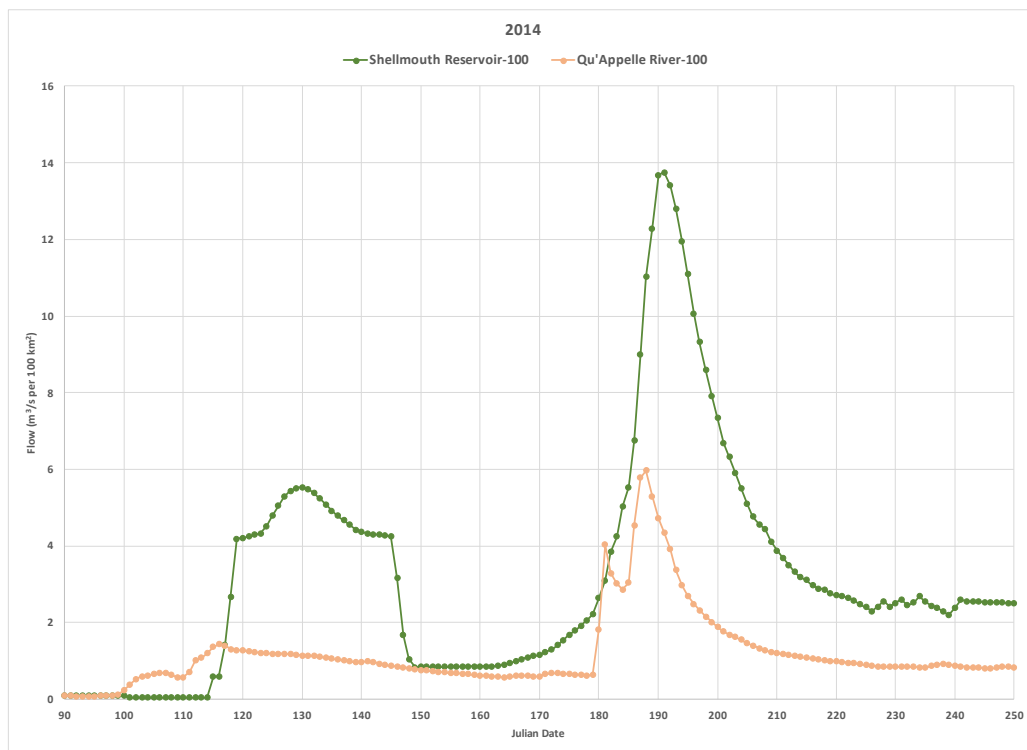


Figure 3.35 - Recorded Major Catchment Inflow – 2014 Normalized

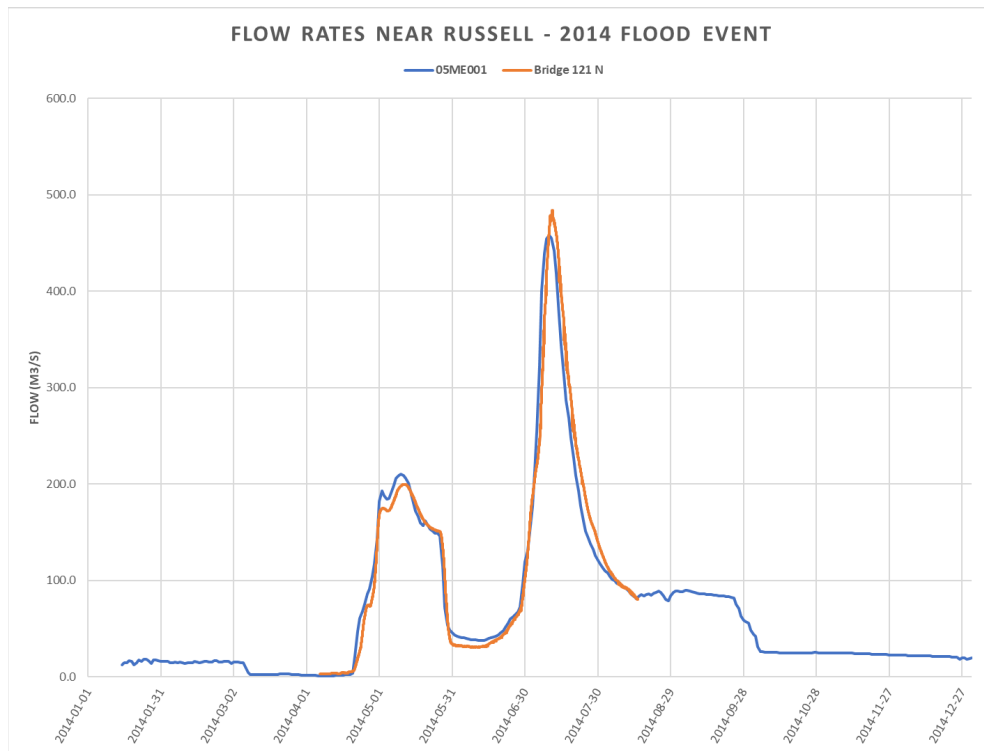


Figure 3.36 - Recorded and Modelled Flow near Russell - 2014

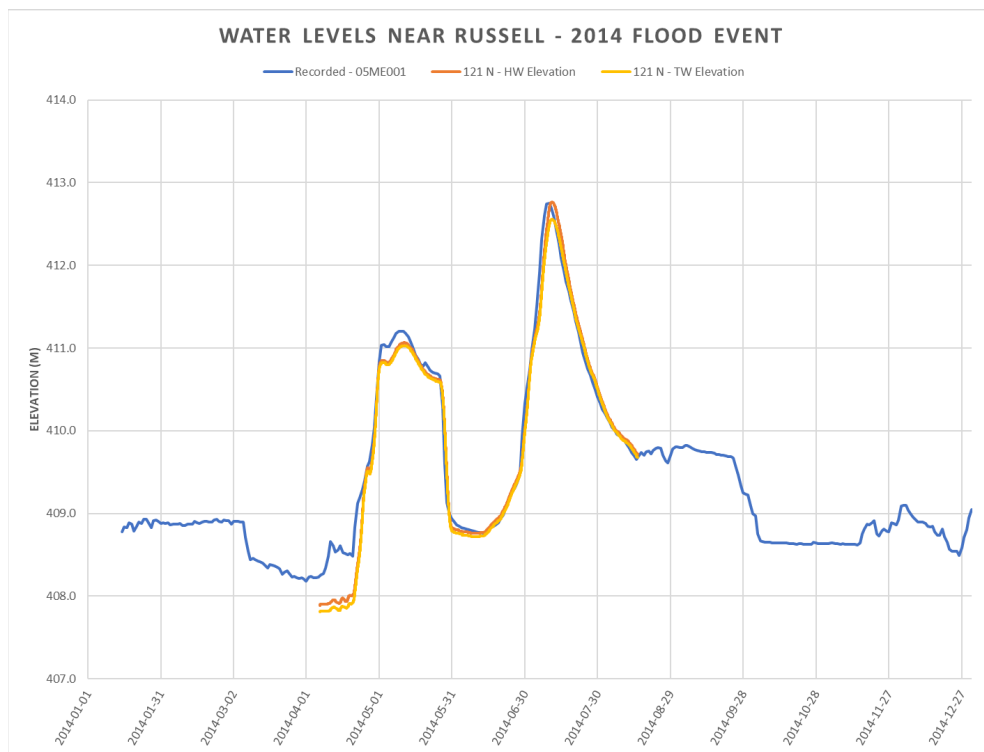


Figure 3.37 - Recorded and Modelled Water Level near Russell - 2014

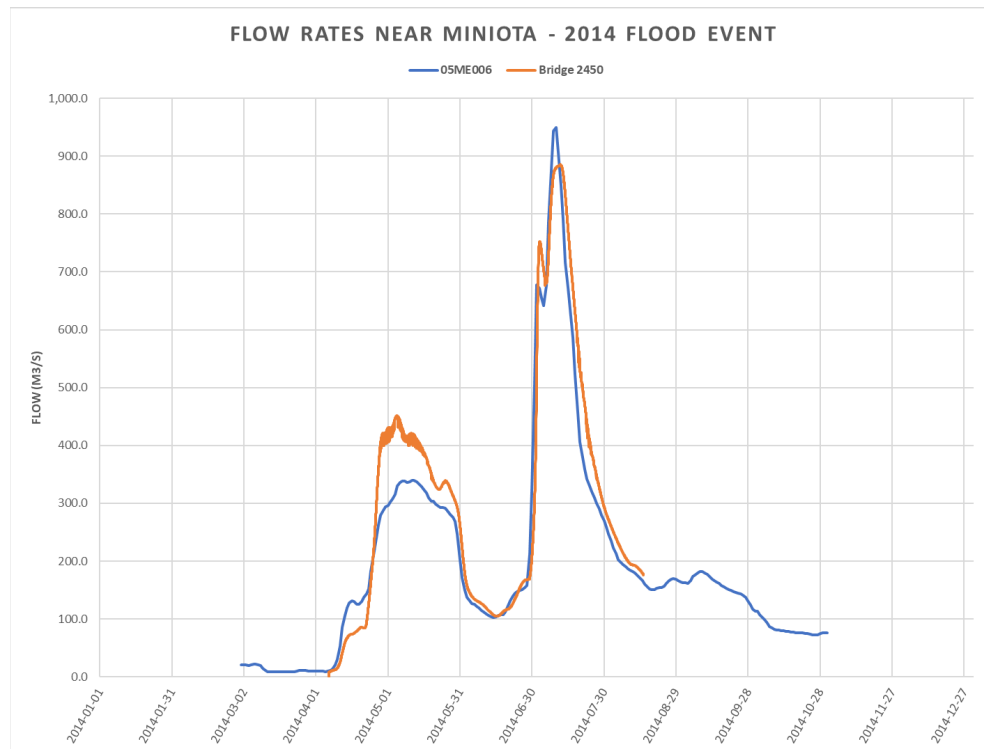


Figure 3.38 - Recorded and Modelled Flow near Miniota - 2014

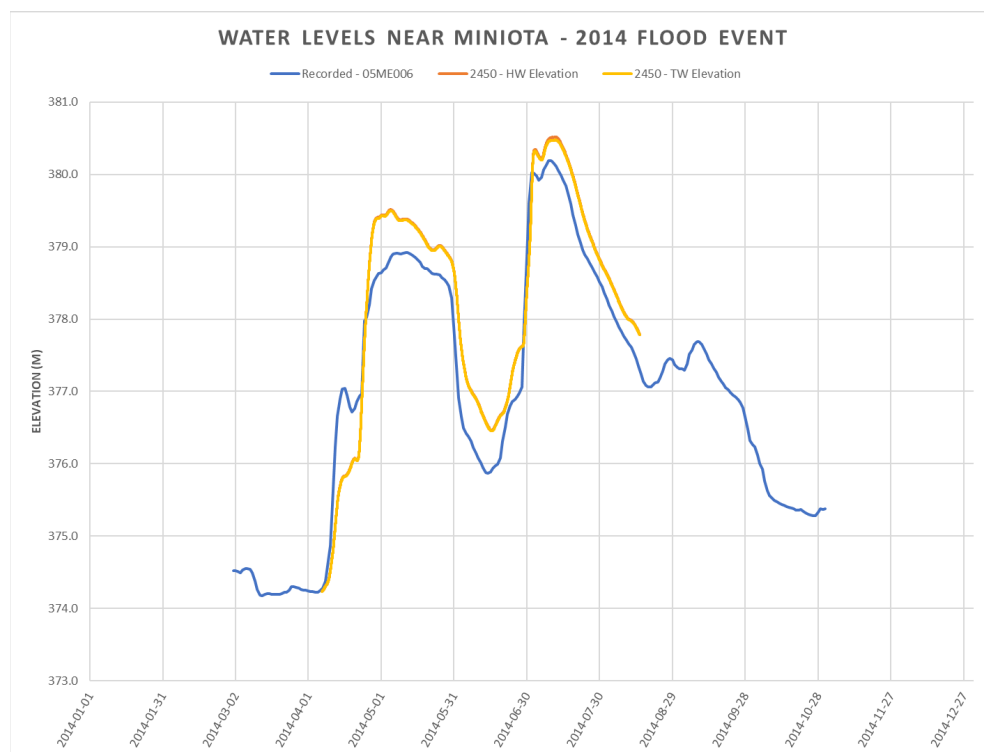


Figure 3.39 - Recorded and Modelled Water Level near Miniota - 2014

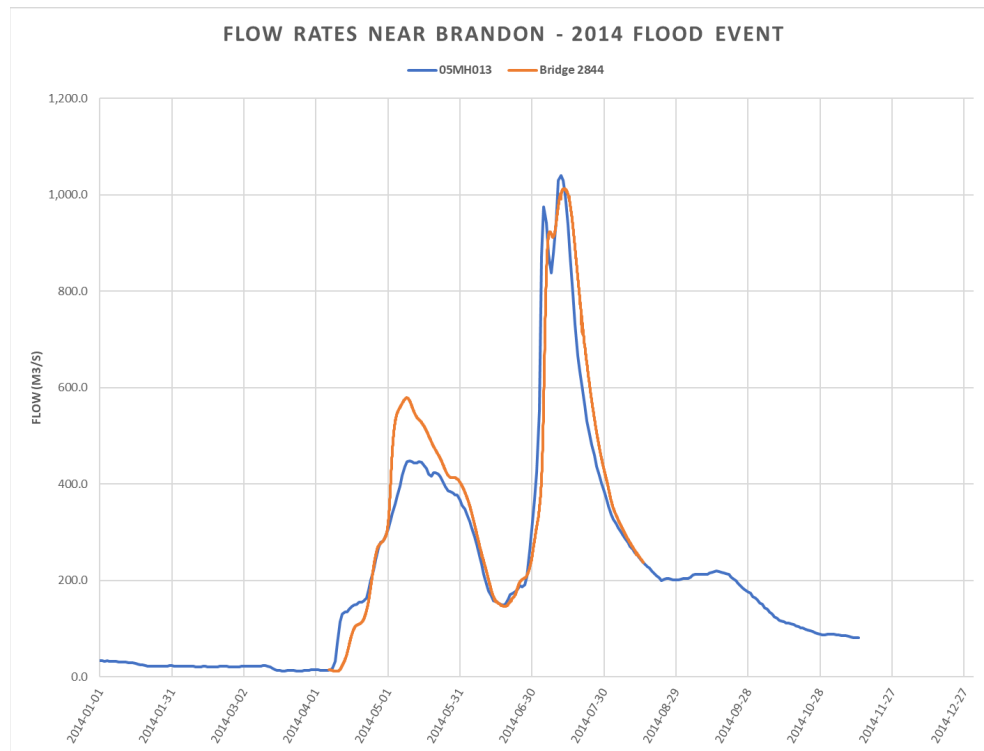


Figure 3.40 - Recorded and Modelled Flow near Brandon - 2014

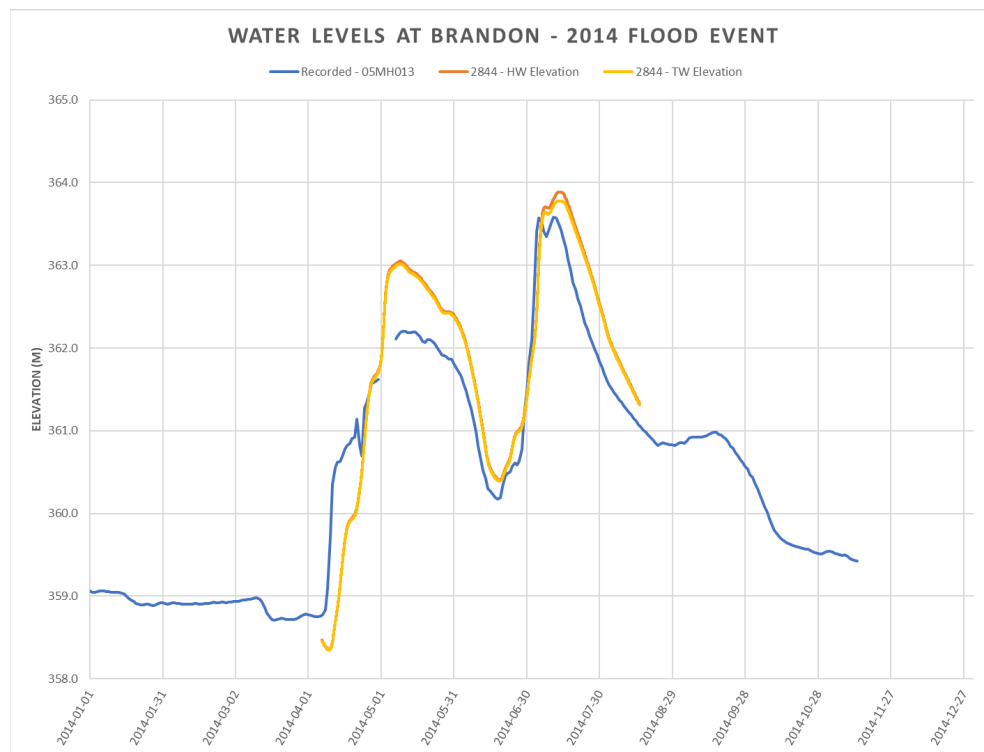


Figure 3.41 - Recorded and Modelled Water Level near Brandon – 2014

3.3.6 2017

The 2017 event is characterized by a single snowmelt-driven runoff with minimal subsequent rainfall-driven peaks. Recorded flow data is available at the following gauge locations shown in Table 3.14.

Table 3.14 - Gauge Locations - 2017

Location	Gauge Number
Smith Creek near Marchwell	05ME007
Conjuring Creek near Russell	05ME005
Silver Creek near Binscarth	05ME010
Scissor Creek near McAuley	05ME009
Birdtail Creek near Birtle	05ME003
Arrow River near Arrow River	05MG001
Gopher Creek near Virden	05MG003
Baileys Creek near Oak River	05MG015
Oak River near Rivers	05MG004
Little Saskatchewan River near Rivers	05MF018

Normalized recorded flow is provided in Figure 3.42 and Figure 3.43 as m^3/s per 100 km^2 . The recorded data indicates that all catchments contributed to the spring peak of the 2017 event with similar timing and similar hydrograph shape. Birdtail Creek, Silver Creek, and Conjuring Creek appear to have generated the highest rate of runoff during the summer event, while both the Shellmouth Reservoir and the Qu'Appelle River provided reasonable inflow. The peak flow from the Shellmouth Reservoir is $106.6 \text{ m}^3/\text{s}$ and the peak flow from the Qu'Appelle River is $98.4 \text{ m}^3/\text{s}$. The Qu'Appelle River is shown to have peaked earlier than the peak discharge from the Shellmouth Reservoir.

Recorded and modelled flow and water level results are shown in Figure 3.44 through Figure 3.49. A summary of the results is presented in Table 3.15. Almost all compliance locations satisfy the calibration criteria.

Table 3.15 - Recorded and Modelled Results of Discharge and Water Level - 2017

	Russell	Miniota	Brandon
Discharge (m^3/s)			
Recorded	133.0 (April 6)	510.0 (April 6)	670.0 (April 10)
Modelled	136.3 (April 6)	485.9 (April 6)	655.1 (April 12)
Difference	+ 3.3 (2.5%)	- 24.1 (4.7%)	- 14.9 (2.2%)
Water Level (m)			
Recorded	407.37 (April 1)	379.58 (April 5)	360.24 (April 10)
Modelled	407.64 (April 6)	379.66 (April 6)	360.20 (April 12)
Difference	+ 0.27	+ 0.08	- 0.04

The hydrographs for 2017 track the recorded data very well across the whole event. Generally, the modelled results of the 2017 event follow the recorded data very well. The 2017 event is seen as the cleanest event with no subsequent rainfall that extends or further peaks the hydrograph. For this reason, the 2017 hydrographs and catchment assignments are used to develop the 200-year inflow hydrographs for flood mapping.

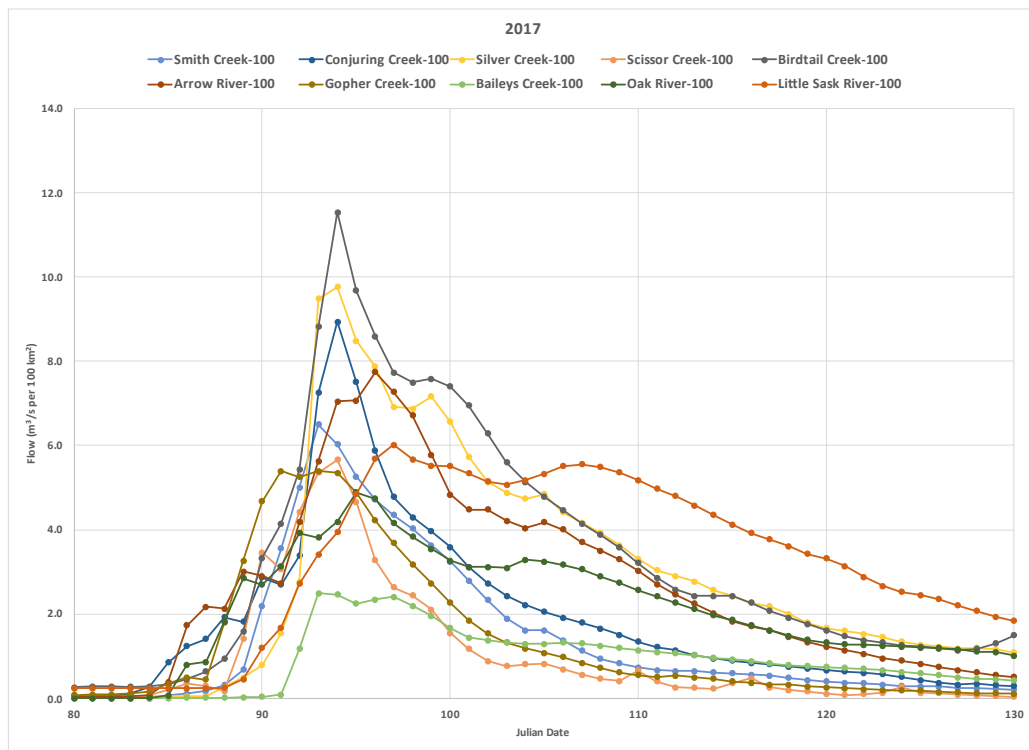


Figure 3.42 - Recorded Tributary Catchment Inflow – 2017 Normalized

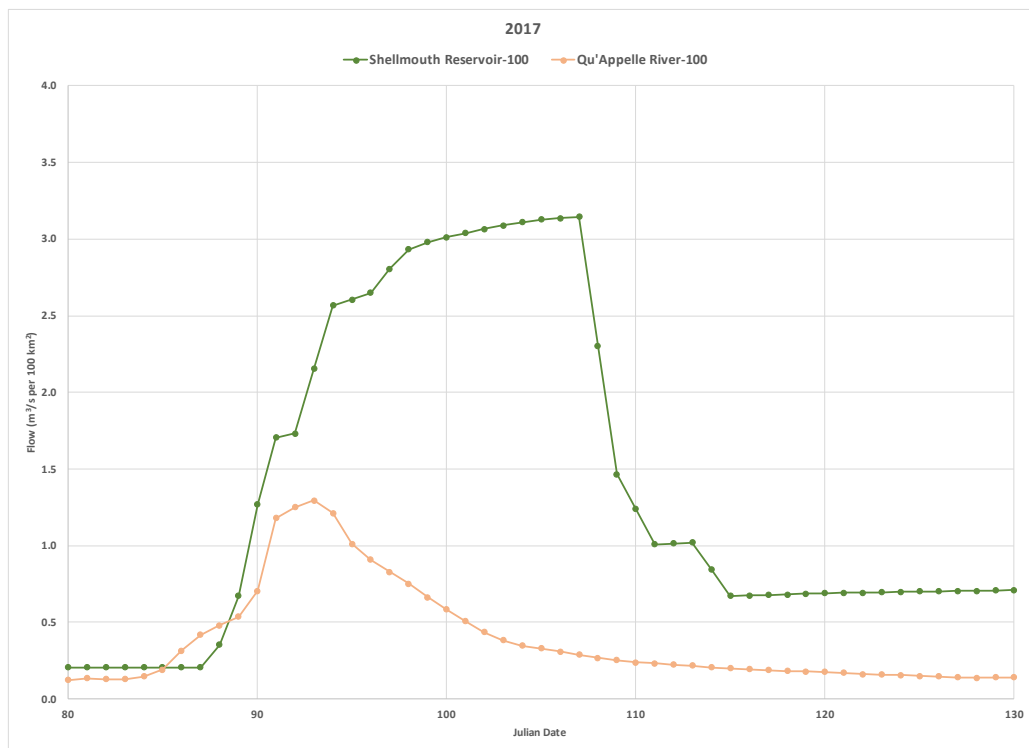


Figure 3.43 - Recorded Major Catchment Inflow – 2017 Normalized

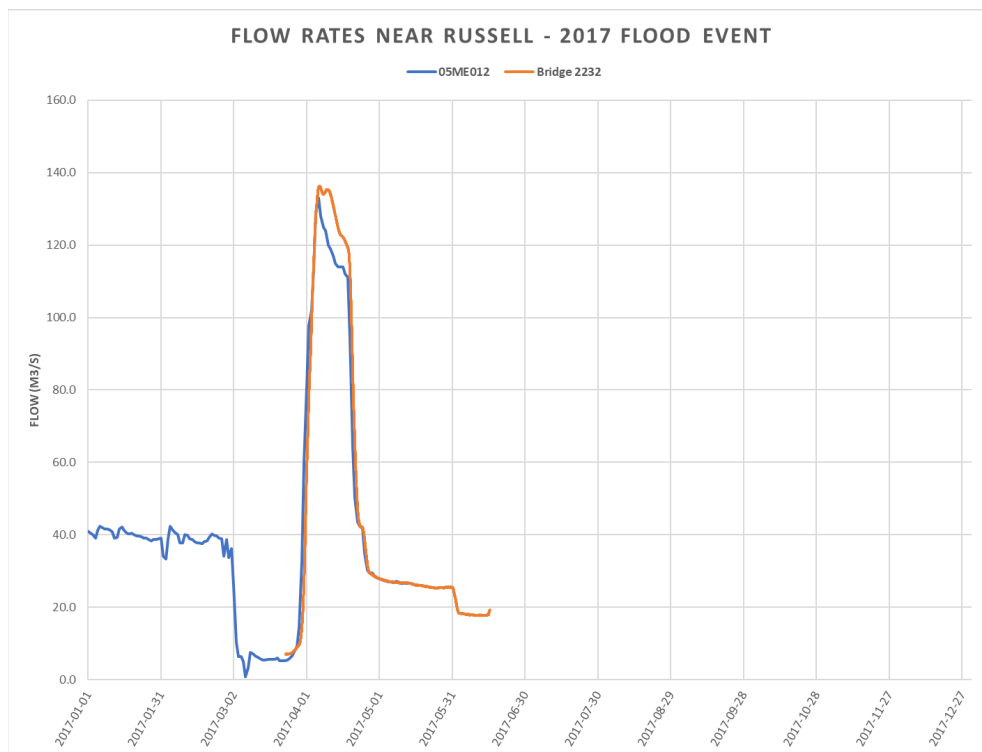


Figure 3.44 - Recorded and Modelled Flow near Russell - 2017

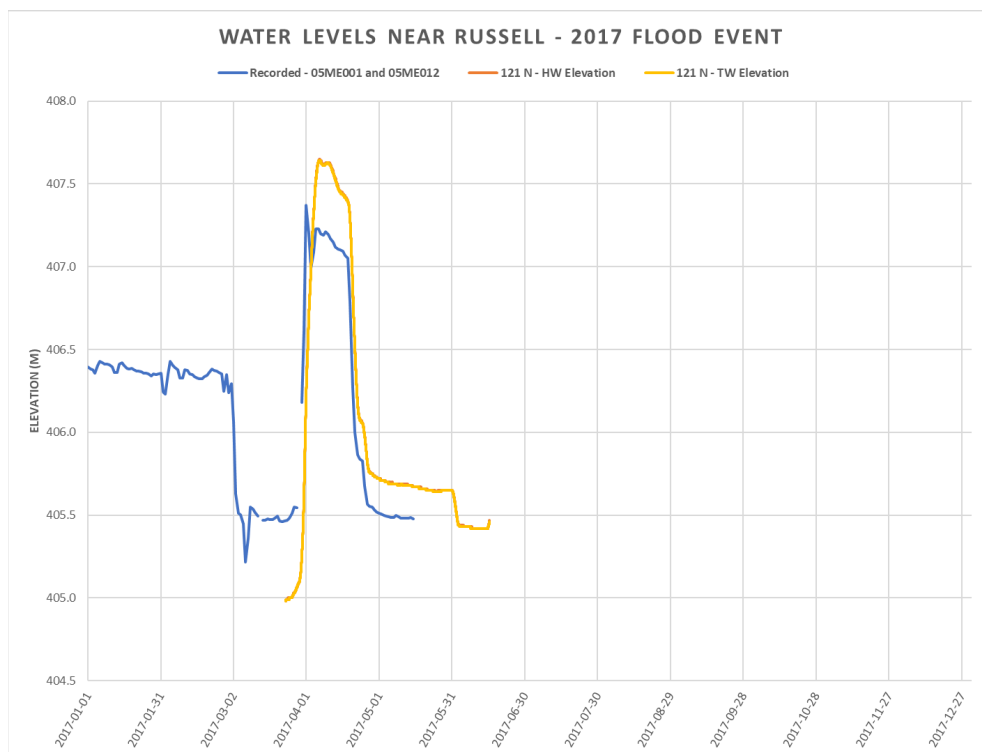


Figure 3.45 - Recorded and Modelled Water Level near Russell - 2017

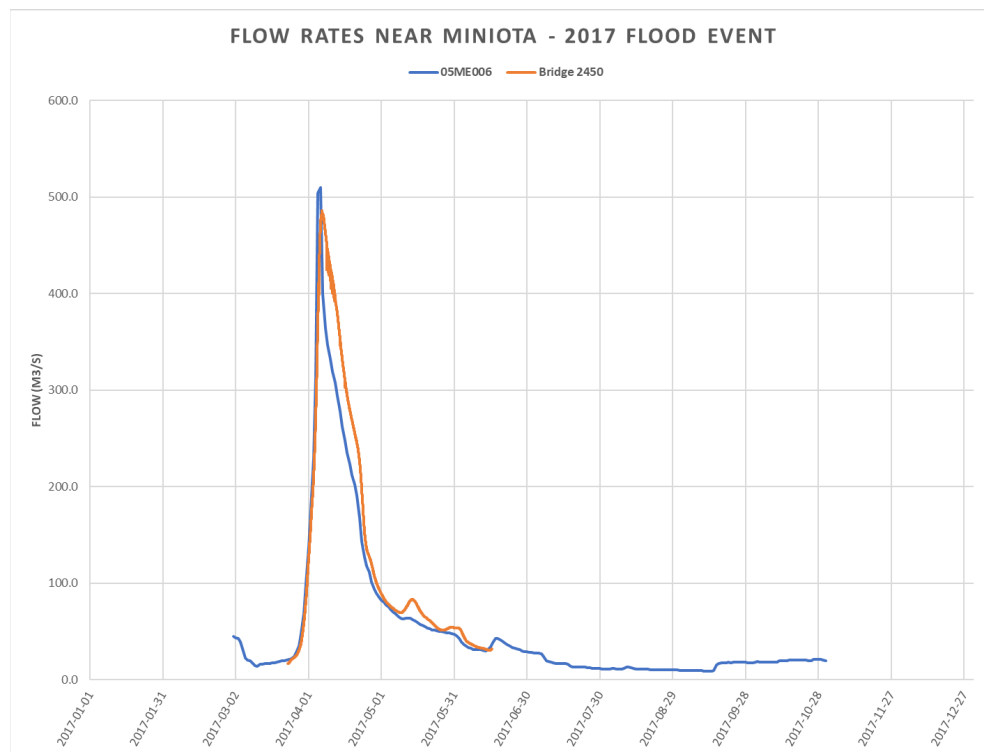


Figure 3.46 - Recorded and Modelled Flow near Miniota - 2017

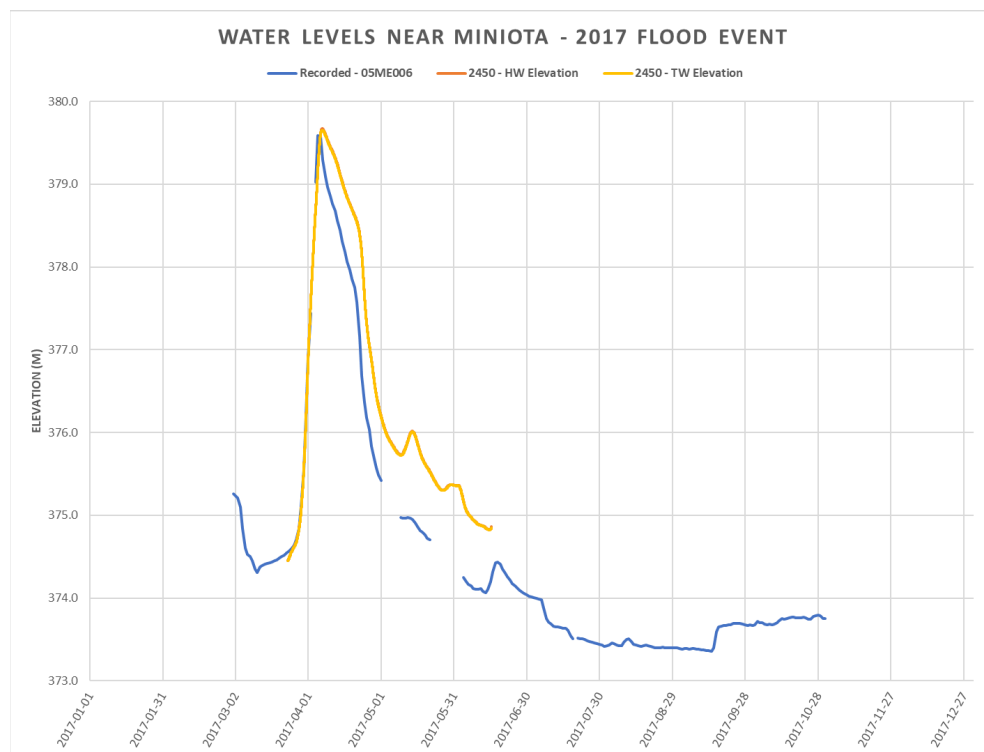


Figure 3.47 - Recorded and Modelled Water Level near Miniota - 2017

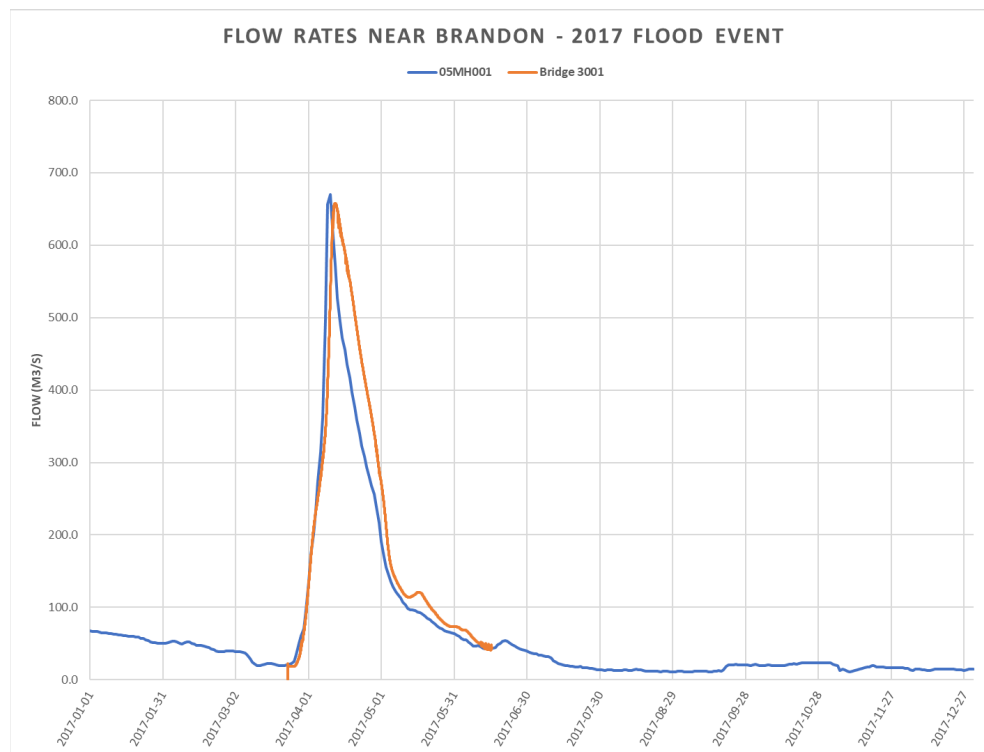


Figure 3.48 - Recorded and Modelled Flow near Brandon - 2017

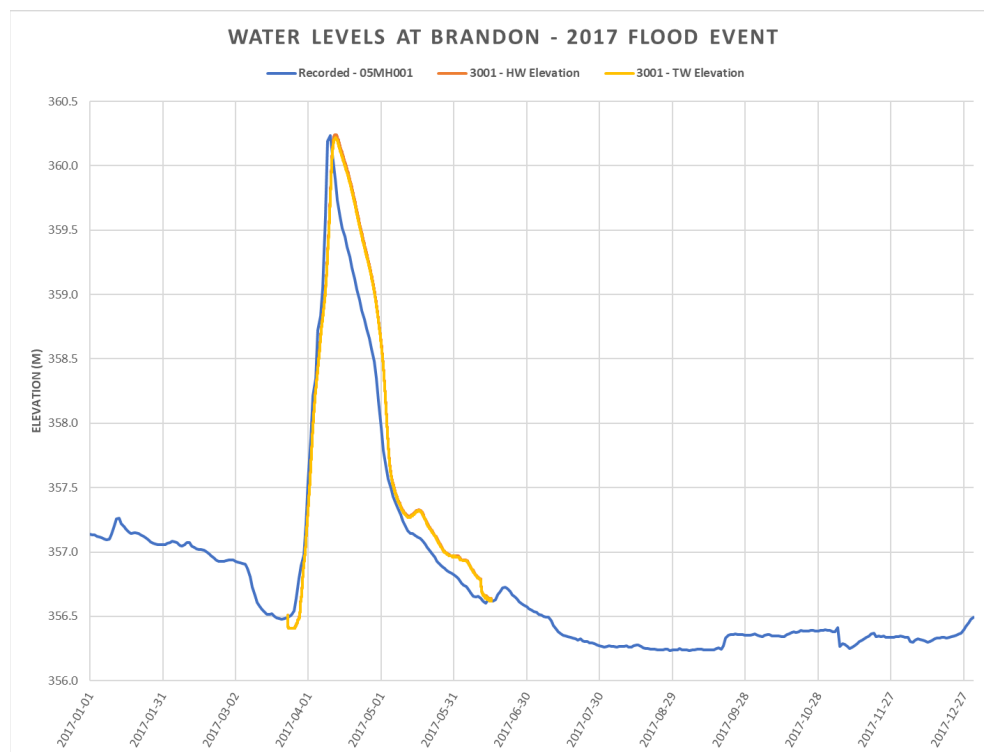


Figure 3.49 - Recorded and Modelled Water Level near Brandon - 2017

4. Frequency Flow Events Hydrographs Development

4.1 Unit Hydrograph Method

The unit hydrograph method is used to generate runoff hydrographs of required frequency flow events.

Unit hydrographs for each gauged catchment were generated using t/T_r (time/time to rise) as the x-axis and Q/Q_{peak} (flow/peak flow) as the y-axis, based on a selected recorded hydrograph derived from historical events. Most unit hydrographs were generated from the 2005 and 2017 recorded flows, as they are most likely to represent single rainfall or snowmelt events without the influence of aggregated mass rainfall events.

A linear relationship between the peak flow and time to rise was determined for each gauged catchment. The unit hydrographs were calibrated and verified against historical events by applying the recorded peak flows and calculated time to rise to the unique unit hydrographs. The unit hydrographs were then slightly modified based on the comparisons between the recorded hydrographs and the synthetic hydrographs generated from unit hydrographs.

In addition to gauged catchments, the Shellmouth Reservoir is a special catchment where outflows are typically regulated through operational controls. However, due to the reservoir's relatively small storage capacity, the water level can reach the spillway elevation and result in unregulated flow during heavy rainfall events. The unregulated portion of the 2014 event was used to produce the unit hydrograph for the unregulated flow of the Shellmouth Reservoir, as the 2014 event has the largest recorded peak flow and detailed operational records.

The unit hydrographs for Shellmouth Reservoir and eleven (11) other gauged catchments are shown in Appendix A, along with the calibration results comparing the recorded hydrographs and the synthetic hydrographs obtained from unit hydrographs.

4.2 Assiniboine River Dominant Frequency Flow Events Hydrographs

The Assiniboine River dominant frequency flow events hydrographs of 20-year (5%), 50-year (2%), 100-year (1%), 200-year (0.5%), 300-year (0.33%), and 500-year (0.2%) were generated. Frequency flow events were assumed to be driven by single peaks reaching the peak flows, rather than multiple peaks, for flood mapping purposes.

Hydrographs for twelve (12) gauged catchments under six (6) frequency flow scenarios were generated using unit hydrographs, peak flows, and time of rise.

The peak flows of the Shellmouth Reservoir and the Qu'Appelle River were obtained from the frequency event target peak flows provided by MTI, as shown in Table 4.1. Flow relationships between other catchments and their next downstream gauged communities (Russell, Miniota, or Brandon) were investigated using historical data from six (6) calibration and verification events. Based on these flow relationships and the target peak flows at gauged locations, the peak flows for these catchments were determined, as shown in Table 4.2. Detailed flow relationships and analysis processes are provided in Appendix B.

The time of rise was calculated from the peak flow. The flowtime of rise relationship for each catchment was investigated using historical data from six (6) calibration and verification events. Based on this relationship and the peak flow for each catchment, the time of rise was calculated, as shown in Table 4.3. Detailed flowtime of rise relationships and analysis processes are provided in Appendix C.

Table 4.1 - The Assiniboine River Dominant Frequency Flow Events Target Peak Flows

Frequency	Return Period (Years)	Shellmouth Reservoir (m ³ /s)	Russell (m ³ /s)	St. Lazare (m ³ /s)	Miniota (m ³ /s)	Virden (m ³ /s)	Griswold (m ³ /s)	Brandon (m ³ /s)	Qu'Appelle Contribution (m ³ /s)
0.2%	500	855	861	1305	1359	1515	1586	1674	598
0.33%	300	750	756	1138	1178	1303	1362	1438	512
0.5%	200	671	677	997	1045	1141	1198	1263	430
1%	100	515	521	779	835	915	966	1025	344
2%	50	396	399	580	648	714	767	818	245
5%	20	215	244	379	430	481	541	580	181

Table 4.2 - Used Peak Flows under the Assiniboine River Dominant Frequency Flow Events

Frequency	Return Period (Years)	Shellmouth Reservoir (m ³ /s)	Smith Creek (m ³ /s)	Conjuring Creek (m ³ /s)	Silver Creek (m ³ /s)	Qu'Appelle River (m ³ /s)	Scissor Creek (m ³ /s)	Birdtail Creek (m ³ /s)	Arrow River (m ³ /s)	Gopher Creek (m ³ /s)	Baileys Creek (m ³ /s)	Oak River (m ³ /s)	Little Saskatchewan River (m ³ /s)
0.2%	500	855	40	11	50	598	25	78	42	28	6	20	157
0.33%	300	750	36	10	43	512	24	73	37	24	5	21	140
0.5%	200	671	33	10	38	430	23	70	34	21	5	21	127
1%	100	515	27	9	31	344	21	64	29	17	4	22	109
2%	50	396	22	8	24	245	20	59	25	14	3	22	94
5%	20	215	17	7	16	181	18	53	21	10	2	23	76

Table 4.3 - Used Time of Rise under the Assiniboine River Dominant Frequency Flow Events

Frequency	Return Period (Years)	Shellmouth Reservoir (Days)	Smith Creek (Days)	Conjuring Creek (Days)	Silver Creek (Days)	Qu'Appelle River (Days)	Scissor Creek (Days)	Birdtail Creek (Days)	Arrow River (Days)	Gopher Creek (Days)	Baileys Creek (Days)	Oak River (Days)	Little Saskatchewan River (Days)
0.2%	500	51.0	21.1	8.5	10.6	11.6	5.1	12.2	8.2	4.8	4.3	7.4	23.1
0.33%	300	44.5	19.1	8.1	9.6	11.1	5.0	11.5	8.0	4.5	4.1	7.4	20.7
0.5%	200	39.7	17.6	7.8	8.8	10.6	5.0	11.0	7.8	4.2	4.0	7.4	18.8
1%	100	30.0	14.5	7.3	7.6	10.0	4.9	10.2	7.5	3.9	3.8	7.4	16.4
2%	50	22.7	12.2	6.9	6.6	9.4	4.9	9.5	7.3	3.6	3.7	7.4	14.2
5%	20	11.5	9.1	6.3	5.3	9.1	4.8	8.7	7.0	3.3	3.5	7.4	11.7

Note: The peak dates for all hydrographs, including flow from Shellmouth Dam and lateral inflows and tributaries, are assumed to be aligned with the peak dates of the 2017 event, as the 2017 event represents a scenario where the Assiniboine River was the dominant flow.

The Shellmouth Reservoir is a unique catchment among the twelve (12) gauged catchments, as it is regulated by operations and provides the dominant flow. The hydrographs for the Shellmouth Reservoir during frequency flow events used the recorded 2014 event's operational method as a reference, given that the 2014 event had the largest recorded peak flow and detailed operational documentation. The Report on 2014 Artificial Flooding due to Operation of the Shellmouth Dam can be found in Appendix F.

Four (4) stages appear in the Shellmouth hydrograph, as shown in Figure 4.1, which uses the 200-year event as an example and the 2014 event as a reference.

- Stage 1: The water level in the Shellmouth Reservoir is conservatively assumed to be close to the spillway elevation of 429.31 m before the frequency flow event starts. The conduit in the Shellmouth Dam is assumed to maintain a constant flow rate of 28.32 m³/s (1000 ft³/s) before and during the frequency flow event, based on the 2014 event record.
- Stage 2: The water level reaches the spillway elevation at the start of stage 2 due to the frequency flow contributions. Total outflow in stage 2 equals the conduit flow (28.32 m³/s) plus spillway flow (generated from unit hydrograph). The maximum total outflows hit the targeted peak flows of different frequency events. Stage 2 ends when the total outflow declines to 84.95 m³/s (3000 ft³/s).
- Stage 3: During stage 3, the conduit flow is increased to keep the total outflow from the dam to a target of 84.95 m³/s (3000 ft³/s) to draw down the reservoir to help prevent potential future flooding. As the spillway flow continues to decline, the conduit flow is increased every few days to maintain a total outflow of 84.95 m³/s. This is in reference to the 2014 operation.
- Stage 4: The water level drops to the spillway elevation at the beginning of stage 4. The conduit flow becomes the total outflow. A conduit flow of around 84.95 m³/s is maintained to draw down the reservoir for several days.

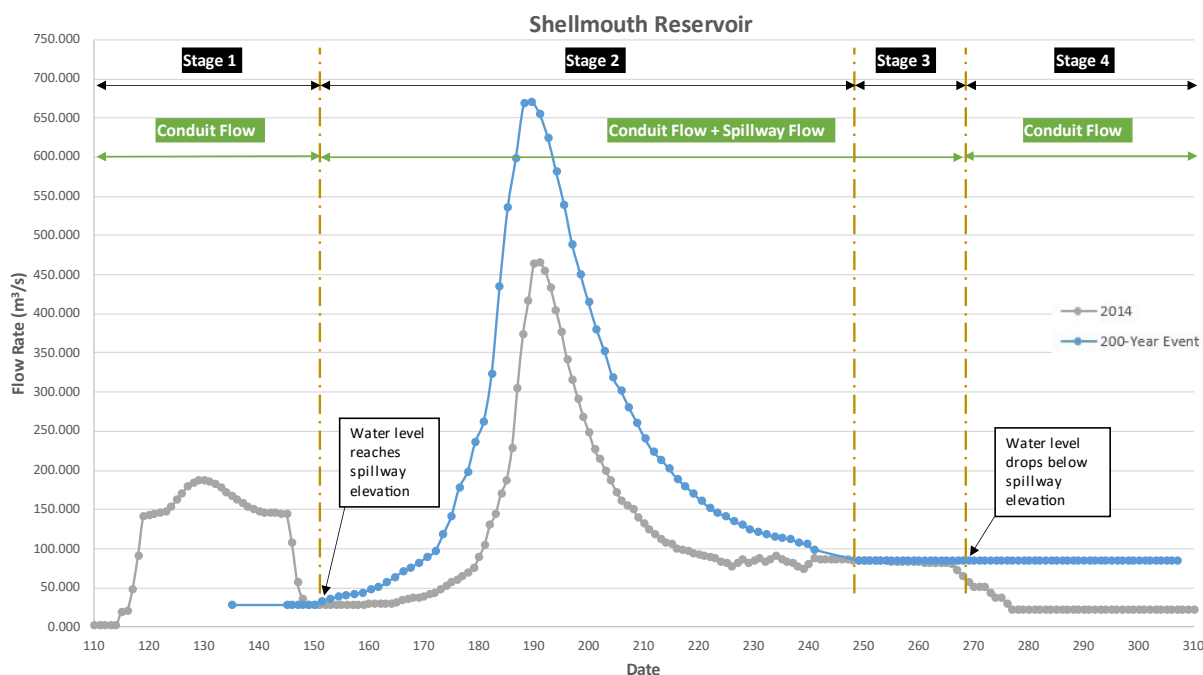


Figure 4.1 - Shellmouth Reservoir Frequency Flow Stages – 200-Year Event

The remaining fifty-two (52) catchments were assigned gauged hydrographs using the same catchment reference as the 2017 event. The peak days for all hydrographs align with those of the 2017 event, as it represents a scenario where the peak flow from the Shellmouth Reservoir exceeds that of the Qu'Appelle River, matching the situation where the Assiniboine River is the dominant flow.

Hydrographs of frequency events of 20-year (5%), 50-year (2%), 100-year (1%), 200-year (0.5%), 300-year (0.33%), and 500-year (0.2%) are shown in Figure 4.2 through Figure 4.7.

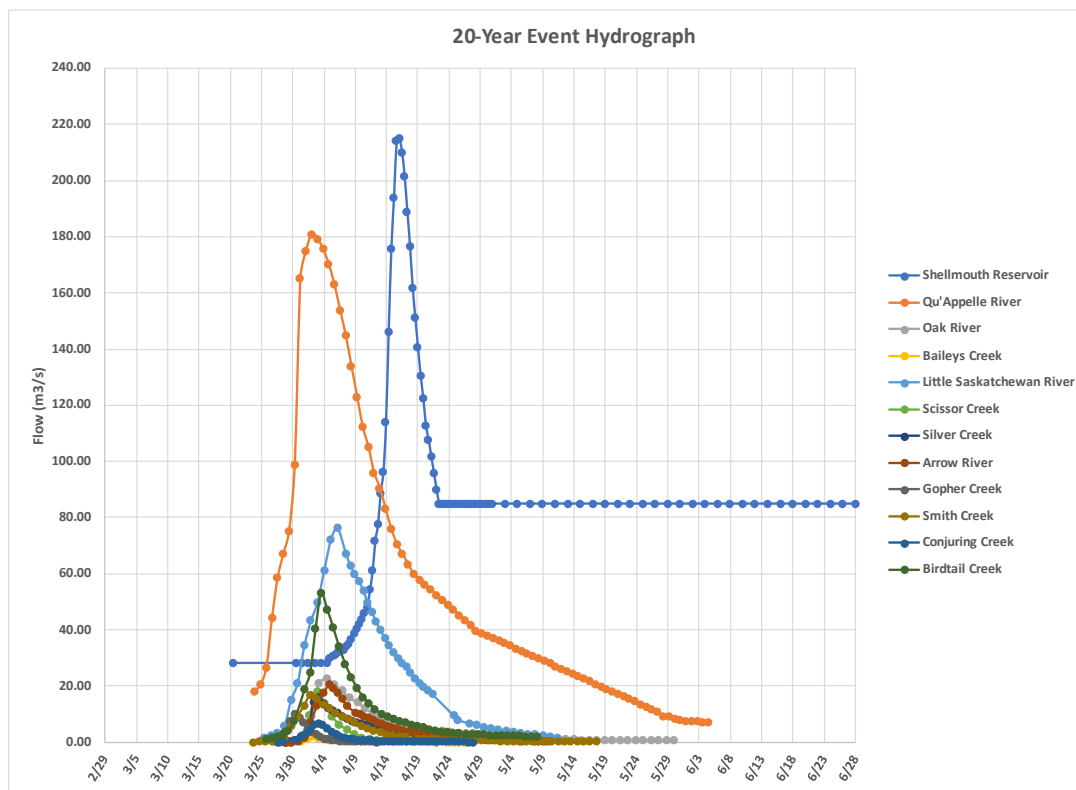


Figure 4.2 - Assiniboine River Dominant 20-Year Event Hydrograph

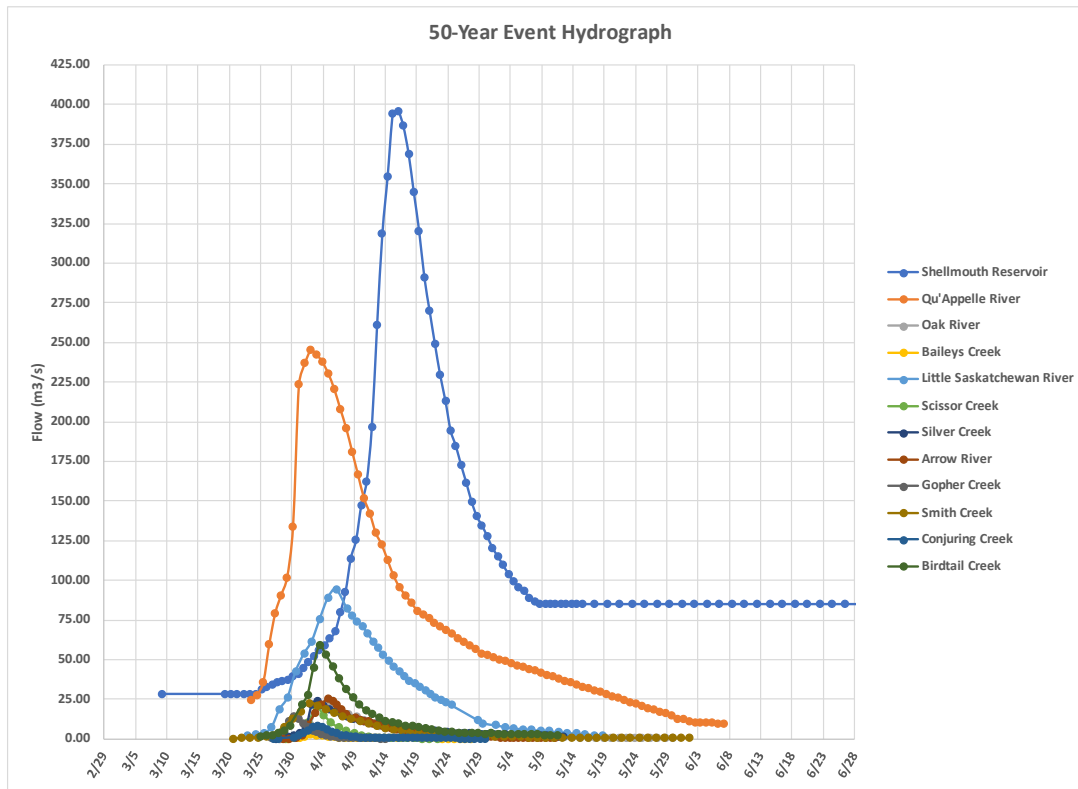


Figure 4.3 - Assiniboine River Dominant 50-Year Event Hydrograph

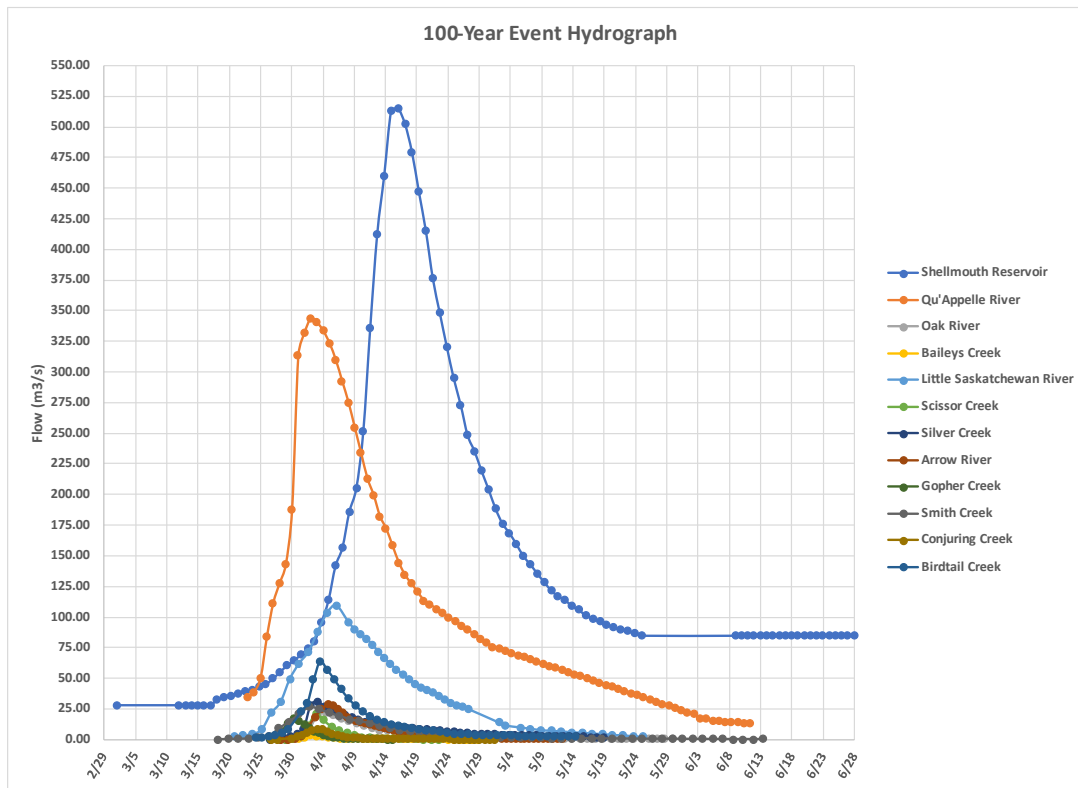


Figure 4.4 - Assiniboine River Dominant 100-Year Event Hydrograph

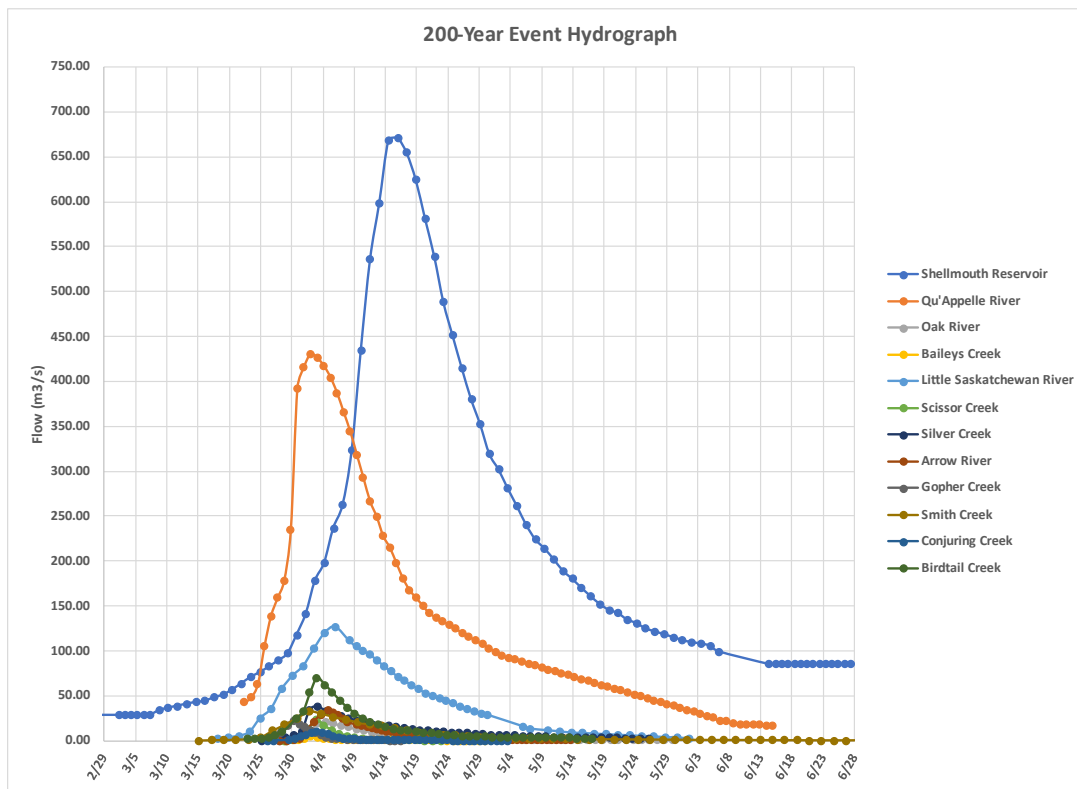


Figure 4.5 - Assiniboine River Dominant 200-Year Event Hydrograph

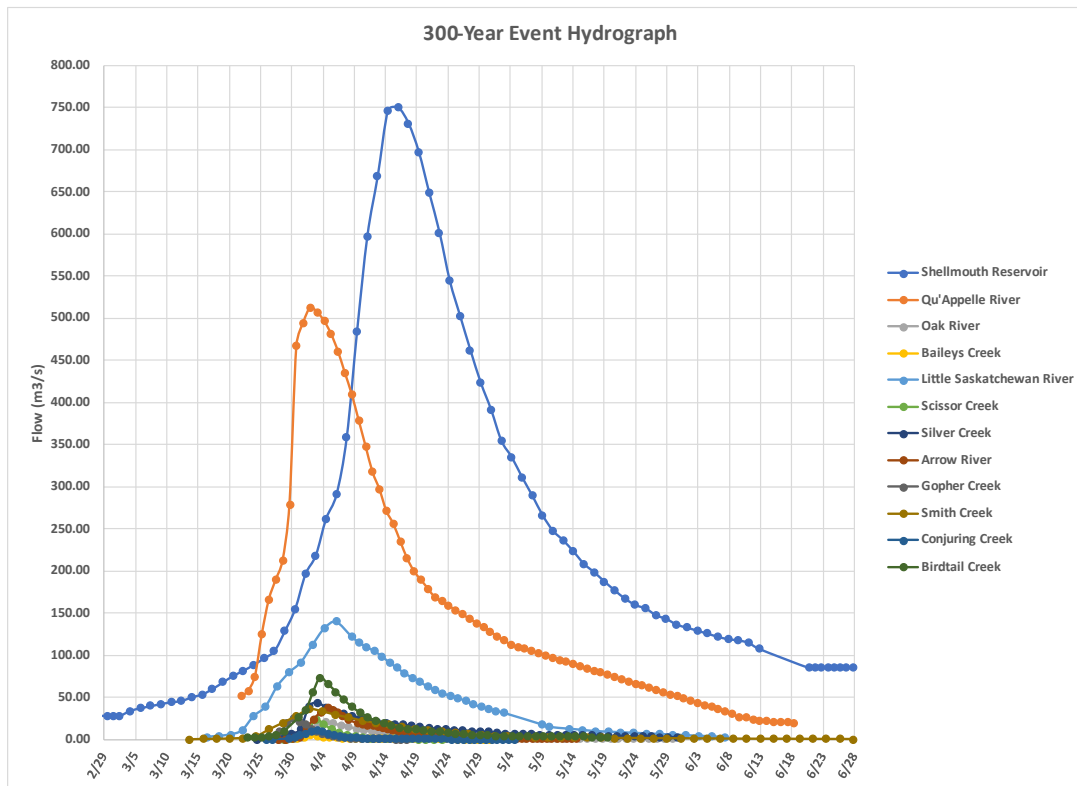


Figure 4.6 - Assiniboine River Dominant 300-Year Event Hydrograph

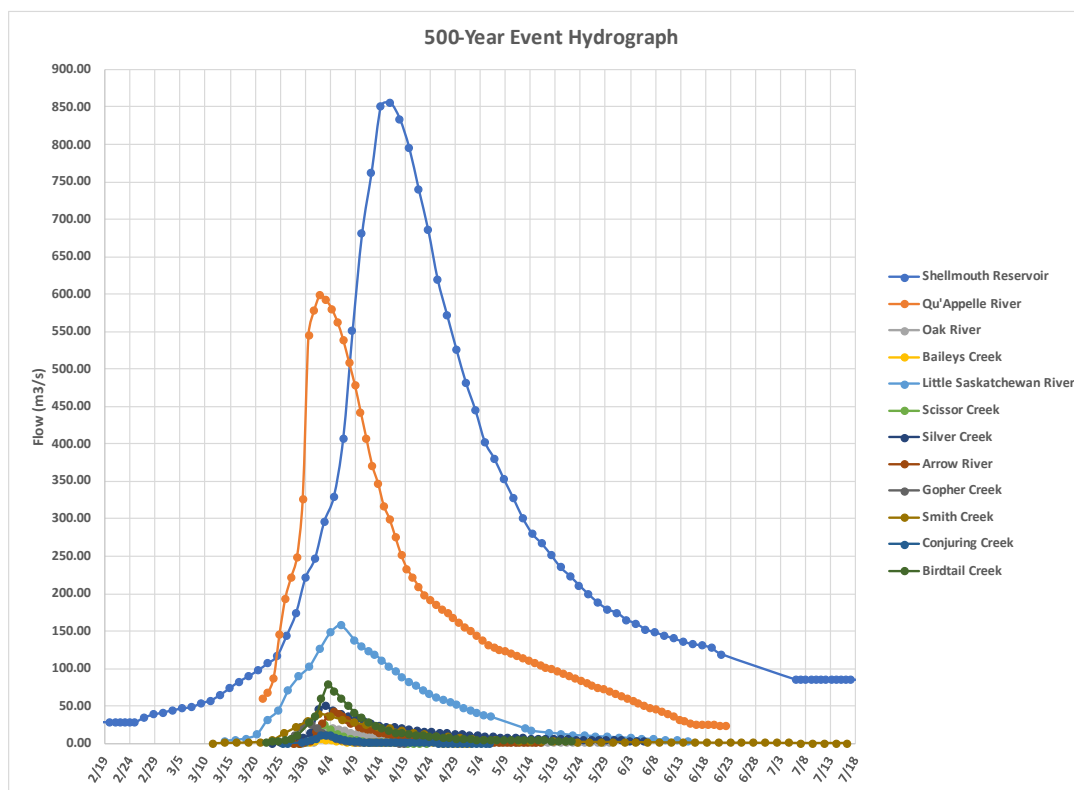


Figure 4.7 - Assiniboine River Dominant 500-Year Event Hydrograph

4.3 Qu'Appelle River Dominant Frequency Flow Event Hydrograph

Hydrographs for the 200-year (0.5%) Qu'Appelle River dominant frequency flow event were generated. Frequency flow event was assumed to be driven by a single peak reaching the peak flow rather than multiple peaks for flood mapping purposes.

Hydrographs for twelve (12) gauged catchments under the 200-year (0.5%) frequency flow scenario were generated using unit hydrographs, peak flows, and time of rise, as described in Section 4.2.

The peak flow of the Qu'Appelle River was obtained from the 200-year target peak flow provided by MTI, as shown in Table 4.4. The peak flows and time of rise used for the catchments, as shown in Table 4.5 and Table 4.6, were generated using the same methodology outlined in Section 4.2.

It is worth mentioning that the Shellmouth Reservoir's hydrograph was assumed to have a consistent conduit flow of 84.95 m³/s (3000 ft³/s) to achieve the target peak flow at St. Lazara. The remaining catchments were assigned gauged hydrographs using the same catchment reference as the 2005 event. The peak days for all hydrographs align with those of the 2005 event, as it represents a scenario where the peak flow from the Qu'Appelle River exceeds that of the Shellmouth Reservoir, matching the situation where the Qu'Appelle River is the dominant flow.

The hydrograph of the 200-year (0.5%) frequency flow event is shown in Figure 4.8.

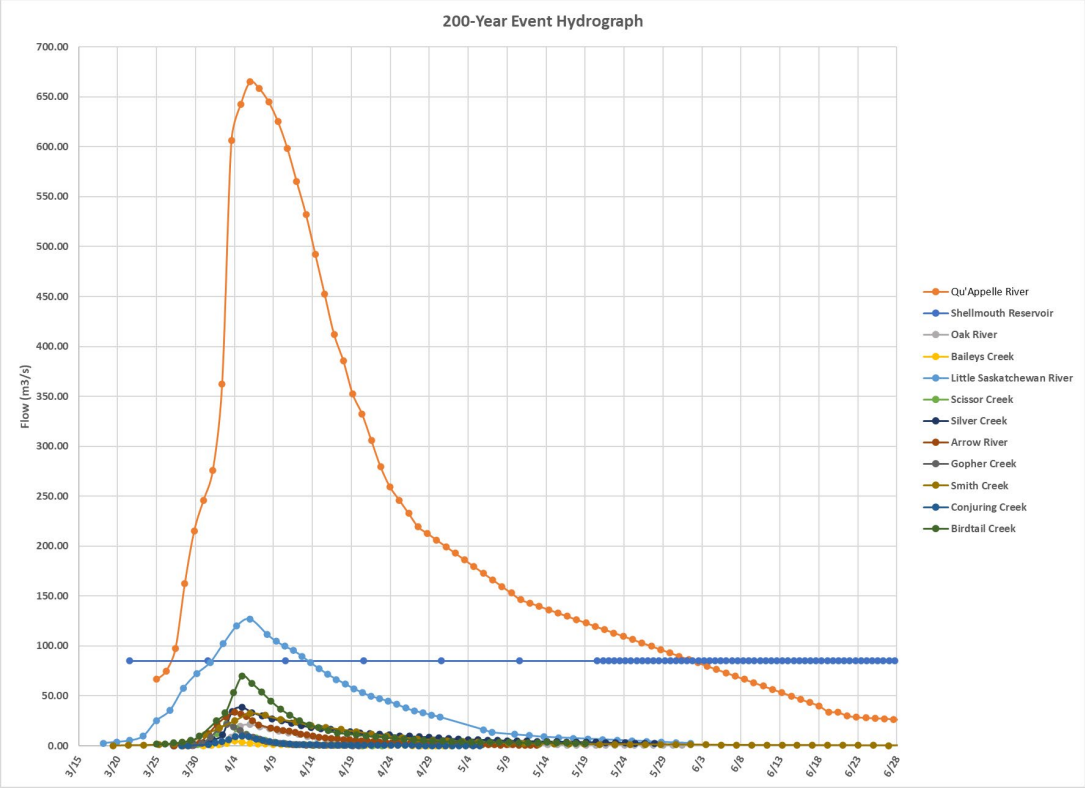


Figure 4.8 - Qu'Appelle River Dominant 200-Year Event Hydrograph

Table 4.4 - The Qu'Appelle River Dominant Frequency Flow Event Target Peak Flows

Frequency	Return Period (Years)	Qu'Appelle River (m ³ /s)	Russell (m ³ /s)	St. Lazare (m ³ /s)	Miniota (m ³ /s)	Virden (m ³ /s)	Griswold (m ³ /s)	Brandon (m ³ /s)
0.5%	200	665	-	997	1045	1141	1198	1263

Table 4.5 - Used Peak Flows under the Qu'Appelle River Dominant Frequency Flow Event

Frequency	Return Period (Years)	Qu'Appelle River (m ³ /s)	Shellmouth Reservoir (m ³ /s)	Smith Creek (m ³ /s)	Conjuring Creek (m ³ /s)	Silver Creek (m ³ /s)	Scissor Creek (m ³ /s)	Birdtail Creek (m ³ /s)	Arrow River (m ³ /s)	Gopher Creek (m ³ /s)	Baileys Creek (m ³ /s)	Oak River (m ³ /s)	Little Saskatchewan River (m ³ /s)
0.5%	200	665	85	33	10	38	23	70	34	21	5	21	127

Table 4.6 - Used Time of Rise under the Qu'Appelle River Dominant Frequency Flow Event

Frequency	Return Period (Years)	Qu'Appelle River (Days)	Shellmouth Reservoir (Days)	Smith Creek (Days)	Conjuring Creek (Days)	Silver Creek (Days)	Scissor Creek (Days)	Birdtail Creek (Days)	Arrow River (Days)	Gopher Creek (Days)	Baileys Creek (Days)	Oak River (Days)	Little Saskatchewan River (Days)
0.5%	200	12.0	-	17.6	7.8	8.8	5.0	11.0	7.8	4.2	4.0	7.4	18.8

Note: The peak dates for all hydrographs, including the Qu'Appelle River and lateral inflows and tributaries, are assumed to be aligned with the peak dates of the 2005 event, as the 2005 event represents a scenario where the Qu'Appelle River was the dominant flow.

5. Frequency Flow Events Results

5.1 Assiniboine River Dominant 200-Year Event Results

Target and modelled flow at each compliance location under the 200-year event are shown in Table 5.1. The modelled results are shown to be within the required 5% for flow at each of the six (6) compliance locations.

Modelled flow hydrographs at six (6) compliance locations are shown in Figure 5.1. Two (2) peaks appear in hydrographs downstream of St. Lazare. The first peak is caused by flow from the Qu'Appelle River, and the second peak is caused by the Shellmouth Reservoir.

Figure 5.1 shows that peak flows at Russell and St. Lazare are governed by the Shellmouth Reservoir, and peak flows at Miniota, Virden, Griswold, and Brandon are governed by the Qu'Appelle River.

Consequently, this hydraulic model with developed inflow hydrographs can well represent the peak flow under a 200-year event.

Table 5.1 - Assiniboine River Dominant 200-Year Event Results

	Russell	St. Lazare	Miniota	Virden	Griswold	Brandon
Target Peak Flow (m³/s)	676.8	996.8	1044.9	1141.2	1197.8	1262.9
Modelled Peak Flow (m³/s)	707.8	949.2	1062.0	1156.0	1200.1	1308.3
Difference	+ 31.0 (4.6%)	- 47.6 (4.8%)	+ 17.1 (1.6%)	+ 14.8 (1.3%)	+ 2.3 (0.2%)	+ 45.4 (3.6%)
Modelled Peak Water Surface Elevation (m)	413.40	393.77	380.71	372.58	367.81	364.29

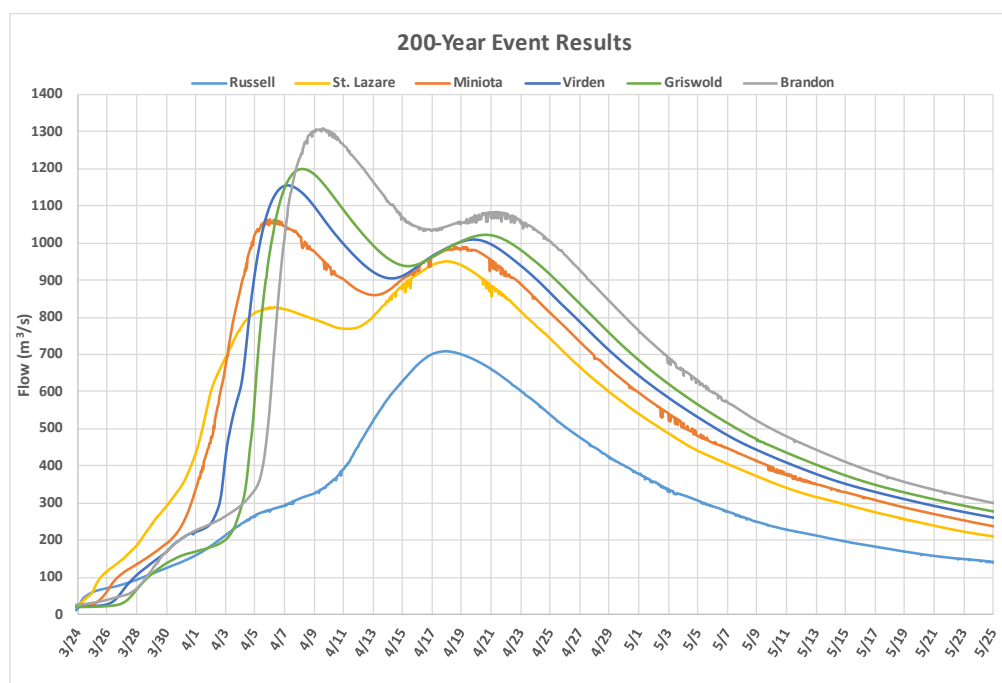


Figure 5.1 - Assiniboine River Dominant 200-Year Event Results

5.2 Other Assiniboine River Dominant Frequency Flow Events Results

5.2.1 20-Year Event

Target and modelled flow at each compliance location under the 20-year event are shown in Table 5.2. The modelled results at Griswold and Brandon are shown to be within the required 5% for flow, while the modelled results at Russell, St. Lazare, Miniota, and Virden are out of the 5% target range.

The 20-year event is the only event showing a discrepancy of over 10% at four (4) compliance locations, suggesting that the inflow hydrographs under the 20-year event might be inappropriate. The assumption of the Shellmouth Reservoir hydrograph is based on larger events with a greater amount of unregulated flow from the spillway.

Table 5.2 - Assiniboine River Dominant 20-Year Event Results

	Russell	St. Lazare	Miniota	Virden	Griswold	Brandon
Target Peak Flow (m³/s)	243.5	379.4	430.4	481.4	540.9	580.5
Modelled Peak Flow (m³/s)	209.2	340.7	514.8	537.7	556.7	584.8
Difference	- 34.3 (14.1%)	- 38.7 (10.2%)	+ 84.4 (19.6%)	+ 56.3 (11.7%)	+ 15.8 (2.9%)	+ 4.3 (0.7%)
Modelled Peak Water Surface Elevation (m)	411.10	392.28	379.71	371.49	366.64	363.03

Modelled flow hydrographs at six (6) compliance locations are shown in Figure 5.2. Two (2) peaks appear in hydrographs downstream of St. Lazare. The first peak is caused by flow from the Qu'Appelle River, and the second peak is caused by the Shellmouth Reservoir.

Figure 5.2 shows that peak flow at Russell is governed by the Shellmouth Reservoir, and peak flows at St. Lazare, Miniota, Virden, Griswold, and Brandon are governed by the Qu'Appelle River.

Consequently, this hydraulic model with developed inflow hydrographs is more suitable for events larger than 20-year.

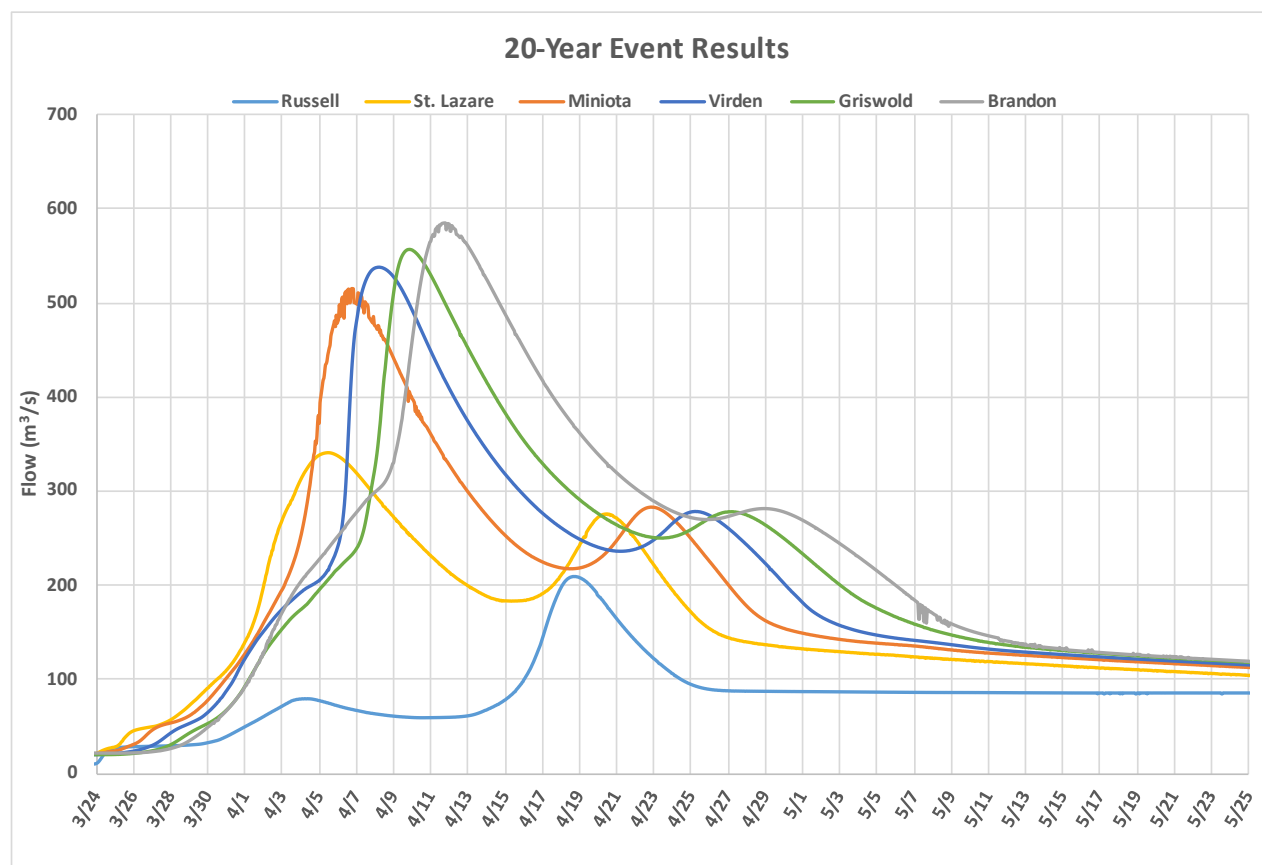


Figure 5.2 - Assiniboine River Dominant 20-Year Event Results

5.2.2 50-Year Event

Target and modelled flow at each compliance location under the 50-year event are shown in Table 5.3. The modelled results are shown to be within the required 5% for flow at five (5) compliance locations, while the result at St. Lazare is lower than the target peak flow.

Table 5.3 - Assiniboine River Dominant 50-Year Event Results

	Russell	St. Lazare	Miniota	Virden	Griswold	Brandon
Target Peak Flow (m³/s)	399.3	580.5	648.5	713.6	767.4	818.4
Modelled Peak Flow (m³/s)	403.6	515.9	663.3	704.3	733.2	789.7
Difference	+ 4.3 (1.1%)	- 64.6 (11.1%)	+ 14.8 (2.3%)	- 9.3 (1.3%)	- 34.2 (4.5%)	- 28.7 (3.5%)
Modelled Peak Water Surface Elevation (m)	412.22	392.92	380.15	371.81	366.96	363.42

Modelled flow hydrographs at six (6) compliance locations are shown in Figure 5.3. Two (2) peaks appear in hydrographs downstream of St. Lazare. The first peak is caused by flow from the Qu'Appelle River, and the second peak is caused by the Shellmouth Reservoir.