

# Report on 2014 Artificial Flooding due to Operation of the Shellmouth Dam

July 7, 2015

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# Report on 2014 Artificial Flooding due to Operation of the Shellmouth Dam

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**Manitoba Infrastructure and Transportation**

**7/7/2015**

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## Introduction

### Legislative Background

In 2008, the Manitoba government amended *The Water Resources Administration Act* to establish compensation for damages due to artificial flooding caused by the operation of designated water control works. More specifically, the amendments establish the Shellmouth Dam as a designated water control work, define artificial flooding and other key terms, establish a requirement for Manitoba to report on artificial flooding that causes damages and establish eligibility for compensation. Regulations under the act stipulate the information that must be included in the artificial flood report and outline how compensation is to be administered. The amended act came into force in February 2011.

The following definitions from the act are pertinent to this report:

**"artificial flooding"**, in relation to a given event, means flooding of a water body

- (a) that is caused by the operation of a designated water control work, or the operation of a designated water control work and one or more other water control works, and
- (b) whereby the water body exceeds its unregulated level at the time of the event;

**"designated water control work"** means

- (a) the Shellmouth Dam, or
- (b) any other water control work designated in the regulations for the purpose of this definition, not including the "floodway" as defined in *The Red River Floodway Act* insofar as it relates to "spring flooding" as defined in that Act;

**"unregulated level"**, in relation to artificial flooding, means the scientifically demonstrable level that would be expected in the water body at a given time

- (a) in the absence of the designated water control work, or
- (b) if specified by regulation in respect of the water body, in the absence of the designated water control work and one or more other specified water control works;

Put more simply, artificial flooding in the Assiniboine River valley downstream of the Shellmouth Dam occurs when the regulated water level is above flood stage and is higher than the unregulated water level. Regulated water levels are those that did occur, and which were influenced by the operation of the Shellmouth Dam. Unregulated water levels are those that would have occurred if the Shellmouth Dam did not exist.

*The Water Resources Administration Act* stipulates that once it is determined that damage to eligible property or economic loss has occurred as a result of artificial flooding on the Assiniboine River caused by the operation of the Shellmouth Dam, a report must be prepared on the artificial flooding. The report must include:

- a statement of the period reported on
- a statement that the minister responsible for *The Water Resources Administration Act* has determined that damages due to the artificial flooding have occurred
- for the regulated and the unregulated conditions, charts of the discharges from the Shellmouth Dam and river water levels at relevant hydrometric monitoring stations
- charts showing the dates that artificial flooding began and ended
- a description of how the regulated and unregulated levels were determined
- a description of all dam operations and any technical issues that arose
- a description of how the operation did or did not conform to the operating guidelines
- a tabulation of the dam gate adjustments, including the dates and times of the adjustments, the reservoir levels and volume stored at each adjustment, and the flows resulting from each adjustment

Within this report, all flows and levels are discussed in imperial units. Flows can be converted from cubic feet per second (cfs) to cubic metres per second (cms) by dividing by 35.3148. River levels can be converted from feet to metres by dividing by a factor of 3.28084. Hydrographs showing flows and water levels in metric and imperial units can be found at the end of the report. All data in this report is real-time data with quality control provided by the Hydrologic Forecasting and Water Management Branch of Manitoba Infrastructure and Transportation (MIT).

## Background

Following the disastrous Winnipeg flood of 1950, a Royal Commission on Flood Cost Benefit was formed to review the landscape and flood threat in southern Manitoba. The Royal Commission recommended a system of water control infrastructure to protect the City of Winnipeg and the Province of Manitoba from future flood events, specifically the Red River Floodway, the Portage Diversion and the Shellmouth Dam and Reservoir. The Shellmouth Dam was constructed in a deep, wide portion of the Assiniboine Valley (See Figure 1) located approximately 24 km (15 miles) northwest of Russell. The reservoir created by the dam is known as the Lake of the Prairies and is approximately 56 km (35 miles) in length.

Construction of the dam began in 1964, the dam came into full operation including filling of the reservoir in the summer of 1971, with construction completed in 1972 at a cost of \$10.8 million. Operation of the dam was initially the responsibility of the Prairie Farm Rehabilitation Administration (PFRA), but ownership of the dam and operational responsibility were transferred to the Province of Manitoba in 1975. The dam was designed to provide both flood protection and water supply benefits to communities along the Assiniboine River. Since its construction, additional considerations such as ecosystem requirements on both the river and the reservoir, and recreational interests on the Shellmouth Reservoir, are included in the management regime for the structure.



Figure 1: An aerial view of Shellmouth Dam and Reservoir (Lake of the Prairies) looking upstream. Upper right is the Shell River. The outlet is on the right hand side of the photo and the spillway is on the left hand side of the photo.

The dam is approximately 70 feet (21.3 m) high and has a crest length (length) of 4,166 feet (1,270 m). The facility includes a 15 feet (4.6 m) diameter reinforced concrete conduit for releasing flow from the reservoir and an ungated concrete chute spillway designed to spill water when reservoir levels are high.

The reservoir is capable of storing approximately 387,000 acre feet (477,365 dam<sup>3</sup>) of water at the spillway crest elevation of 1,408.5 feet (429.31 m) (see Figure 2).



Figure 2: Shellmouth Reservoir operating levels

The dam provides a flood reduction benefit by storing water from upstream and reducing flows on the river during periods of high flow, for example, during spring runoff. The water retained by the dam can also be released during drier periods to help augment low flows on the river downstream. Downstream water supply is used for irrigation, industrial, municipal and domestic uses. During periods of low flow, stored water may also be released to help maintain flows on the river to support a healthy aquatic ecosystem. The operation of the Shellmouth Dam and Reservoir can be complex due to a relatively small reservoir storage capacity, the management of multiple objectives, which are sometimes at odds, and the uncertainty associated with forecasting inflows and downstream tributary flows. Therefore, Manitoba Infrastructure and Transportation (MIT) utilizes operating guidelines (see Table 2), applied knowledge of past and present climatic events, as well as hydrological conditions in the basin, upstream and downstream tributary flow conditions, and hydrologic models to make operating decisions about the dam in order to deal with flooding and drought situations.

Following a large flood event in 1996, the Shellmouth Reservoir Regulation Liaison Committee was created in order to assist with operating decisions. MIT has continued to hold regular meetings with the committee. There is a broad range of stakeholders represented on the committee and their representatives provide information about local conditions, feedback and recommendations on operation of the dam, and also serve to communicate dam operations to their respective stakeholder communities. Membership is based on major interest groups along the river with consideration for regional representation. Membership is as follows:



- Assiniboine Valley Producers Association (Shellmouth to St. Lazare)
- Assiniboine Valley Producers Association (St. Lazare to Brandon)
- Association of Irrigators of Manitoba
- Rural Municipality of Russell-Binscarth
- Rural Municipality of Riding Mountain West
- Rural Municipality of Hillsburg-Roblin-Shell River
- Shellmouth Assiniboine Valley Economic Development
- Lake of The Prairies Conservation District
- Upper Assiniboine Conservation District
- Little Saskatchewan River Conservation District
- Assiniboine Hills Conservation District
- La Salle-Redboine Conservation District
- Manitoba Infrastructure and Transportation (Chair)
- Manitoba Agriculture, Food and Rural Development
- City of Winnipeg
- City of Brandon

Over the past 15 to 20 years, Manitoba watersheds, and in particular the Assiniboine River watershed has been experiencing a wet cycle. Through this wet cycle the Shellmouth Dam and Reservoir has significantly reduced peak flood flows on the Assiniboine River, benefitting downstream communities such as Brandon, as well as agricultural producers and other interests in the valley. Figure 3 illustrates the reduction in peak flows provided by Shellmouth Dam, at the location of the dam, with the recorded peak flow shown in blue and the peak flow that would have occurred in the absence of the dam shown in green. The dam has also reduced peak flows further downstream at the Portage Reservoir.

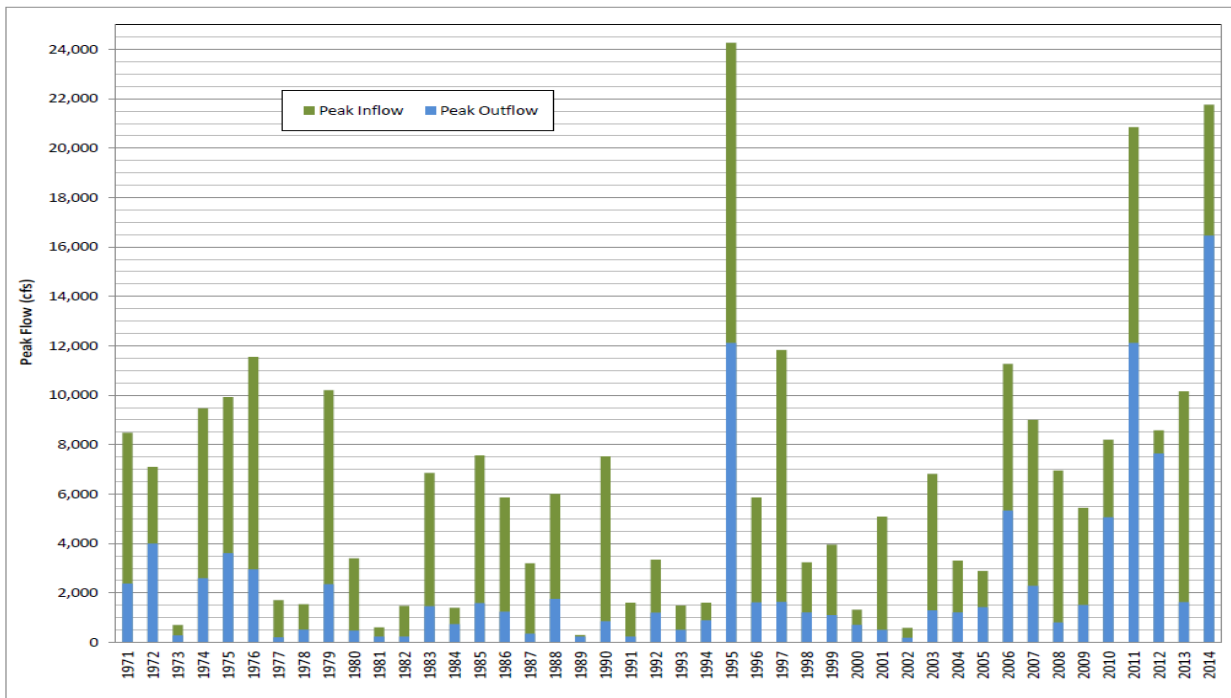


Figure 3: Shellmouth Reservoir annual peak inflows and outflow

## Benefits of Shellmouth Dam Operation and the Nature of Artificial Flooding

Operation of the Shellmouth Dam provides a significant flood reduction benefit to communities, agricultural producers and other interests downstream of the dam in most years. In such years, operation of the dam results in a reduction in the peak flows downstream on the Assiniboine River, and therefore reduces the extent and height of flooding experienced, and generally provides a reduction in the net length of flooding. In some years, operation of the Shellmouth Dam does not completely eliminate flooding downstream of the dam but it does reduce the height of flood waters (usually by a significant amount) and often reduces the total duration of flooding. The conceptual hydrograph in Figure 4 illustrates the reduction in peak flow (A), the duration of flooding under unregulated flow conditions (B), the duration of flooding under regulated flow conditions (C), and the reduction in the duration of flooding (difference in the lengths of lines B and C).

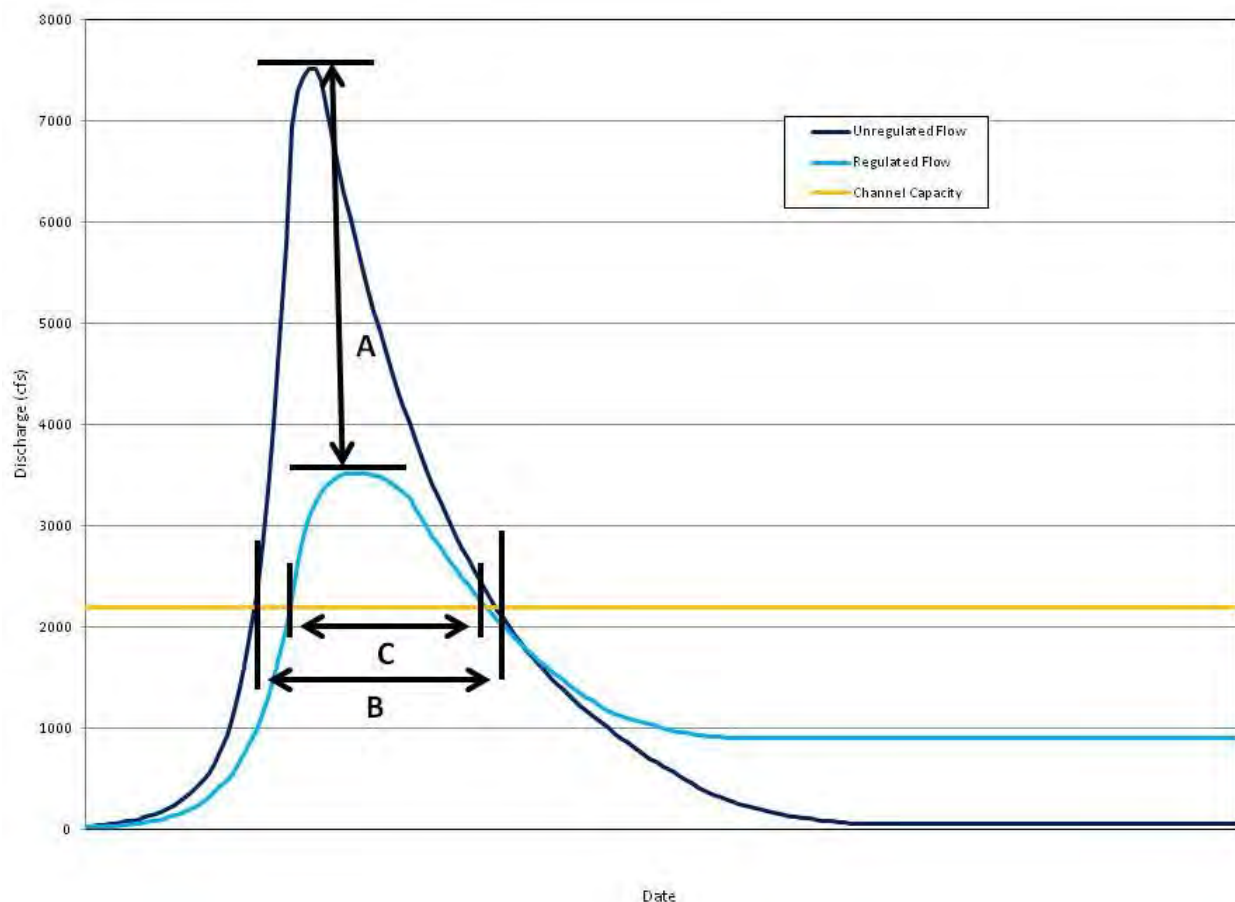


Figure 4: Conceptual hydrograph showing the reduction in peak flow (A) and reduction in duration of flooding (B-C)

Unfortunately, the Shellmouth Dam and Reservoir have a finite water storage capacity, just like all dams and reservoirs. In some years the inflows into the reservoir can cause the water level to rise above the spillway elevation, resulting in uncontrolled flows over the spillway that increase as the level of the reservoir rises. Reservoir levels generally only rise above the spillway elevation as a result of significant snowmelt runoff and rainfall events that cause high reservoir inflow volumes. The reservoir level will only begin to fall when total outflows exceed inflows, and it is generally under these conditions that artificial flooding may occur. Once inflows into the reservoir begin to fall, uncontrolled flows over the

spillway will continue until the reservoir water level falls below the spillway elevation. This can result in a situation where regulated outflows from the reservoir (over the spillway) exceed the unregulated flows that would have occurred in the absence of the dam (the inflows to the reservoir), resulting in artificially high flows downstream of the dam. Artificial flooding can also occur when the reservoir water level is below the spillway elevation and the dam is operated to allow for greater outflows through the conduit than what is flowing into the reservoir. If these artificially high flows exceed the channel capacity of the river, which is approximately 1,600 cfs immediately below the dam, then artificial flooding is deemed to have occurred. Even if outflows from the dam remain below 1,600 cfs, artificial flooding may still occur further downstream as a result of high tributary inflows causing the river to exceed channel capacity.

Artificial flooding caused by operation of the Shellmouth Dam will typically occur after the regulated and unregulated flood peaks have occurred, on what is called the recession limb of the hydrograph (see Figure 5).

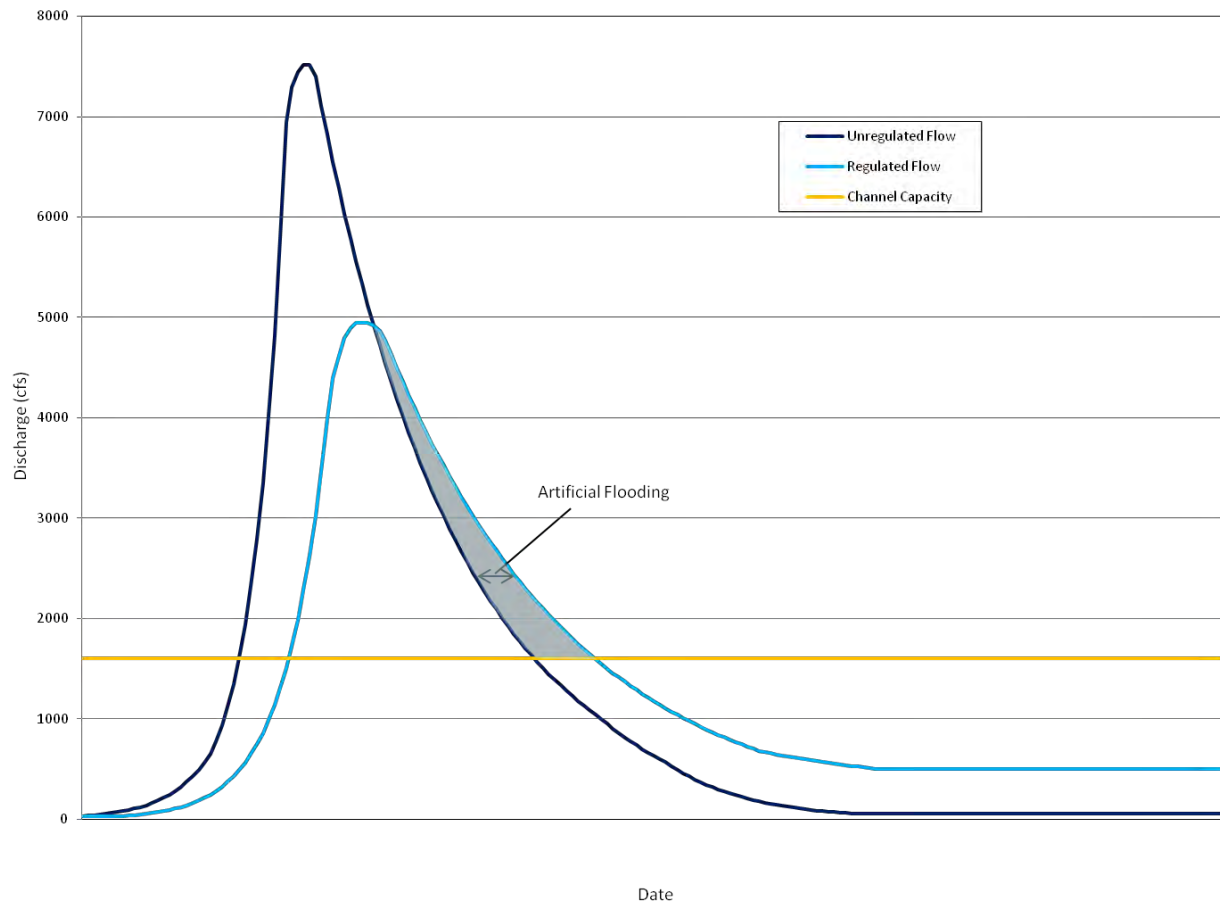


Figure 5: Conceptual hydrograph illustrating an example of artificial flooding

Following the peak of a flood event, as the flows on the river are decreasing and the flood waters recede towards the river channel, artificial flooding occurs when the regulated water level is higher than the unregulated water level. Thus, it can be useful to visualize artificial flooding caused by the operation of the Shellmouth Dam as a delay in the recession of flood waters or as a delay in the overall timing of a flood event that would have otherwise occurred under unregulated conditions. Since artificial flooding

does not begin until a flood event begins to recede, it can be difficult to differentiate artificial flooding from flooding that would have occurred under unregulated flows. It is also important to note that flooding that occurs in the Assiniboine River Valley downstream of the Shellmouth Dam is not always artificial flooding. Only in the circumstances described above, at times where regulated flows exceed unregulated flows and the regulated water level is above the bankfull elevation, does artificial flooding occur.

The duration of artificial flooding at an elevation of land can be determined by comparing the date when the regulated hydrograph crosses the elevation of that land to the date when the unregulated hydrograph crosses the same elevation (on a horizontal line); see line A in Figure 6. Similarly, the incremental height of artificial flood waters at a given time can be determined by comparing the water level on the unregulated hydrograph to the regulated hydrograph (along a vertical line); see line B in Figure 6.

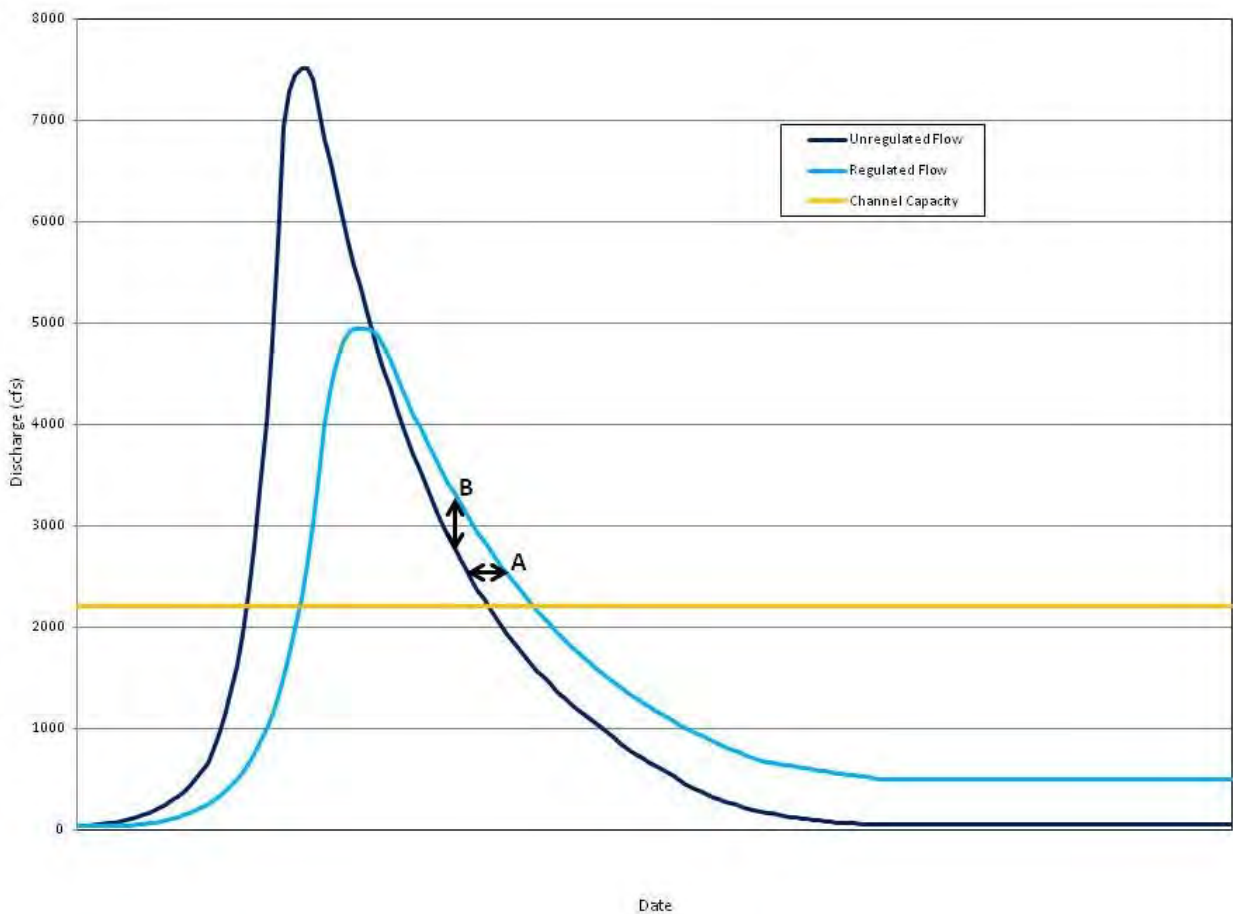


Figure 6: Conceptual hydrograph illustrating how to determine the duration (A) and extent (B) of artificial flooding

## 2014 Shellmouth Dam Operations

In 2014, Manitoba experienced a medium-sized spring runoff and a large summer flood. As spring runoff began to decrease in early May, precipitation maintained high inflows to the Shellmouth Reservoir. Wet conditions in May and June were capped off by a severe rain in late June that led to the large summer flood in the southwestern and western part of the province. The Assiniboine and Qu'Appelle River systems in particular experienced significant flooding and record flows on many tributaries and at many locations on the river. The operation of the dam in 2014 did result in a net reduction of peak outflows both in spring and during the summer; however, significant flooding still occurred in the valley due to the high flow volumes.

Spring runoff potential is estimated based on soil moisture, snowpack conditions and spring weather conditions. Environment Canada stated that December 2013 and early January 2014 had unprecedented low temperatures, with December being the second-coldest December in 120 years. Soil moisture at freeze-up in the fall of 2013 was in general below or near normal across the province. Although soil frost information was sparse, the available data indicates that the soil was considerably frozen at depths of up to 1.5 metres. The increased depth of frozen soil was due to the long periods of below normal temperatures experienced in winter of 2013/2014. Snowpack observations along the southern portion of the Manitoba-Saskatchewan border were below to near normal conditions. From November 2013 to March 2014 the area around the Shellmouth Dam received approximately normal winter precipitation (see Figure 7).

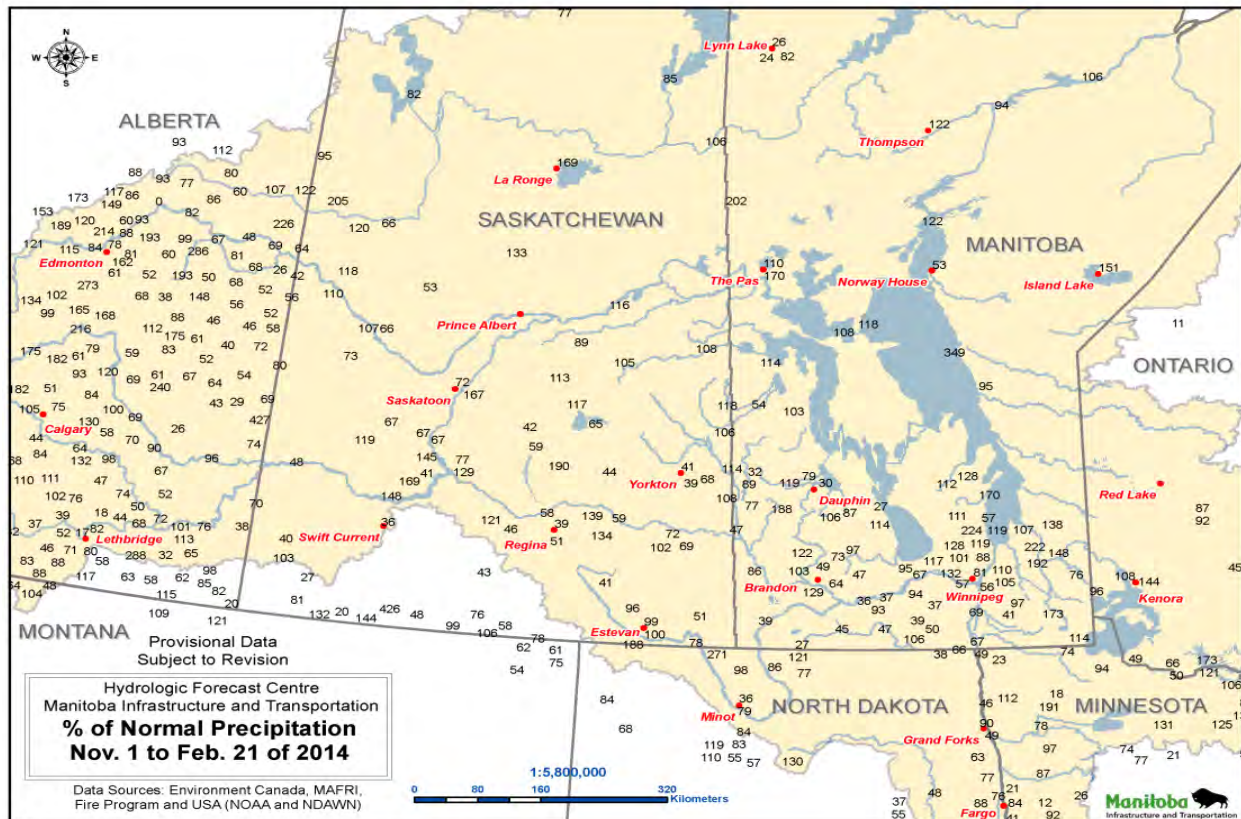


Figure 7: Percent of normal precipitation, November 2013 to February 2014

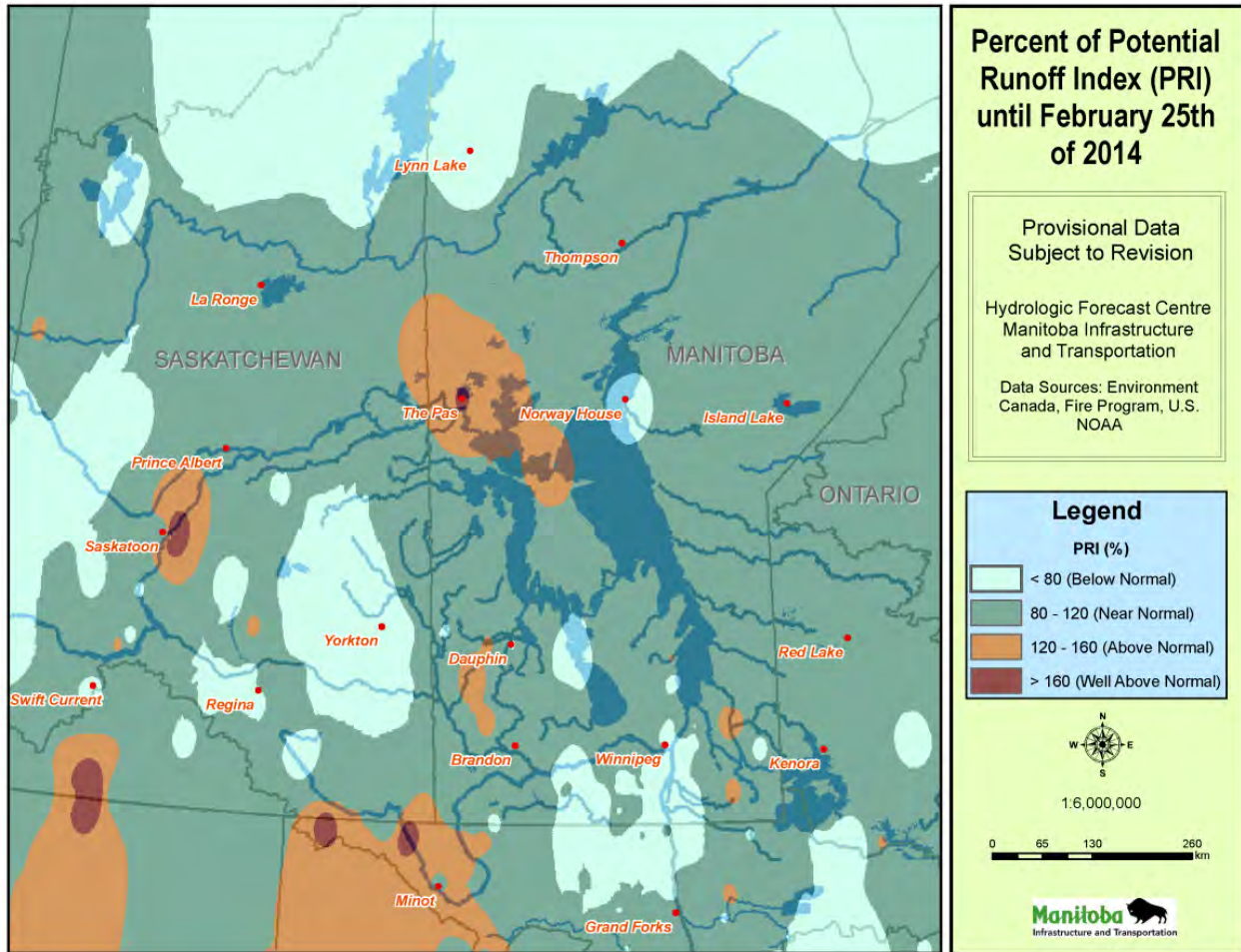


Figure 8: Percent of Potential Runoff Index (PRI) until February 25, 2014

With the above conditions, the spring runoff potential was estimated to be near normal in the Assiniboine River basin (see Figure 8).

Starting in November of 2013, the Shellmouth Dam was operated to draw the reservoir levels down steadily, in accordance with the operating guidelines, in order to make room to store expected spring runoff. For a brief period in January there was concern that flows may not reach summer target levels and outflows were reduced somewhat so a sufficient volume of water would be preserved. By early March, the reservoir level was just below 1,390 feet, approximately four feet above the minimum reservoir level of 1,386 feet, and outflows were reduced to 120 cfs. Outflows were further reduced to 50 cfs in early April, just as inflows to the reservoir began increasing in response to the spring runoff.

As the spring runoff began, the inflows to the reservoir increased, rising to approximately 2,000 cfs in mid-April. Inflows stayed at this level for approximately one week before rapidly climbing to 11,500 cfs in late April. The inflows remained above 10,000 cfs for the period of April 25 to May 2, with the reservoir levels rising from 1,399.9 feet to 1,407.8 feet during this same period. In compliance with operating guidelines for the spring, conduit outflows were increased above the downstream bankfull capacity of 1,600 cfs on April 27, rising to the maximum possible outflow of 5,000 cfs on April 29.

Conduit outflows were increased in order to try and slow the rise of the reservoir to avoid water levels overtopping the spillway.

Despite the increased outflows in accordance with the operation guidelines, the reservoir continued to rise as inflow was greater than the outflow. The water level reached the spillway elevation of 1,408.5 feet on May 4 and the reservoir level peaked at 1,410.2 on May 9-10 as outflows dropped to match inflows. On May 10, the total inflow to the reservoir was 6,767 cfs and the total outflow dropped to approximately 6,616 cfs, marking the beginning of the first period of artificial flooding which is discussed in greater detail in the next section of the report.

From May 10, inflows to the reservoir generally declined until hitting approximately 2,500 cfs on May 21. During this period outflows through the conduit were maintained at 5,000 cfs. As inflows to the Shellmouth Reservoir continued to decline it was forecast that reservoir levels would drop below the spillway level by May 18 and that the reservoir level would be decreased to the target spring reservoir level 1,407 feet by May 22 to 23. With the forecasted lower inflows, it was expected that conduit outflows would be reduced below the channel capacity of 1,600 cfs by May 23, ending the period of artificial flooding. Spillway flows ceased on May 21 as the reservoir dropped below 1,408.5 feet.

Significant precipitation on May 19 and 20 caused a spike of approximately 4,100 cfs inflow to the reservoir before inflows declined slowly and irregularly from 2,700 cfs on May 21 to 1,650 cfs by June 12. Conduit outflows remained at 5,000 cfs and while outflows were greater than inflows the reservoir level dropped to 1,406.4 feet in late May. The outflows through the conduit were reduced to 2,500 cfs on May 26, and then further reduced to 1,500 cfs on May 27 and 1,000 cfs on May 28. With the reductions in conduit outflow, the inflows were greater than the outflows and the reservoir level began to rise in response. Conduit outflows were maintained at 1,000 cfs throughout the month of June, and the reservoir water level slowly rose to the spillway level of 1,408.5 feet on June 12. Inflows to the reservoir, which were already higher than outflows, began increasing in mid-June in response to precipitation in the watershed. Total outflow from the dam increased during this period as the rising reservoir level increased flows over the spillway. At a June 23 meeting of the Shellmouth Regulation Liaison Committee, a recommendation to increase conduit outflows to 3,000 cfs was deferred, and outflows were maintained at status quo of 1,000 cfs until Assiniboine Valley producers' were consulted.

A wet month of June was capped off by a widespread, large storm that brought significant precipitation throughout the Assiniboine River basin on June 27 to 30 (see Table 1). On the upper end of the scale, Brandon experienced up to 138.4 mm of rain.

**Table 1: Approximate total precipitation for the month of June and the June 27-30 rainstorm**

	<b>Approximate total precipitation (mm)</b>	
	<b>Month of June</b>	<b>June 27-30</b>
Brandon A	251.6	138.4
Elkhorn 2 East	225	125
Langenburg	134	32.8
Rocanville	134	32.8

This rain resulted in flooding on many streams and rivers in Manitoba, including record high flows on 13 streams. It also resulted in washed out roads, localized evacuations, significant overland flooding, numerous flood warnings/watches. Thirty-one municipalities declared a State of Local Emergency in response. For the period of June 23 to 29 the upper Assiniboine River basin experienced a weekly accumulated precipitation in the range of 70.1 mm to 130 mm in areas of the basin (see Figure 10). The area experienced severe rain events with rainfall amounts exceeding 150 percent of the normal amount for the month June (see Figure 9).

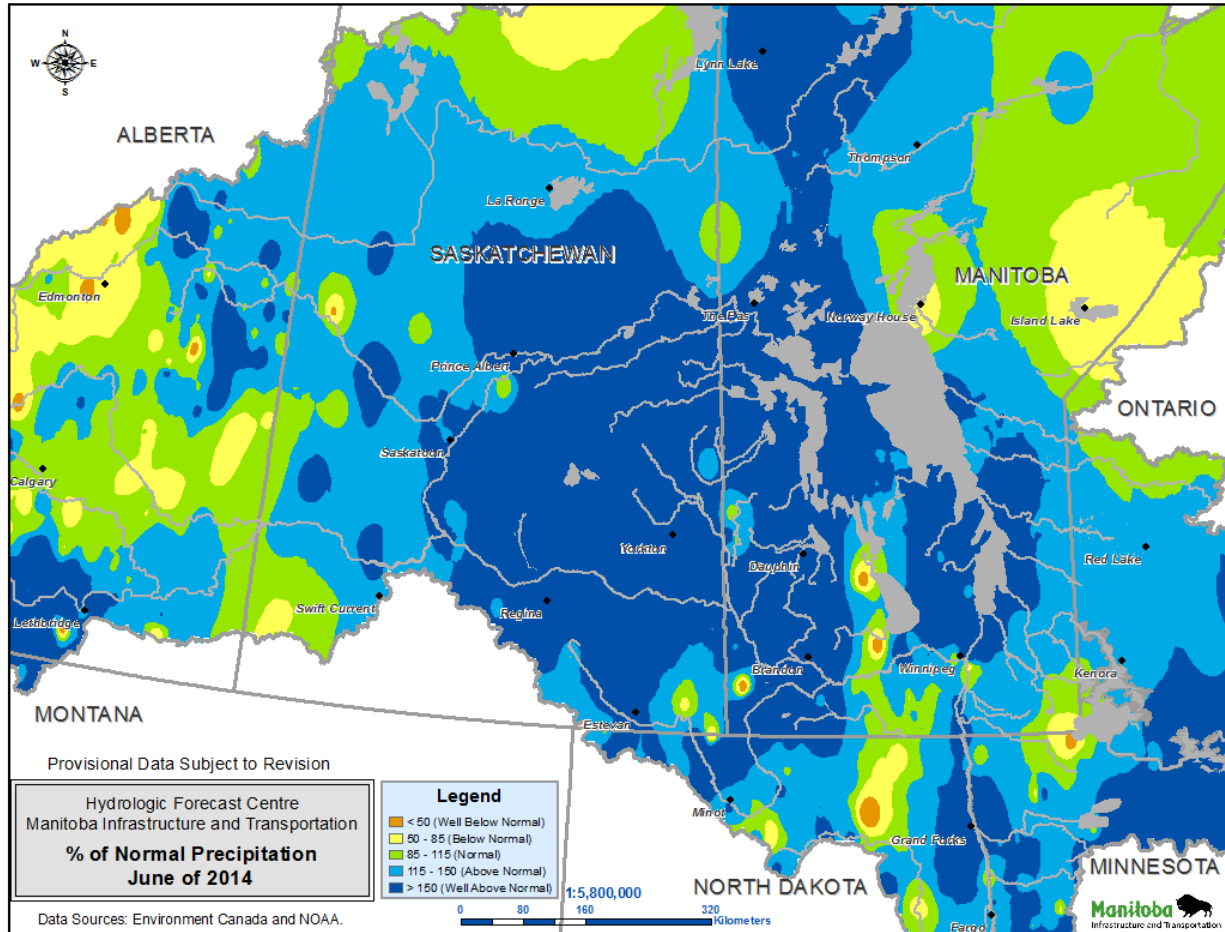
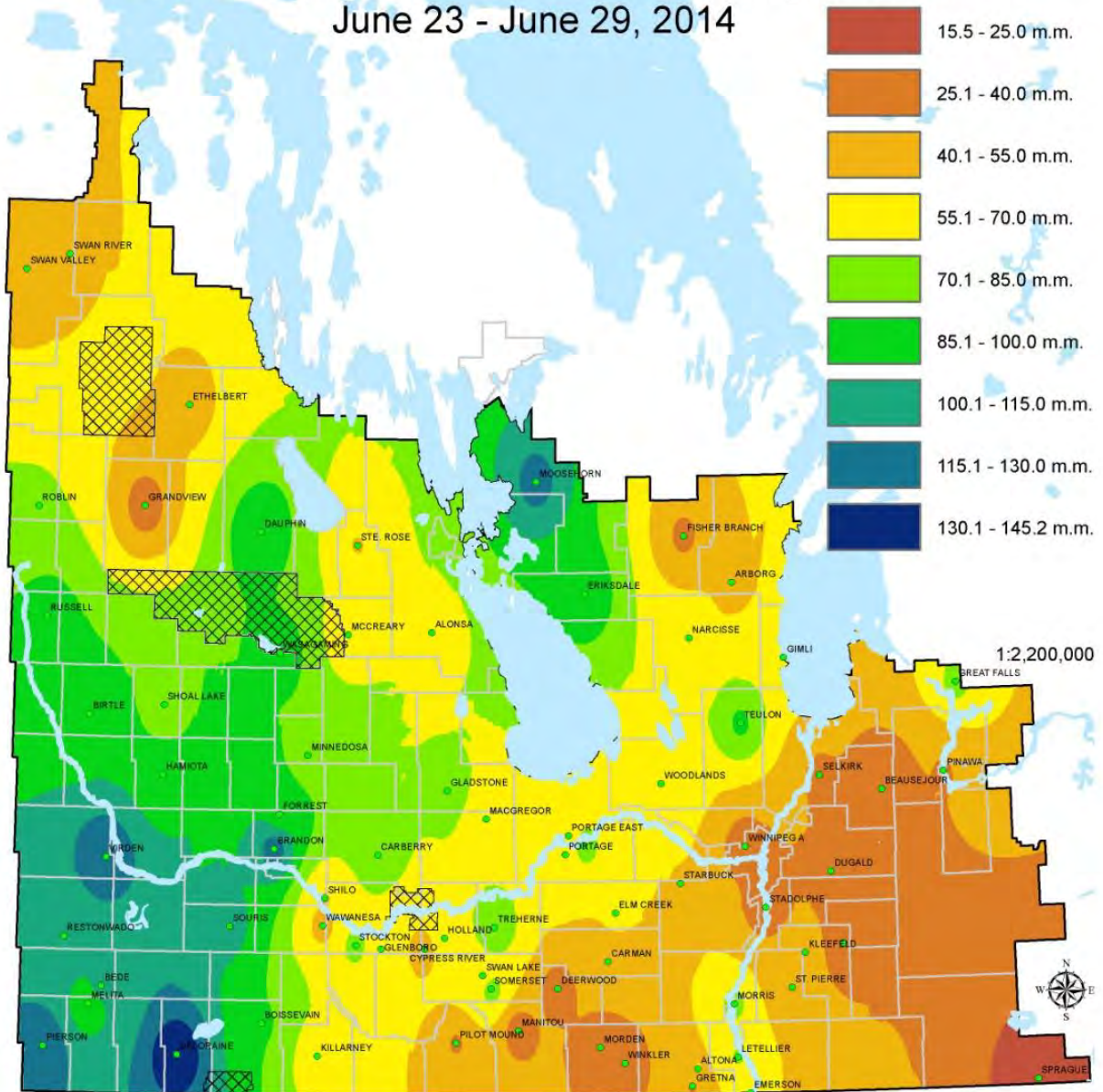


Figure 9: Percent of normal precipitation in June 2014



# Manitoba Ag-Weather Program Weekly Accumulated Precipitation

June 23 - June 29, 2014



Canada

Growing Forward 2

Manitoba

All graphics are interpolated from data collected from the Manitoba Agriculture, Food and Rural Development (MAFRD) Ag-Weather Program and Environment Canada weather stations that has been quality controlled for accuracy. Locations depicted on the graphic have complete records for the valid time period and locations may be removed or added throughout the growing season. The MAFRD Ag-Weather program is funded through the "Growing Forward 2" initiative. For more information contact [Mike.Wroblewski@gov.mb.ca](mailto:Mike.Wroblewski@gov.mb.ca)

Date: 2014-06-30

Figure 10: Weekly accumulated precipitation for June 23 - June 29, 2014

June 27 to 30 rains led to a significant and rapid increase of flows to the reservoir, which peaked at 21,764 cfs on July 7 and resulted in the reservoir rising to a peak water level of 1,416 feet on July 10. The peak reservoir level in 2014 was the record high for the dam, measuring approximately one foot higher than the previous record set in 1995, and higher than experienced in 2011. In comparison, peak inflows during the spring of 2011 were recorded as 20,800 cfs. During the summer flood, conduit flows were maintained at 1,000 cfs and spillway flows continued to increase as the reservoir level rose, with total outflows peaking at 16,450 cfs on July 10. By July 11, the outflows were greater than the inflows, marking the beginning of the second period of artificial flooding.

It is significant to note that the 2014 summer flood was larger than the spring flood. In addition, the reservoir also had less storage capacity available for the large volume of summer inflow, since much of the runoff from the spring flood remained in storage in the reservoir.

Inflows to the dam declined slowly but remained high throughout the remainder of the summer, remaining above 1,600 cfs, the bankfull capacity immediately downstream of the dam, until early September. Conduit outflows were maintained at 1,000 cfs and the reservoir level declined in step with the inflows, resulting in lower spillway flows as the reservoir dropped.

During the August 1 Shellmouth Liaison Committee meeting, it was agreed the reservoir needed to be drawn down before the winter to help prevent potential flooding in 2015. Spillway flows continued to decline with the reservoir levels and conduit outflows maintained at 1,000 cfs until August 15, at which time conduit flows were increased to keep the total outflow from the dam to a target of 3,000 cfs. As the spillway flows continued to decrease, it was necessary increase conduit outflows every few days to maintain 3,000 cfs total outflow. The reservoir level dropped below the spillway level of 1,408.5 feet in late August. A conduit outflow of approximately 3,000 cfs was maintained until September 24 to help drawdown the reservoir. Starting September 24, a 500 cfs reduction in outflow was undertaken every three days for a total of four operations to achieve an outflow of 800 cfs on October 3. The target reservoir level of 1,400 feet was reached by November. Total outflow was maintained close to 800 cfs through the remainder of 2014, in order to reach winter drawdown levels.

Table 2: Shellmouth Dam and Reservoir approved operation guidelines

Guidelines for Spring	Guidelines for Summer
<ol style="list-style-type: none"> <li>1. Target a reservoir level of 1,402-1,404 feet after spring runoff is complete.</li> <li>2. Outflows must meet downstream requirements. Minimum outflow will be 25 cfs to support fish downstream of reservoir.</li> <li>3. Keep outflow below 500 cfs if possible until Assiniboine crest has passed Miniota. All operations will try to prevent or minimize downstream flooding unless this poses a high risk of flooding later during the seeding or growing season.</li> <li>4. Outflows not to exceed 1,200 cfs if forecast based on observed rain and streamflow and an outflow of 1,200 cfs indicates a peak reservoir level below 1,405 feet.</li> <li>5. Outflow not to exceed the downstream bankfull capacity of 1,600 cfs if forecast based on observed rain and streamflow and an outflow of 1,600 cfs indicates a peak reservoir level below 1,407 ft.</li> <li>6. If forecast based on observed rain and streamflow indicates that reservoir level will overtop spillway with 1,600 cfs outflow, set April outflow as high as required to keep level below 1,407 feet. This will maintain 1.5 feet of storage capacity below the spillway to prevent overtopping due to additional rainstorms.</li> <li>7. During May or June, if valley crops have been seeded, allow overtopping of spillway to save crops and use peak shaving if necessary to prevent total outflows from exceeding 2,000 cfs. Peak shaving involves reducing conduit outflows to maintain a maximum total outflow when spillway is overtopped. Flooding at 2,000 cfs is confined to low lying areas such as old oxbows.</li> </ol>	<ol style="list-style-type: none"> <li>1. Target range for summer and autumn is 1,400-1,404 feet.</li> <li>2. Operate to meet downstream needs such as licensed municipal and private uses, irrigation needs, minimum flows for fish and sewage dilution. Minimum needs are 100 cfs at Brandon and 200 cfs at Headingley.</li> <li>3. Minimum outflow of 50 cfs and maximum of 500 cfs while reservoir in target range.</li> <li>4. Increase outflows up to 1,000 cfs if necessary to prevent reservoir level from exceeding 1,405 feet.</li> <li>5. If serious summer flood develops during growing season, adjust outflows up to 1,600 cfs if necessary to prevent overtopping of spillway. If spillway is overtopped anyway, use peak shaving to minimize the peak outflow while reservoir is below 1,410.6 feet.</li> <li>6. If reservoir level in excess of 1,410.6 feet is inevitable with a 2,000 cfs total outflow, increase conduit outflows as required to prevent level from exceeding 1,410.6 if possible.</li> <li>7. On falling limb after spillway overtopped, operate to maintain 1,400 cfs until reservoir down to 1,407 feet and 1,000 cfs until reservoir down to 1,405 feet.</li> <li>8. Operate to prevent decline of more than 0.4 feet per day at bridge downstream of Shellmouth.</li> <li>9. When summer reservoir declines below 1,400 feet, set outflow to minimum of 25 cfs if this is sufficient to meet downstream needs.</li> <li>10. During severe drought, meet downstream requirements to a level of 1,390 feet. At lower levels, outflows to be approved at ministerial level under <i>The Water Protection Act</i>.</li> </ol>

Guidelines for Autumn	Guidelines for Winter
<p>1. Operating guidelines and target levels and flows would be very similar to those for the summer period, with the following exception:</p> <ul style="list-style-type: none"> <li>• If a flood situation develops after harvest in the valley has been completed, outflows would be kept below 1,600 cfs if possible, but peak shaving would not be employed to prevent higher flows due to possible overtopping of the spillway.</li> <li>• “Autumn” refers to the months of September and October</li> </ul>	<ol style="list-style-type: none"> <li>1. Winter outflows shall meet downstream requirements with a minimum of 100 cfs to prevent the river from freezing to bottom with resultant ice buildups.</li> <li>2. Avoid large fluctuations in winter outflow if possible.</li> <li>3. Minimum winter drawdown level to range from 1,386 to 1,400 feet depending on predicted spring runoff volume. Drawdown to be such that target reservoir level is reached after spring runoff. (Fisheries Branch indicates that at winter levels below 1,386 fish kill is a concern)</li> <li>4. Be in a position to draw down to 1,386 by the end of March without exceeding 1,500 cfs outflow, whenever upper decile forecast indicates a spring level near spillway.</li> <li>5. November and December outflows based on lower decile inflow forecast.</li> <li>6. January and February outflows based on lower quartile inflow forecast.</li> <li>7. March outflow to be based on median inflow forecast. However, release up to 1,500 cfs in March to draw reservoir down to 1,386 if spillway is overtopped at lower outflows with upper decile inflow forecast.</li> </ol>

**Operating Guidelines**

In 2014, the Shellmouth Dam was operated in a manner consistent with most of the approved operating guidelines, which are shown in Table 2. Three of the summer operating guidelines were not strictly followed, and the paragraphs below outline the circumstances of this operation.

First, the fifth summer operating guideline states that if a serious summer flood develops during growing season, adjust outflows up to 1,600 cfs to prevent spillway overtopping. If spillway is overtopped anyway, use peak shaving to minimize the peak outflow while reservoir is below 1,410.6 feet. The second part of this guideline was not followed during the summer flood event as conduit flows remained at 1,000 cfs in late June, in other words peak shaving was not employed to minimize total downstream flows. In the later part of June, spillway flow was occurring while the reservoir was still below 1,410.6 feet and even with 1,000 cfs conduit outflow, the reservoir level continued to rise. Peak shaving was not employed at this point in time because the reservoir was already high and continuing to rise, and inflows were expected to rise even further with forecast precipitation for the end of June. Outflows were maintained at 1,000 cfs with the possibility of increasing to 3,000 cfs to reduce reservoir levels and create storage for future precipitation.

Second, the sixth summer operating guideline calls for total outflows to be increased once the reservoir level exceeds 1,410.6 feet in order to prevent the reservoir from rising higher. In 2014, the reservoir level peaked at 1,416.02 feet on July 10, however, conduit outflows were maintained around 1,000 cfs to help reduce peak flows in communities downstream, including Brandon and the Portage Reservoir, where the flood protection system was forecast to be at or near its design limits. If the dam was managed to comply with this guideline, it would have meant increasing total outflow from the dam at

the peak of the flood event by increasing the conduit flow. Operating to increase outflow at this time would have reduced the flood protection afforded by the dam to downstream communities at a critical period of time.

Third, after the spillway was overtopped, and while on the recession limb of the hydrograph, the seventh guideline for summer/autumn operation states that, at this point the dam should be operated to maintain 1,400 cfs outflow until the reservoir reaches a level of 1,407 feet. Attempting to restrict total outflows to 1,400 cfs on the recession limb of the hydrograph would have been extremely difficult in 2014 since the inflows to the reservoir did not drop below 1,400 cfs until August 27, 2014, meaning that the reservoir level would have been relatively stable or increasing up until this date. Spillway outflows dropped below 1,400 cfs on August 17, 2014. If the dam had been operating in accordance with this guideline, the conduit outflows would have been managed to maintain a total outflow of 1,400 cfs, meaning that the reservoir level would have remained at 1,410.2 feet until August 27, 2014, and then levels would have declined very slowly as total outflows were limited to 1,400 cfs. Instead, the dam was operated to bring the reservoir down to the summer target range (1,400 to 1,404 feet) more quickly than a 1,400 cfs total outflow. Maintaining an outflow of 3,000 cfs was agreed to by the Shellmouth Liaison Committee, to lower the reservoir to the target drawdown level more quickly, thereby creating storage capacity in the reservoir for spring runoff and reducing the flooding potential in 2015.

In the years 2010, 2011, 2012 and 2014, the Upper Assiniboine River basin experienced periods of extraordinary wet conditions which resulted in summertime spillway flows and artificial flooding in each of the four years. In light of this, it may be advisable to review the Shellmouth Dam Operation Guidelines to ensure that they continue to meet the best water management interests of Manitoba.

Table 3: 2014 Conduit operations

	Date	Time	Reservoir Level (metres)	Reservoir Level (feet)	Storage Volume (acre-feet)	Conduit Setting (feet)	Conduit Flow (cfs)	Spillway Flow (cfs)	Total Flow (cfs)
1	9-Jan-14	11:45	425.04	1,394.49	202,635	4.59	800	0	800
2	10-Jan-14	11:30	425.00	1,394.37	201,255	4.02	700	0	700
3	13-Jan-14	10:42	424.91	1,394.06	197,690	3.47	600	0	600
4	6-Mar-14	10:50	423.58	1,389.70	152,000	2.22	350	0	350
5	7-Mar-14	11:30	423.58	1,389.70	152,000	0.76	120	0	120
6	24-Mar-14	12:55	423.59	1,389.74	152,400	0.63	100	0	100
7	11-Apr-14	11:45	423.73	1,390.20	157,000	0.31	50	0	50
8	25-Apr-14	18:00	426.70	1,399.93	266,660	3.65	700	0	700
9	27-Apr-14	16:30	427.57	1,402.80	303,800	8.48	1,700	0	1,700
10	28-Apr-14	10:20	428.00	1,404.20	323,400	10.76	2,200	0	2,200
11	28-Apr-14	15:05	427.63	1,403.00	306,500	13.43	2,700	0	2,700
12	28-Apr-14	20:00	428.06	1,404.40	326,300	15.61	3,200	0	3,200
13	29-Apr-14	10:00	428.34	1,405.30	339,500	18.31	3,800	0	3,800
14	29-Apr-14	14:30	428.34	1,405.30	339,500	21.20	4,400	0	4,400
15	29-Apr-14	19:00	428.34	1,405.30	339,500	24.09	5,000	0	5,000
16	26-May-14	11:10	428.70	1,406.50	357,750	11.85	2,500	0	2,500
17	27-May-14	10:00	428.70	1,406.50	357,750	7.11	1,500	0	1,500
18	28-May-14	10:05	428.70	1,406.50	357,750	4.74	1,000	0	1,000
19	15-Aug-14	10:00	429.88	1,410.37	419,790	6.77	1,500	1,601	3,101
20	18-Aug-14	10:15	429.81	1,410.14	415,880	9.06	2,000	1,275	3,275
21	21-Aug-14	10:15	429.68	1,409.71	408,715	11.38	2,500	782	3,282
22	28-Aug-14	10:40	429.37	1,408.69	392,040	14.15	3,070	87	3,157
23	24-Sep-14	10:30	427.60	1,402.89	305,015	11.46	2,300	0	2,300
24	26-Sep-14	14:00	427.49	1,402.51	299,885	9.02	1,800	0	1,800
25	30-Sep-14	14:20	427.28	1,401.84	290,920	6.58	1,300	0	1,300
26	3-Oct-14	11:10	427.24	1,401.71	289,230	4.06	800	0	800

Note: The reservoir levels in the table are based on a single daily value, reservoir levels may have been affected by wind set-up or set-down.

## Artificial Flooding in 2014

Manitoba Infrastructure and Transportation, the department responsible for *The Water Resources Administration Act*, has determined that artificial flooding occurred in 2014. Two periods of artificial flooding occurred in 2014; one period following the spring runoff flood peak and one period following a summer flood event that occurred in early July. MIT, in conjunction with Manitoba Agriculture, Food and Rural Development (MAFRD), has found the second period of artificial flooding could have caused damages or losses for certain types of agricultural activities in some areas.

### Spring Runoff Flood Event

During the spring flood event under unregulated conditions, without the Shellmouth Dam and Reservoir, flooding would have lasted an approximate average duration of 51 days, ranging between approximately 40 days at Russell and up to 67 days at Brandon. Unregulated flooding would have started as early as April 12 immediately below the dam, at Russell and at Brandon. At Brandon, flooding would have ended as late as June 18. It is worth noting that immediately below Shellmouth Dam, under unregulated conditions, the flooding would not have stopped between the spring and summer flood peaks (that is, the river would not have receded back in bank). Unregulated flooding at various locations on the river can be seen on the hydrographs on Figure 11 through Figure 35, wherever the dark blue unregulated flow line is above the channel capacity. The dates, durations, peak flows and peak stages of unregulated flow conditions are also summarized in the first section of Table 4.

Under regulated conditions, with the dam in operation, spring flooding lasted for an approximate average duration of 41 days, ranging from 30 days at Russell to 61 days at Brandon. Brandon experienced the longest period of spring flooding, starting April 12 and ending by June 12. Spring flooding under regulated conditions at various locations on the river can be seen on the hydrographs on Figure 11 through Figure 35, wherever the light blue regulated flow line is above the channel capacity. The dates, durations, peak flows and peak stages of regulated flow conditions are also summarized in the second section of Table 4.

Table 5 summarizes the effect that operation of the Shellmouth Dam had during the spring flood. In general, operation of the Shellmouth Dam during the spring shifted the timing of the flood later, and reduced its magnitude, reducing peak flows by an average of 6,387 cfs and reducing peak stage by an average of 2.72 feet.

The first period of artificial flooding occurred on the recession limb of the spring runoff peak. In the upstream reaches immediately below the dam, artificial flooding occurred as early as May 10 at higher elevations and ended as late as May 25 in lower areas. Depending on the elevation of the land, artificial flooding in the upstream reaches of the Assiniboine Valley lasted from 1 to 10 days. Downstream in the Assiniboine Valley, in the vicinity of Brandon, artificial flooding started as early as May 21 at higher elevations and ended as late as June 6 in lower areas. Depending on the elevation of the land, artificial flooding in the downstream reaches of the Assiniboine Valley lasted from 1 to 7 days. The maximum length that artificial flooding occurred was 11 days in the Russell, St. Lazare and Virden areas (see Table 5).

## Summer Flood Event

As described previously in the Shellmouth Dam Operations section, the 2014 summer flood occurred following a wet June, which was capped off by a widespread, significant rainstorm at the end of the month. During the summer flood, without the Shellmouth Dam and Reservoir, flooding at any given elevation would have lasted for an approximate average duration of 56 days, ranging from approximately 41 days at Russell up to 92 days at Brandon. Brandon would have experienced the longest period of unregulated summer flooding, starting as early as June 20 and ending as late as September 20. It is worth noting that immediately below Shellmouth Dam, under unregulated conditions, the flooding would not have stopped between the spring and summer flood peaks (that is, the river would not have receded back in bank). Unregulated flooding at various locations on the river can be seen on the hydrographs on Figure 11 through Figure 35, wherever the dark blue unregulated flow line is above the channel capacity. The dates, durations, peak flows and peak stages of unregulated flow conditions are also summarized in the first section of Table 6.

Under regulated conditions, with the dam in operation, summer flooding lasted for an approximate average duration of 72 days, ranging between 43 days at Russell and 100 days at Brandon. Immediately below the dam, summer flooding started as early as June 21 and ended by September 28. Near Brandon, summer flooding started as early as June 22 and ended by September 30. Summer flooding under regulated conditions at various locations on the river can be seen on the hydrographs on Figure 11 through Figure 35, wherever the light blue regulated flow line is above the channel capacity. The dates, durations, peak flows and peak stages of regulated flow conditions are also summarized in the second section of Table 6.

Table 7 summarizes the effect that operation of the Shellmouth Dam had during the summer flood. In general, operation of the Shellmouth Dam during the summer flood shifted the timing of the flood later, and reduced its magnitude, reducing peak flows by an average of 6,855 cfs and reducing peak stage by an average of 1.4 feet.

The second period of artificial flooding occurred on the recession limb of the summer flood that peaked in early July. In the upstream reaches immediately below the dam, artificial flooding occurred as early as July 10 at higher elevations and ended as late as September 28 in lower areas. Depending on the elevation of the land, artificial flooding in the upstream reaches of the Assiniboine Valley lasted from 1 to 30 days. Downstream in the Assiniboine Valley, in the vicinity of Brandon, artificial flooding started as early as July 20 at higher elevations and ended as late as October 1 in lower areas. Depending on the elevation of the land, artificial flooding in the downstream reaches of the Assiniboine Valley lasted from 1 to 32 days. The maximum length that artificial flooding occurred was 32 days in the Brandon area (see Table 7).

In summary, operation of the Shellmouth Dam in 2014 caused two periods of artificial flooding, the first period on the receding limb of spring runoff and a second period on the receding limb of the large summer flood event. The large summer flood that occurred in late June through July was a natural event driven by extreme rainfall and was not caused by, nor could it have been entirely prevented by, operation of the Shellmouth Dam.



**Table 4: Summary of flooding under unregulated and regulated flows (Period 1)**

	Channel Capacity feet (m)	Unregulated Flows Period 1					Regulated Flows Period 1				
		Start of Flooding	End of Flooding	Length of flooding (days)	Peak Flow cfs (cms)	Peak Stage feet (m)	Start of Flooding	End of Flooding	Length of flooding (days)	Peak Flow cfs (cms)	Peak Stage feet (m)
<b>Shellmouth</b>	1600 cfs (45 cms)	12-Apr-14	N/A		11,517 (326)		26-Apr-14	27-May-14	31	6,616 (187)	
<b>Russell</b>	1344.6 (409.83)	12-Apr-14	22-May-14	40	13,504 (382)	1,352.2 (412.2)	28-Apr-14	28-May-14	30	7,371 (209)	1,349.1 (411.2)
<b>St. Lazare</b>	1283.7 (391.27)	14-Apr-14	29-May-14	45	17,769 (503)	1,288.4 (392.7)	25-Apr-14	29-May-14	34	11,117 (315)	1,286.4(392.1)
<b>Miniota</b>	1236.8 (376.98)	13-Apr-14	6-Jun-14	54	19,938 (565)	1,246.4 (379.9)	24-Apr-14	2-Jun-14	39	12,736 (361)	1,243.3 (379.0)
<b>Virden</b>	1217.6 (371.12)	23-Apr-14	5-Jun-14	43	20,411 (578)	1,222.8 (372.7)	25-Apr-14	4-Jun-14	40	13,680 (387)	1,220.3 (371.9)
<b>Griswold</b>	1196.4 (364.66)	16-Apr-14	11-Jun-14	56	21,081 (597)	1,203.2 (366.7)	17-Apr-14	8-Jun-14	52	14,374 (407)	1,201.1(366.1)
<b>Grand Valley near Brandon</b>	1182.6 (360.46)	12-Apr-14	18-Jun-14	67	22,479 (637)	1,191.9 (363.3)	12-Apr-14	12-Jun-14	61	15,833 (448)	1,188.4 (362.2)

**Note:** All dates and durations are pulled from the stage hydrographs (except Shellmouth) in Figure 11 through Figure 35.

**Table 5: Summary of effect of Shellmouth Dam operation (Period 1)**

	Effect of Shellmouth Dam Operation – Period 1						
	Channel Capacity feet (m)	Change in Peak Flow cfs (cms)	Change in Peak Stage feet (m)	Net Change in Length of flooding (days)	First Day with some Artificial Flooding at Higher Elevations	Day when all Artificial Flooding Ended at Lower Elevations	Approximate Average Duration of Artificial Flooding at a Given Elevation (Days)
Shellmouth	1600 cfs (45 cms)	-4,901 (-139)		-2 <sup>1</sup>	10-May-14	25-May-14	1-10
Russell	1344.6 (409.83)	-6,133 (-174)	-3.1 (-0.94)	-10	12-May-14	28-May-14	1-11
St. Lazare	1283.7 (391.27)	-6,652 (-188)	-2 (-0.61)	-11	13-May-14	28-May-14	3-11
Miniota	1236.8 (376.98)	-7,202 (-204)	-3.1 (-0.94)	-15	15-May-14	1-June -14	1-9
Viriden	1217.6 (371.12)	-6,729 (-191)	-2.5 (-.076)	-3	17-May-14	3-June-14	9-11
Griswold	1196.4 (364.66)	-6,707 (-190)	-2.1(-0.64)	-4	19-May-14	5-June-14	1-9
Grand Valley near Brandon	1182.6 (360.46)	-6,646 (-188)	-3.5 (-1.07)	-6	21-May-14	6-June-14	1-7

**Note:** The effect of artificial flooding is site specific based on the location of the land within the river valley and the elevation of the land in question.

**Note 2:** All dates and durations are pulled from the stage hydrographs (except Shellmouth) in Figure 11 through Figure 35.

<sup>1</sup>Due to the area just downstream of Shellmouth having only one period of unregulated flooding (i.e. under unregulated conditions the flows would have remained above bankfull), the net change in length of flooding has been calculated as the total length of flooding under unregulated conditions minus the length of flooding under regulated conditions in periods 1 and 2.

**Table 6: Summary of flooding under unregulated and regulated flows (Period 2)**

	Channel Capacity feet (m)	Unregulated Flows Period 2					Regulated Flows Period 2				
		Start of Flooding	End of Flooding	Length of flooding (days)	Peak Flow cfs (cms)	Peak Stage feet (m)	Start of Flooding	End of Flooding	Length of flooding (days)	Peak Flow cfs (cms)	Peak Stage feet (m)
<b>Shellmouth</b>	1600 cfs (45 cms)	N/A	23-Aug-14		21,764 (616)		22-June-14	30-Sept-14	100	16,456.7 (466)	
<b>Russell</b>	1344.6 (409.83)	25-Jun-14	5-Aug-14	41	21,408 (606)	1,356.1 (413.3)	29-Jun-14	9-Aug-14	41	16,141 (457)	1,354.1 (412.7)
<b>St. Lazare</b>	1283.7 (391.27)	29-Jun-14	12-Aug-14	44	36,857 (1,044)	1,292.4 (393.9)	29-Jun-14	14-Aug-14	46	29,580 (838)	1,290.8 (393.4)
<b>Miniota</b>	1236.8 (376.98)	22-Jun-14	17-Aug-14	56	40,534 (1,148)	1,248.6 (380.6)	27-Jun-14	22-Sept-14	87	32,560 (922)	1,247.3 (380.2)
<b>Virden</b>	1217.6 (371.12)	29-Jun-14	16-Aug-14	48	41,093 (1,164)	1,222.8(372.7)	29-Jun-14	17-Aug-14	49	33,003 (935)	1,221.9(372.4)
<b>Griswold</b>	1196.4 (364.66)	27-Jun-14	21-Aug-14	55	41,383 (1,172)	1,205.2 (367.3)	28-June-14	22-Sept-14	86	34,800(985)	1,204 (367)
<b>Grand Valley near Brandon</b>	1182.6 (360.46)	20-Jun-14	20-Sept-14	92	42,160 (1,194)	1,194.6 (364.1)	22-Jun-14	1-Oct-14	101	34,670 (980)	1,192.9 (363.6)

**Note:** All dates and durations are pulled from the stage hydrographs (except Shellmouth) in Figure 11 through Figure 35.

Table 7: Summary of effect of Shellmouth Dam operation (Period 2)

	Effect of Shellmouth Dam Operation – Period 2						
	Channel Capacity feet (m)	Change in Peak Flow cfs (cms)	Change in Peak Stage feet (m)	Net Change in Length of flooding (days)	First Day with some Artificial Flooding at Higher Elevations	Day when all Artificial Flooding Ended at Lower Elevations	Approximate Average Duration of Artificial Flooding at a Given Elevation (Days)
Shellmouth	1600 cfs (45 cms)	-5,307 (-150)		-2 <sup>1</sup>	10-July-14	28-Sept-14	1-30
Russell	1344.6 (409.83)	-5,267 (-149)	-1.9 (-0.58)	0	11-July-14	9-Aug-14	1-7
St. Lazare	1283.7 (391.27)	-7,277 (-206)	-1.6 (-0.49)	2	14-July-14	14-Aug-14	1-5
Miniota	1236.8 (376.98)	-7,974 (-226)	-1.3 (-0.4)	31	16-July-14	22-Sept-14	1-27
Virden	1217.6 (371.12)	-8,090 (-229)	-0.9 (-0.27)	1	16-July-14	17-Aug-14	1-11
Griswold	1196.4 (364.66)	-6,583 (-186)	-1.2 (-0.37)	31	17-July-14	22-Sept-14	1-27
Grand Valley near Brandon	1182.6 (360.46)	-7,490 (-212)	-1.7 (-0.53)	9	18-July-14	1-Oct-14	1-32

**Note:** The effect of artificial flooding is site specific based on the location of the land within the river valley and the elevation of the land in question.

**Note 2:** All dates and durations are pulled from the stage hydrographs (except Shellmouth) in Figure 11 through Figure 35.

<sup>1</sup>Due to the area just downstream of Shellmouth having only one period of unregulated flooding (i.e. under unregulated conditions the flows would have remained above bankfull), the net change in length of flooding has been calculated as the total length of flooding under unregulated conditions minus the length of flooding under regulated conditions in periods 1 and 2.

Regulated flows are the water levels that actually occurred. At Russell, Miniota and Brandon, both flows and levels were recorded by hydrometric gauging stations on the river. At St. Lazare, Virden and Griswold, only water levels were recorded. In cases where the gauging stations did not collect recorded data for some period of time, due to mechanical or similar problems, a hydrodynamic model was used to simulate the missing values. A HEC-RAS hydrodynamic model was used to simulate flows and water levels at all locations between Shellmouth and Brandon, using available gauge data to calibrate the model. The HEC-RAS model is a detailed, 1D hydraulic model that calculates flow and water level at over 200 river/flood plain cross sections on the Assiniboine River between Shellmouth Dam and Brandon.

The unregulated flows at the Shellmouth Dam site are computed as being equal to the computed inflows into the Shellmouth Reservoir. The rationale for this approach is that if the dam was not in place, the inflows to the reservoir would be flowing unimpeded down the river. Unregulated levels and flows at each downstream gauging station must be calculated, since the existence of the dam results in only regulated levels and flows being available for measurement. The unregulated levels and flows at each of the sites downstream of the Shellmouth Dam were computed by using the calibrated HEC-RAS model to simulate the movement of the Shellmouth inflows downstream from the Shellmouth Dam site, incorporating the addition of tributary flows as they join the river.

See Figure 11 for the regulated flows from the Shellmouth Dam (labelled as Total Outflow) and the unregulated flow at the dam (labelled as Total Inflows Including Over-Reservoir Precipitation). A number of other relevant parameters, including reservoir water level and spillway elevation, are also shown in this figure. See Figure 12 through Figure 35 for hydrographs that show the unregulated and regulated water levels and flows at six locations downstream of the Shellmouth Dam. These hydrographs depict the flow and water levels recorded or modelled specifically at the gauge location. Flow and water level at locations in between gauge locations may vary and must be derived from the HEC-RAS model.

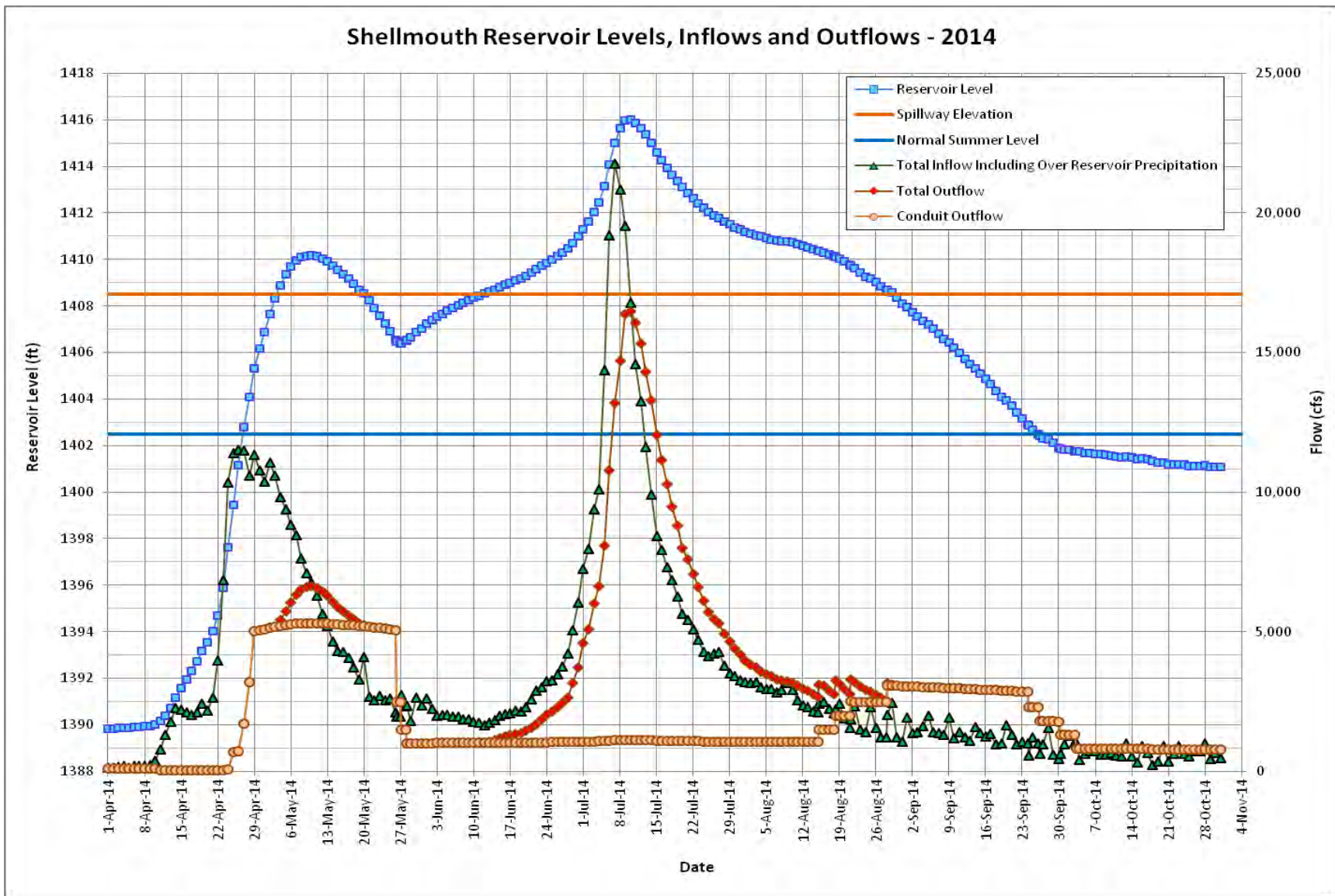


Figure 11: Hydrograph showing 2014 reservoir levels, inflows and outflows at the Shellmouth Dam

## Hydrographs (Imperial Measurements)

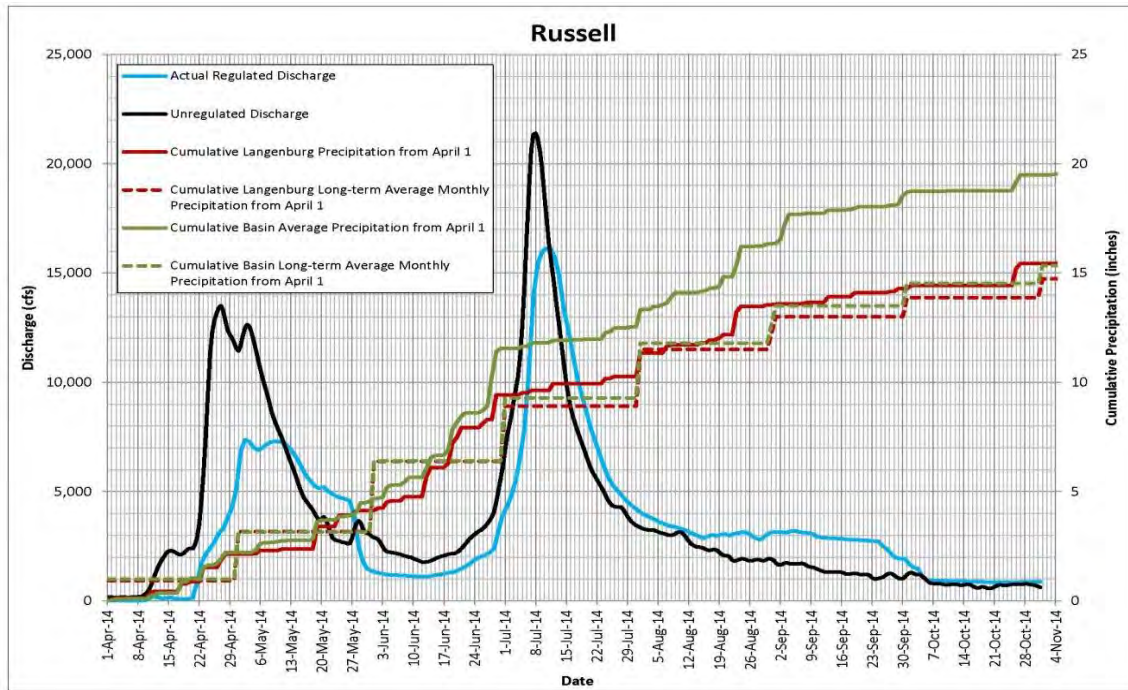


Figure 12: Hydrograph showing regulated and unregulated discharge at Russell (cfs)

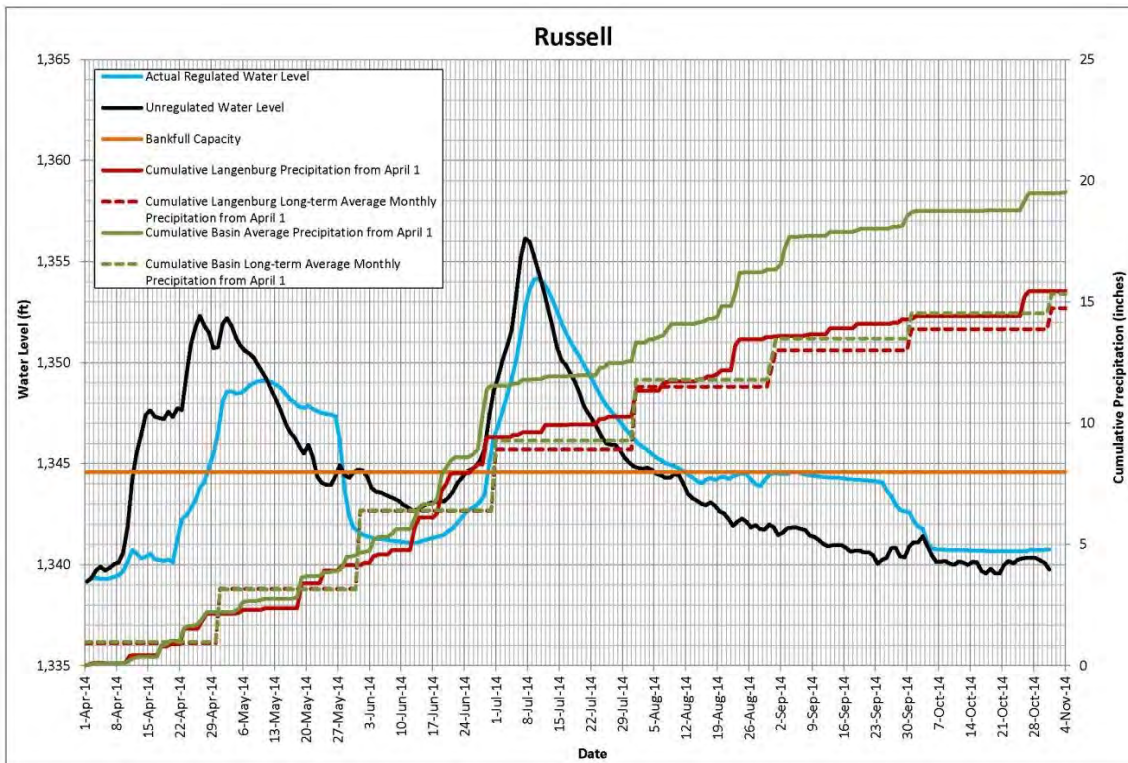


Figure 13: Hydrograph showing regulated and unregulated water levels at Russell (feet)

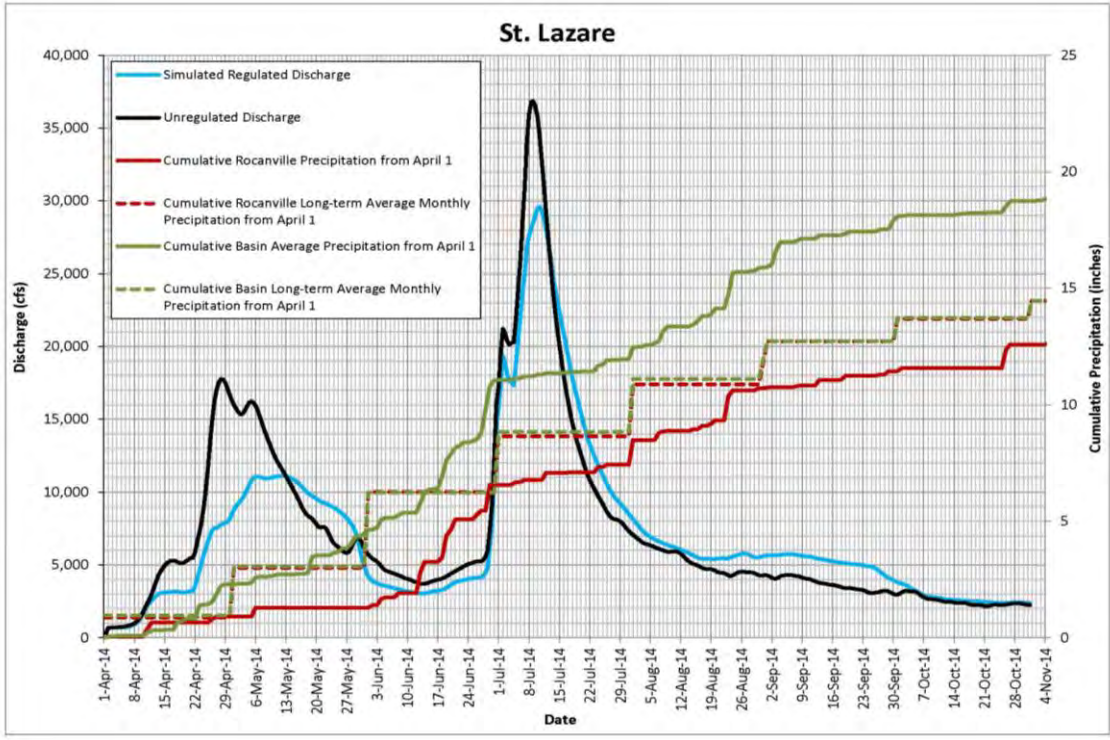


Figure 14: Hydrograph showing regulated and unregulated flows at St. Lazare (cfs)

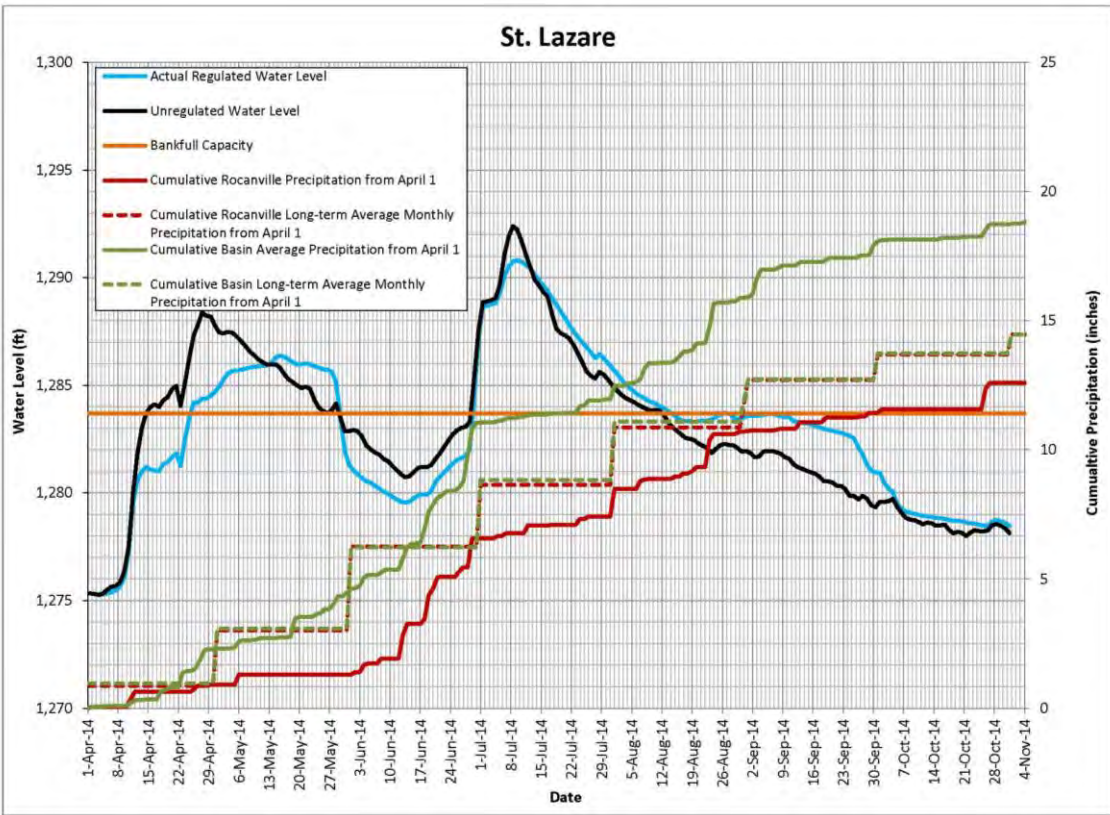


Figure 15: Hydrograph showing regulated and unregulated water levels at St. Lazare (feet)



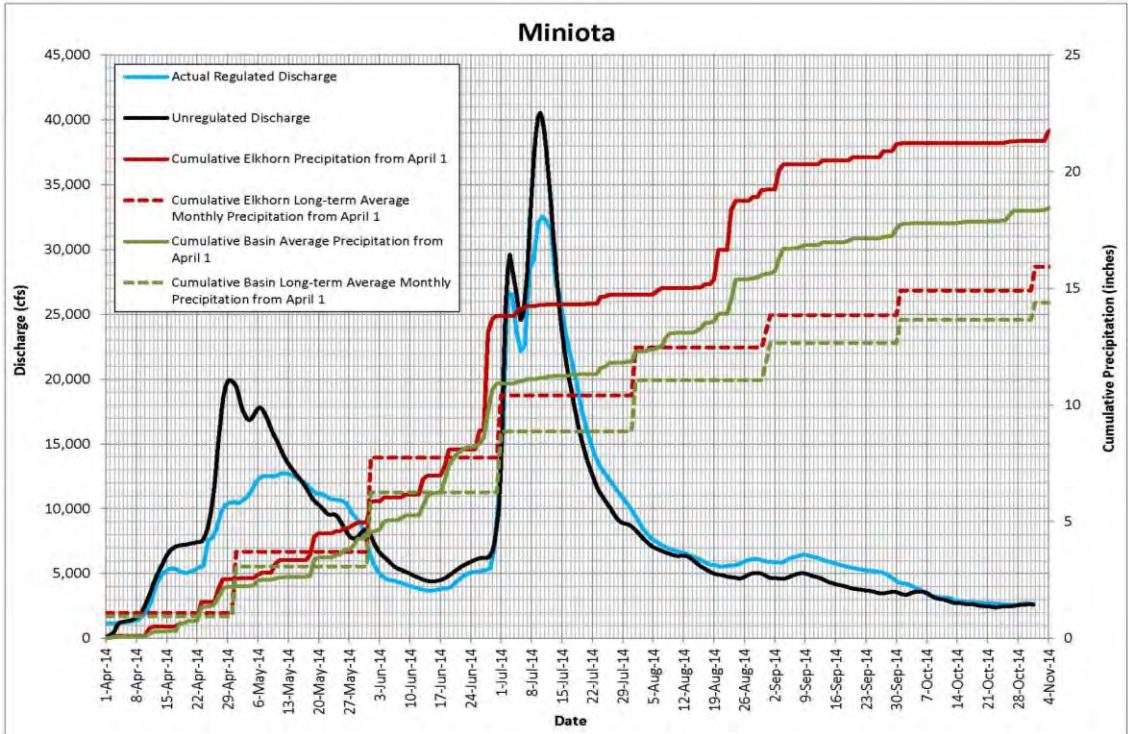


Figure 16: Hydrograph showing regulated and unregulated flows at Miniota (cfs)

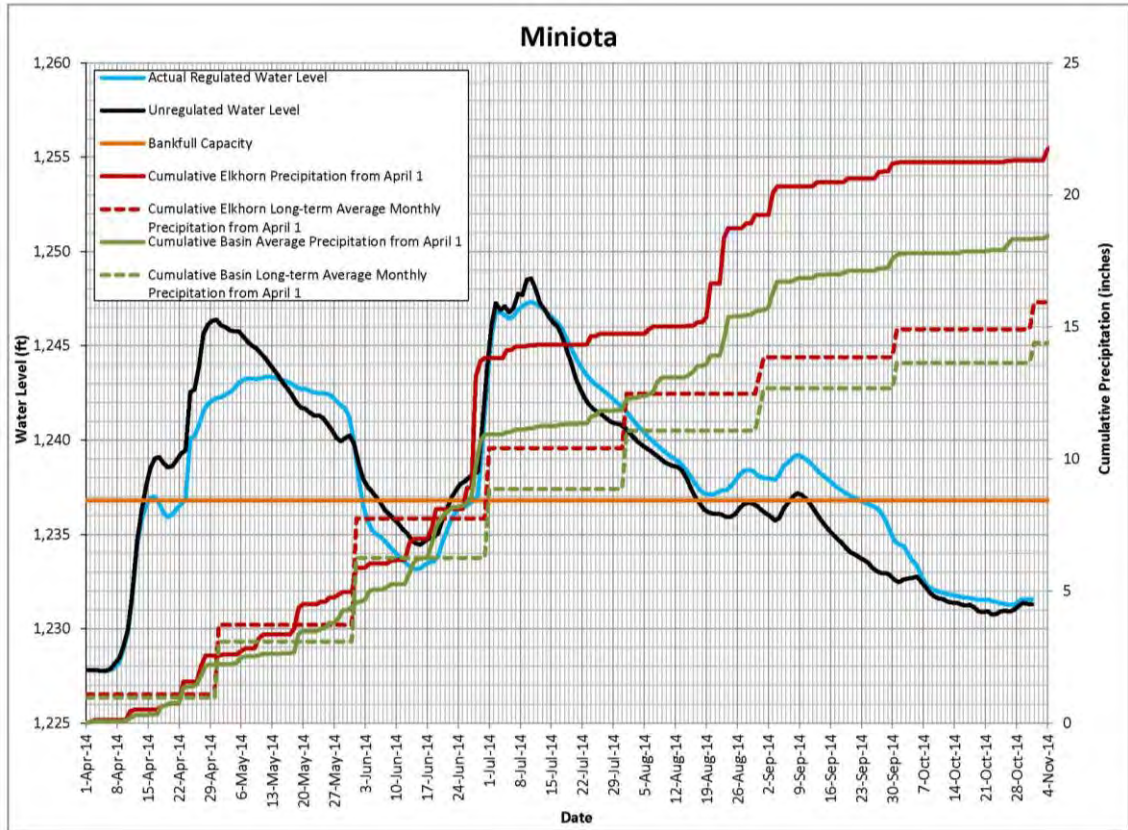


Figure 17: Hydrograph showing regulated and unregulated water levels at Miniota (feet)

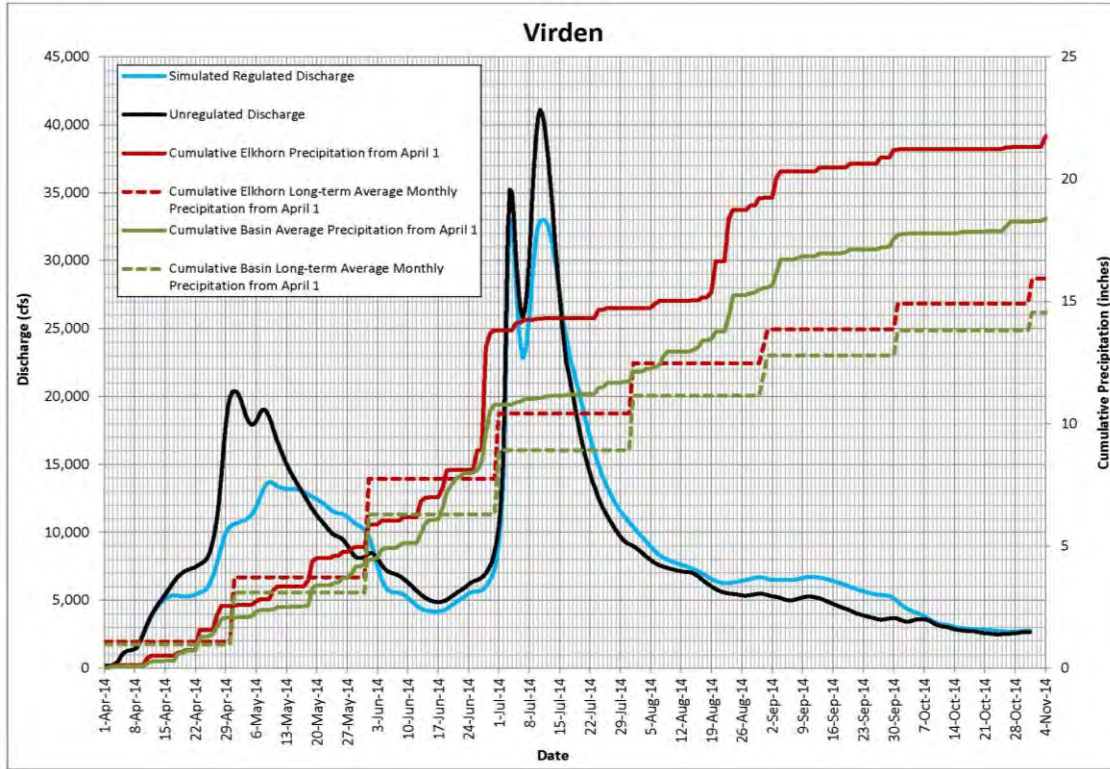


Figure 18: Hydrograph showing regulated and unregulated flows at Virden (cfs)

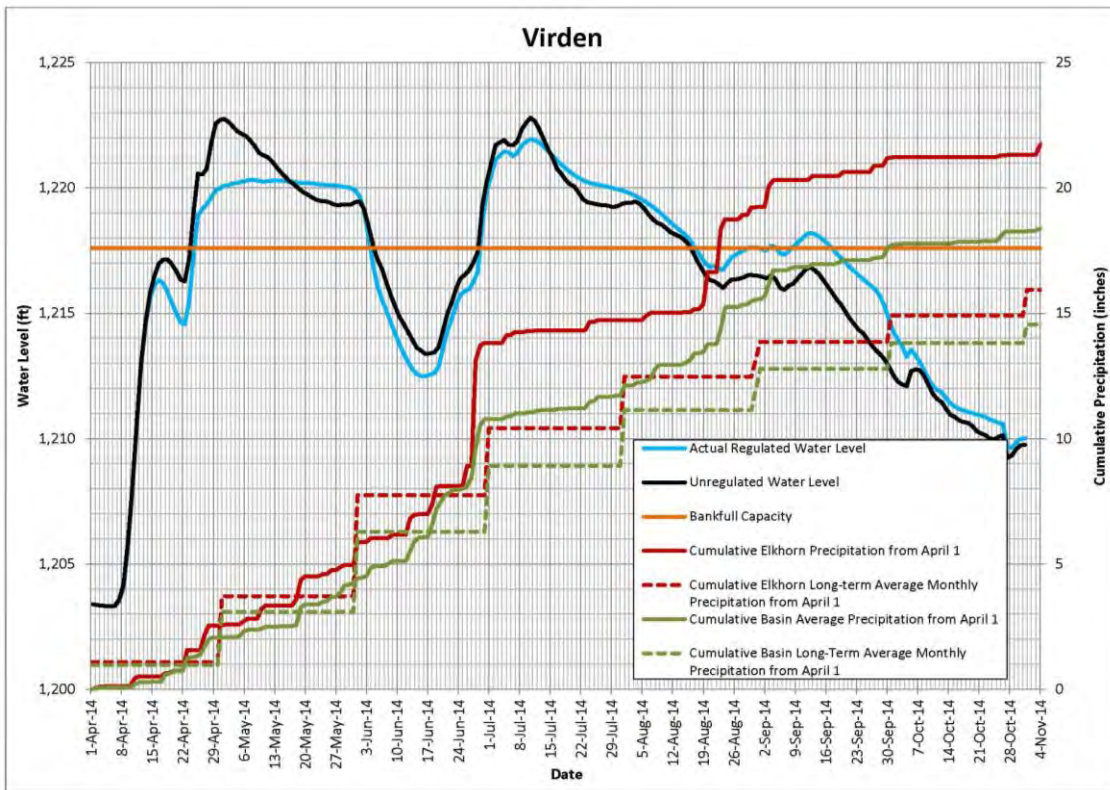


Figure 19: Hydrograph showing regulated and unregulated water levels at Virden (feet)

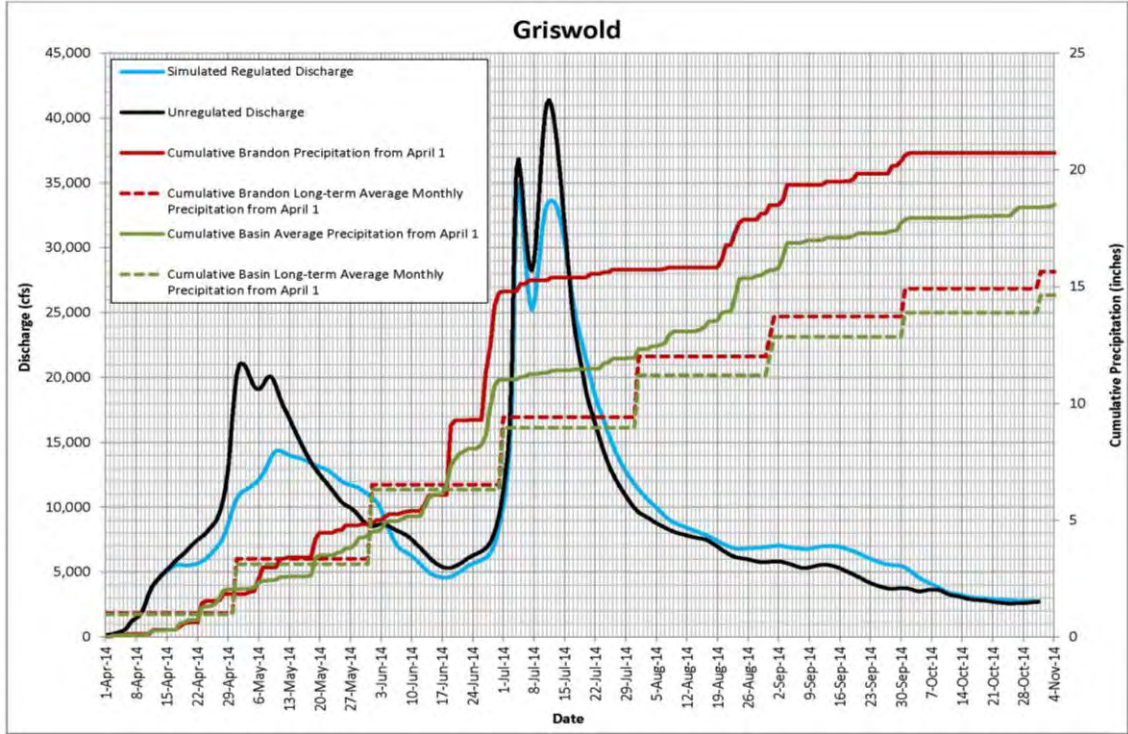


Figure 20: Hydrograph showing regulated and unregulated flows at Griswold (cfs)

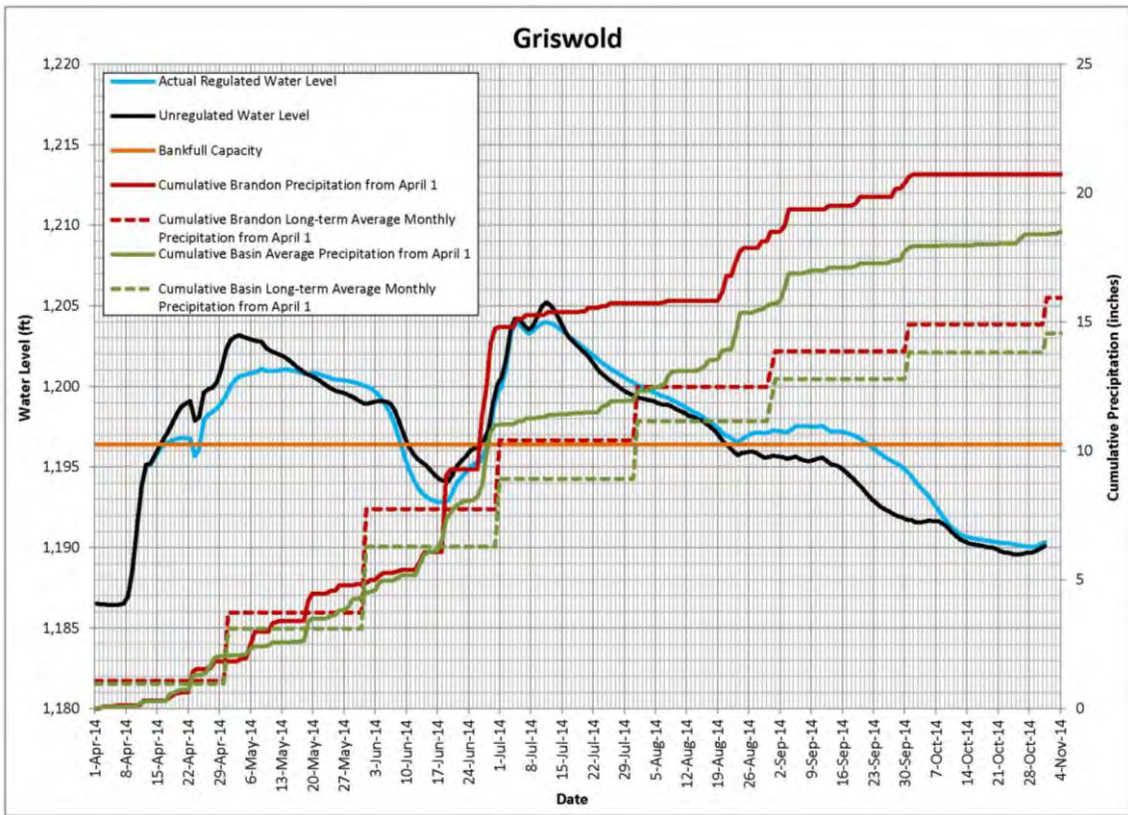


Figure 21: Hydrograph showing regulated and unregulated water levels at Griswold (feet)

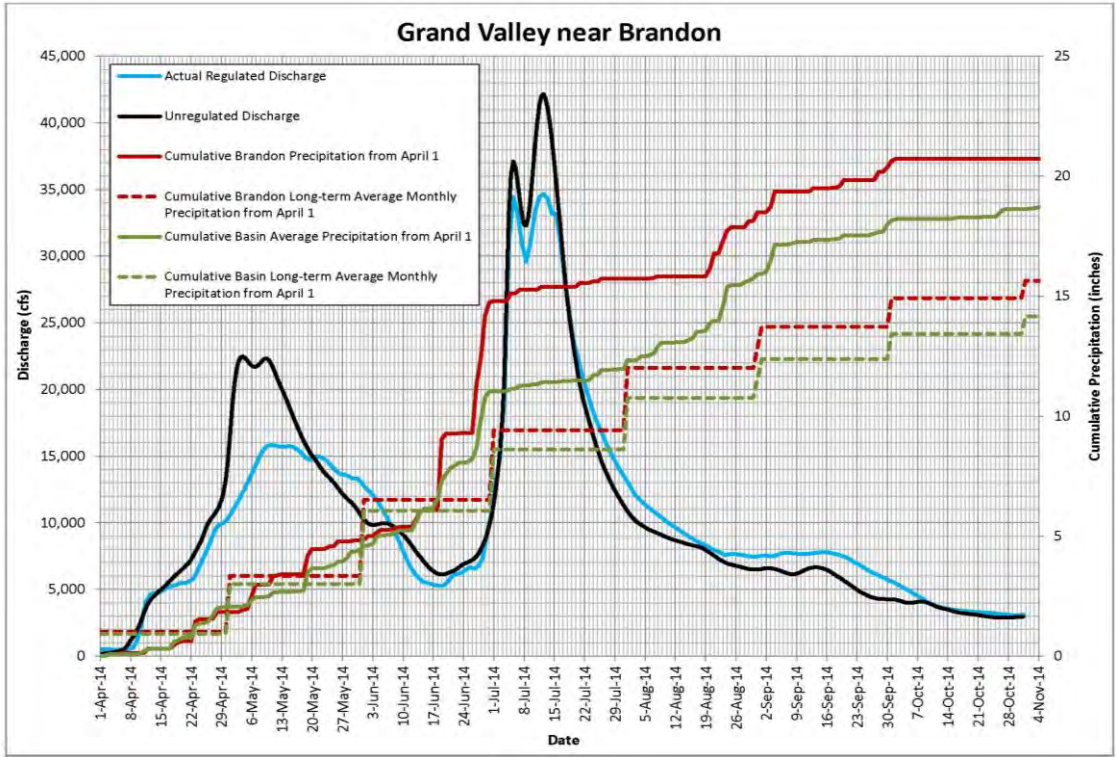


Figure 22: Hydrograph showing regulated and unregulated flows at Brandon (cfs)

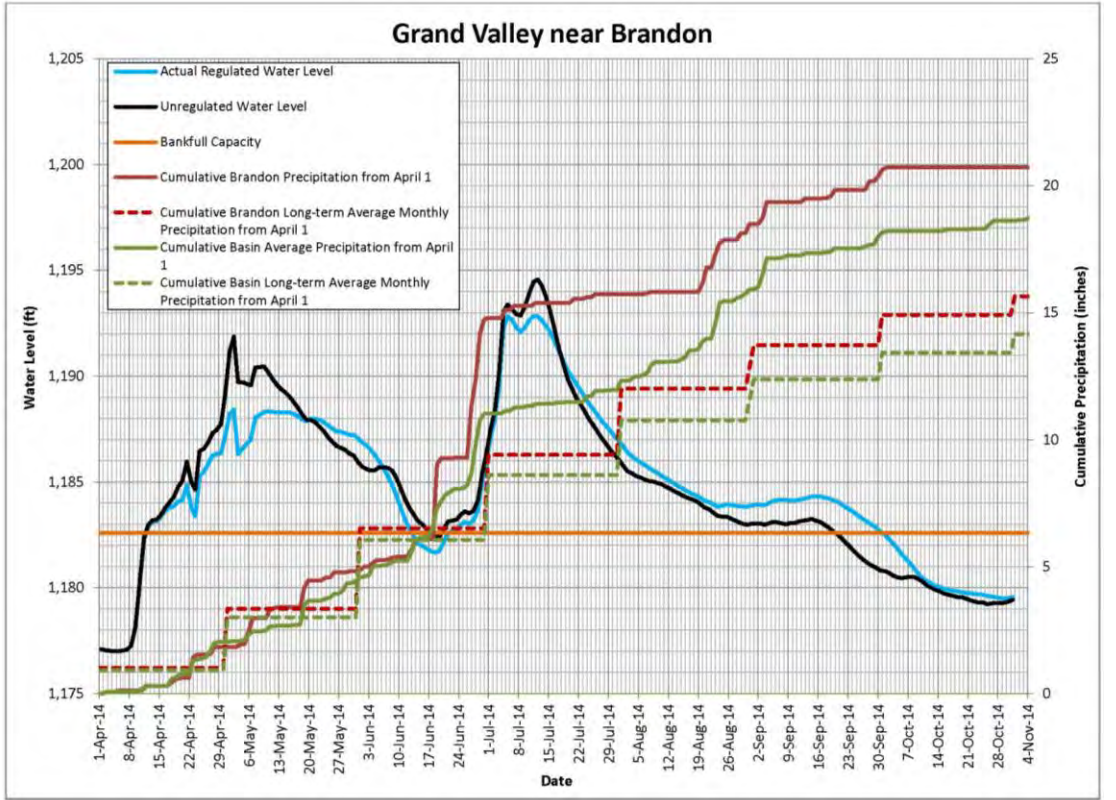


Figure 23: Hydrograph showing regulated and unregulated water levels at Brandon (feet)

## Hydrographs (Metric Measurements)

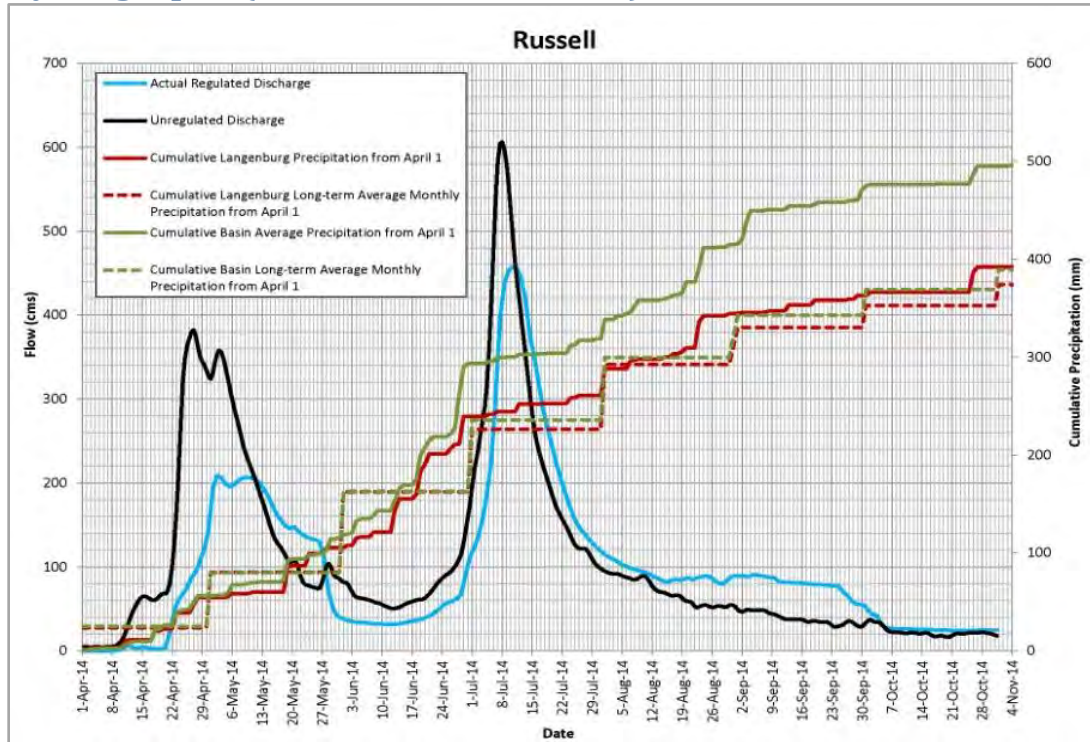


Figure 24: Hydrograph showing regulated and unregulated discharge at Russell (cms)

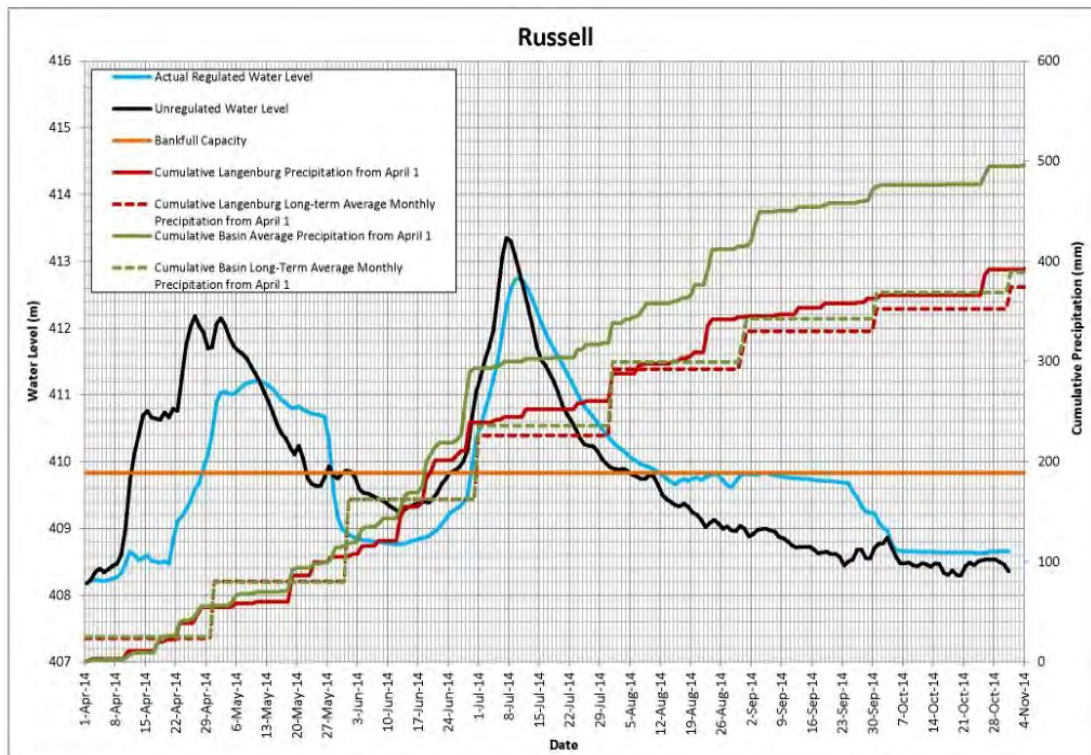


Figure 25: Hydrograph showing regulated and unregulated water levels at Russell (m)

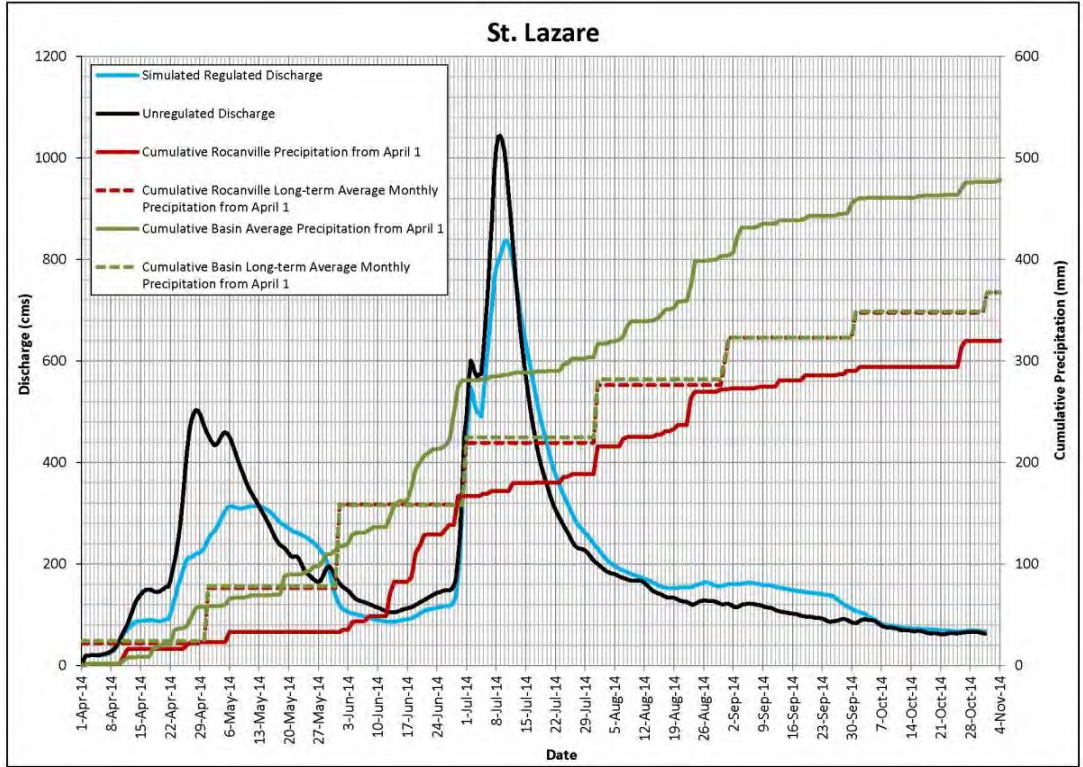


Figure 26: Hydrograph showing regulated and unregulated discharge at St. Lazare (cms)

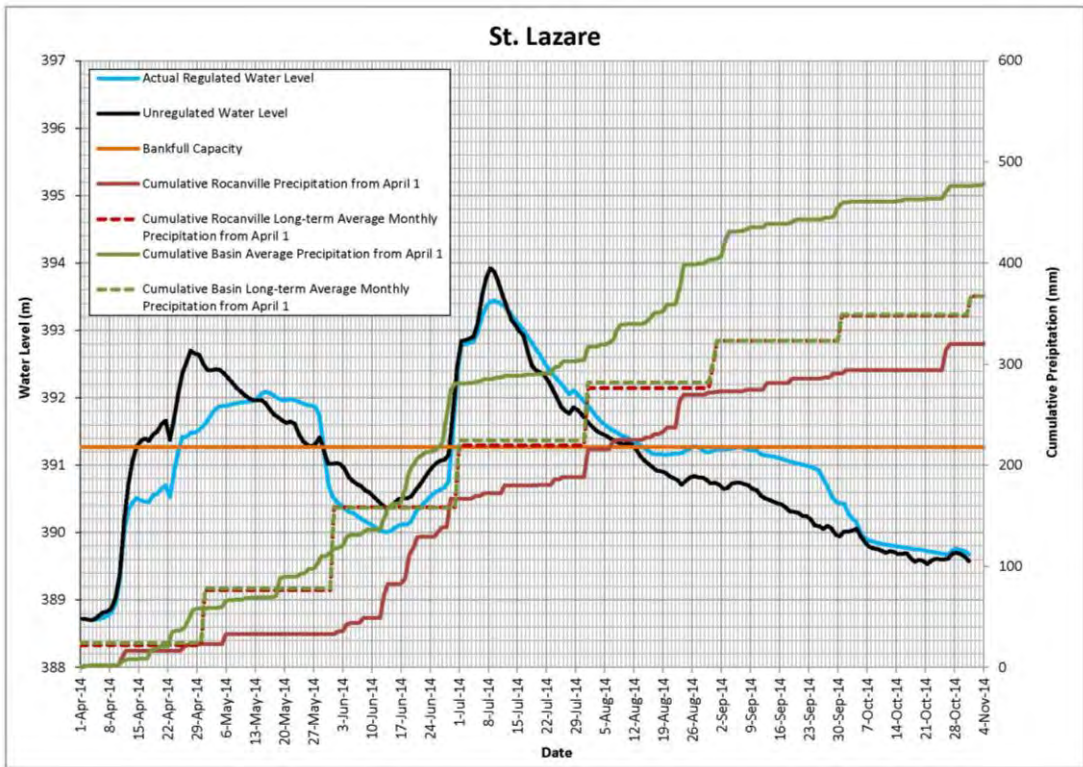


Figure 27: Hydrograph showing regulated and unregulated water levels at St. Lazare (m)

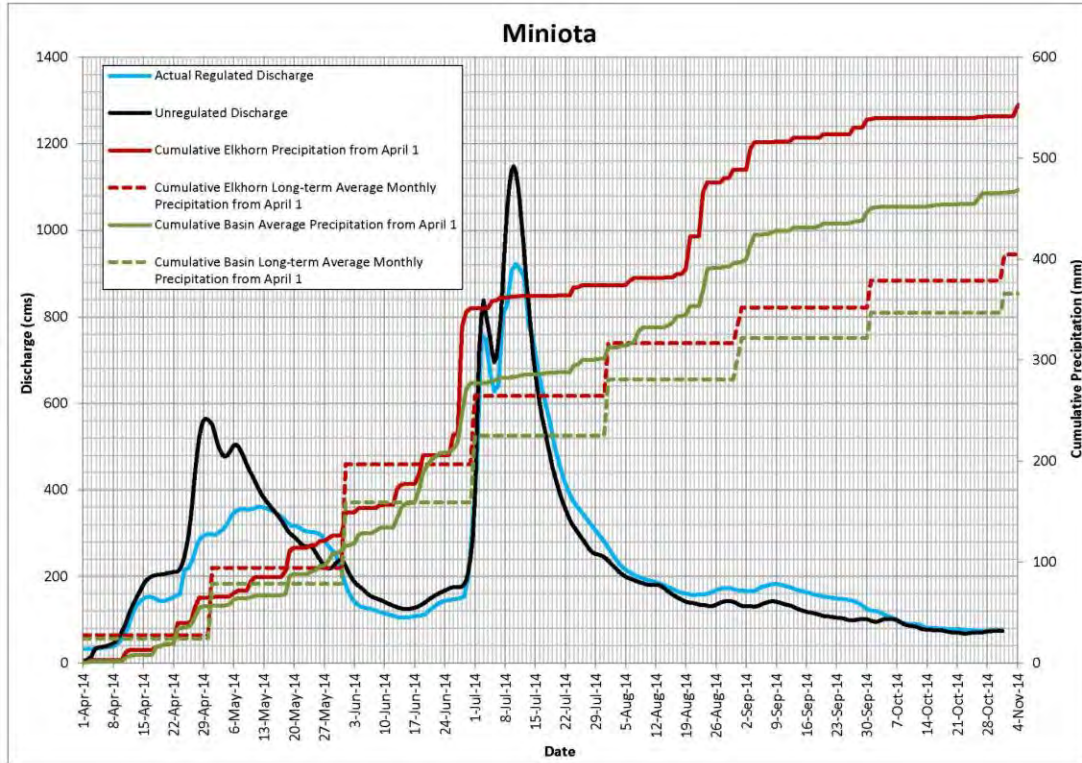


Figure 28: Hydrograph showing regulated and unregulated discharge at Miniota (cms)

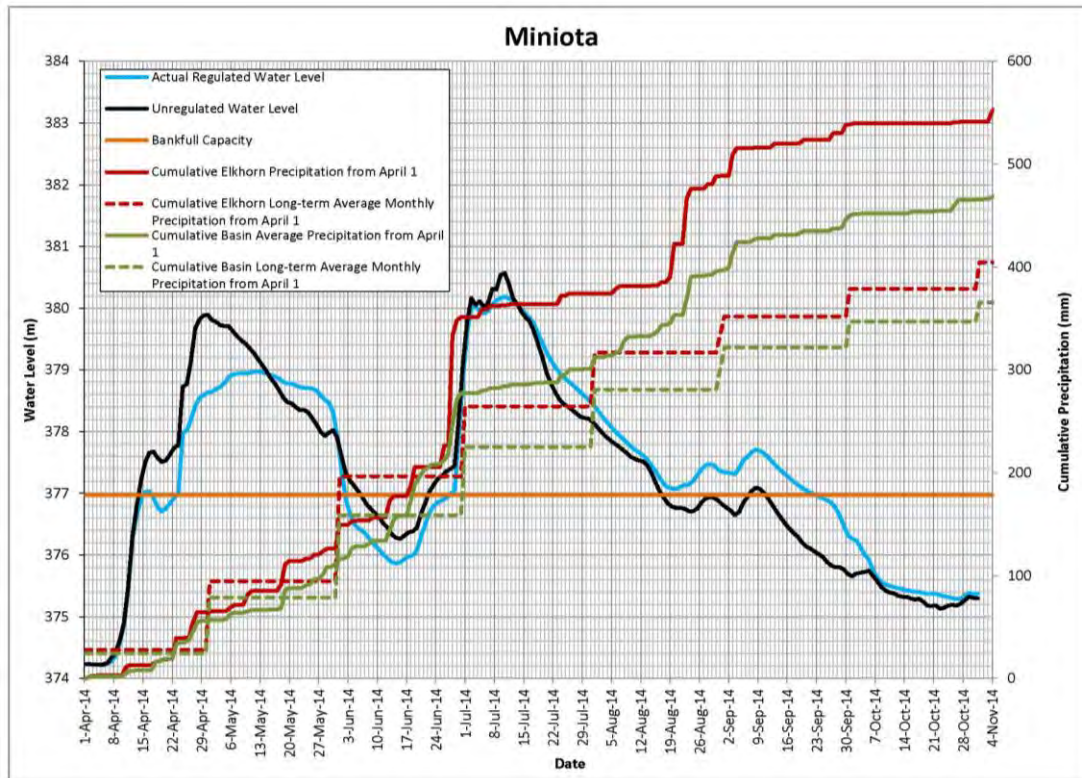


Figure 29: Hydrograph showing regulated and unregulated water levels at Miniota (m)

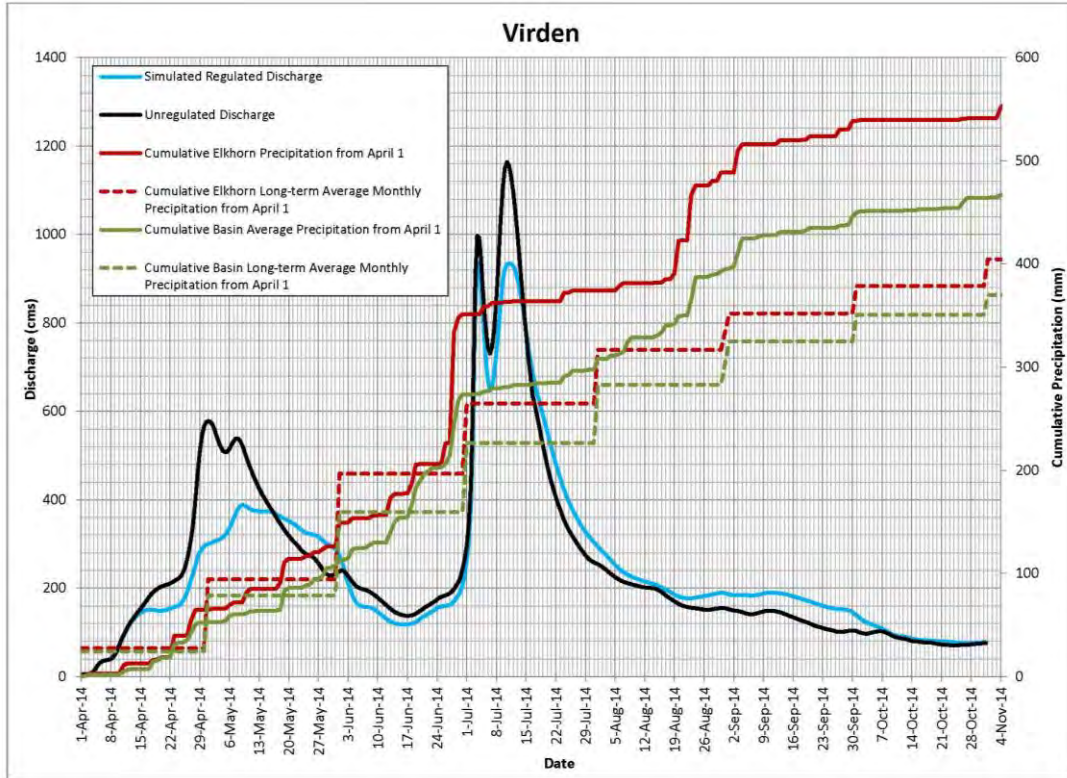


Figure 30: Hydrograph showing regulated and unregulated discharge at Virden (cms)

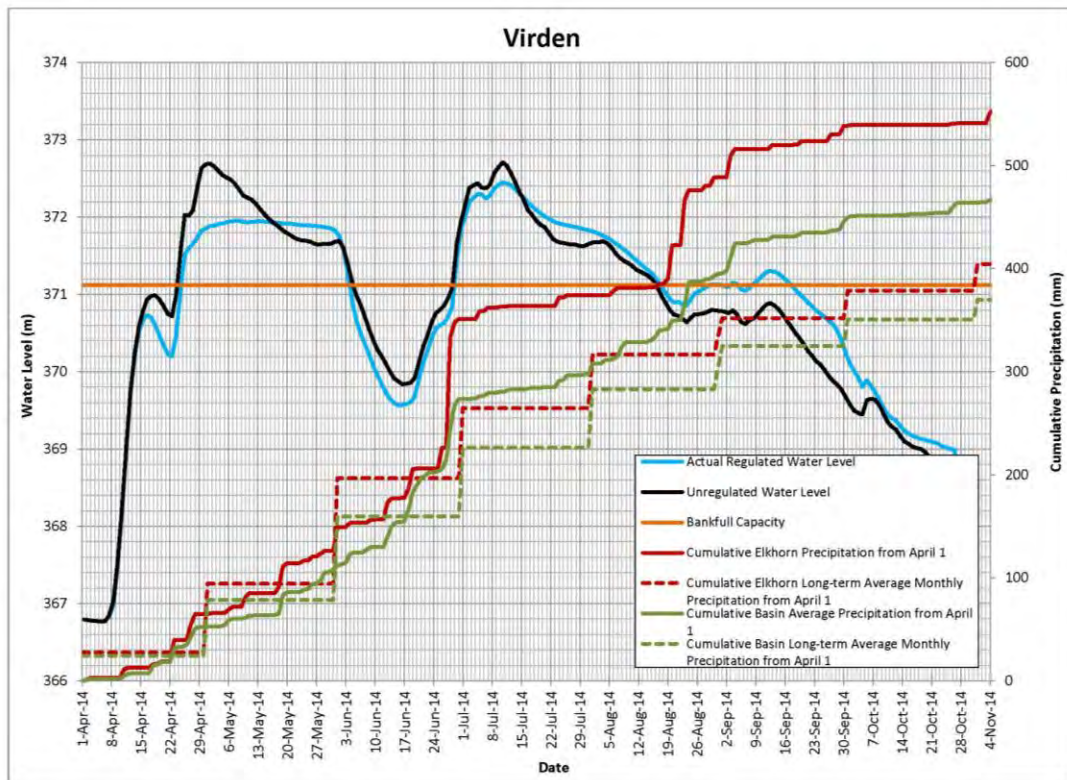


Figure 31: Hydrograph showing regulated and unregulated water levels at Virden (m)



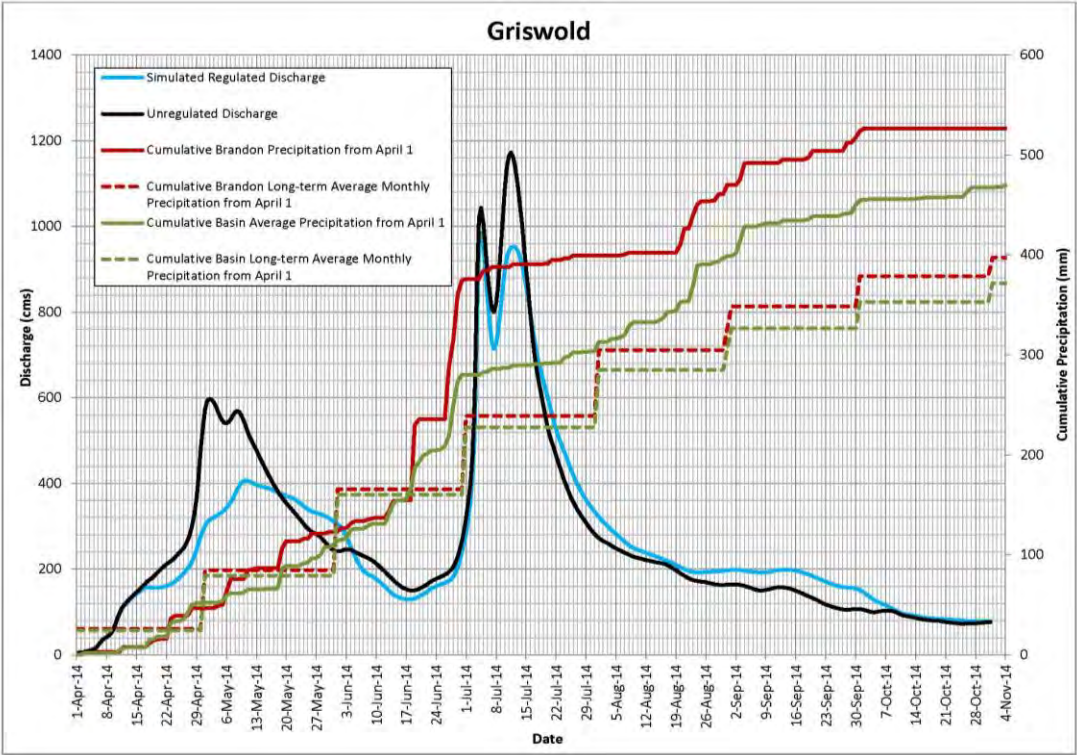


Figure 32: Hydrograph showing regulated and unregulated discharge at Griswold (cms)

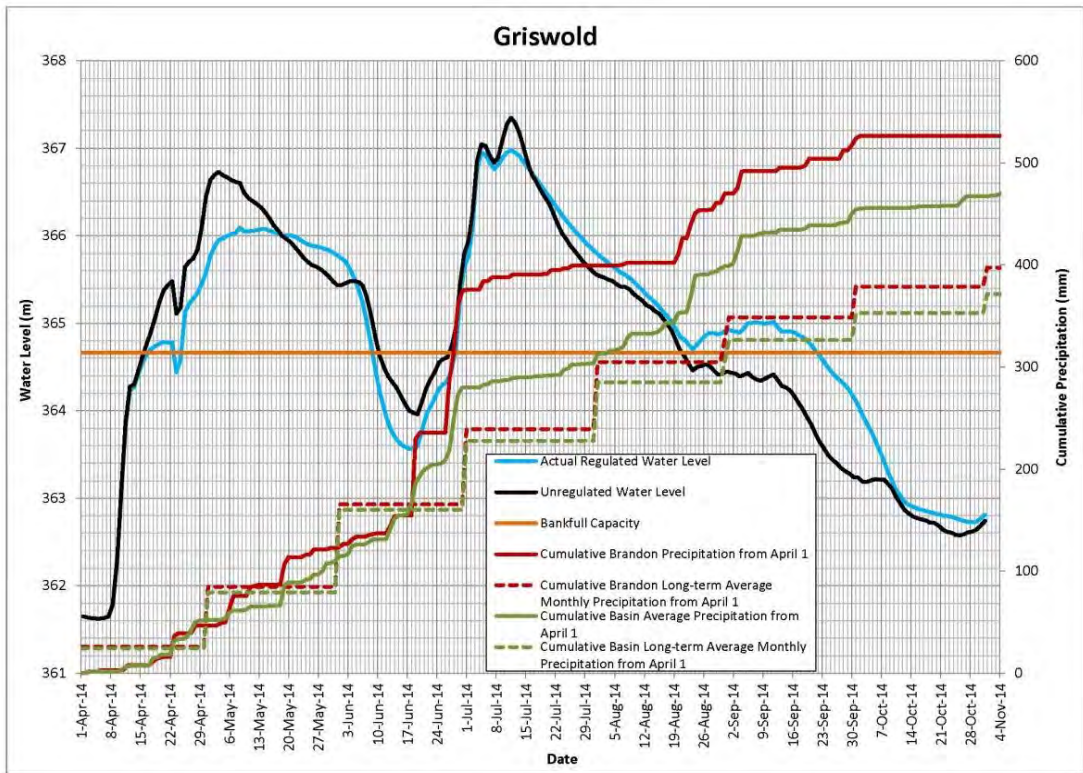


Figure 33: Hydrograph showing regulated and unregulated water levels at Griswold (m)

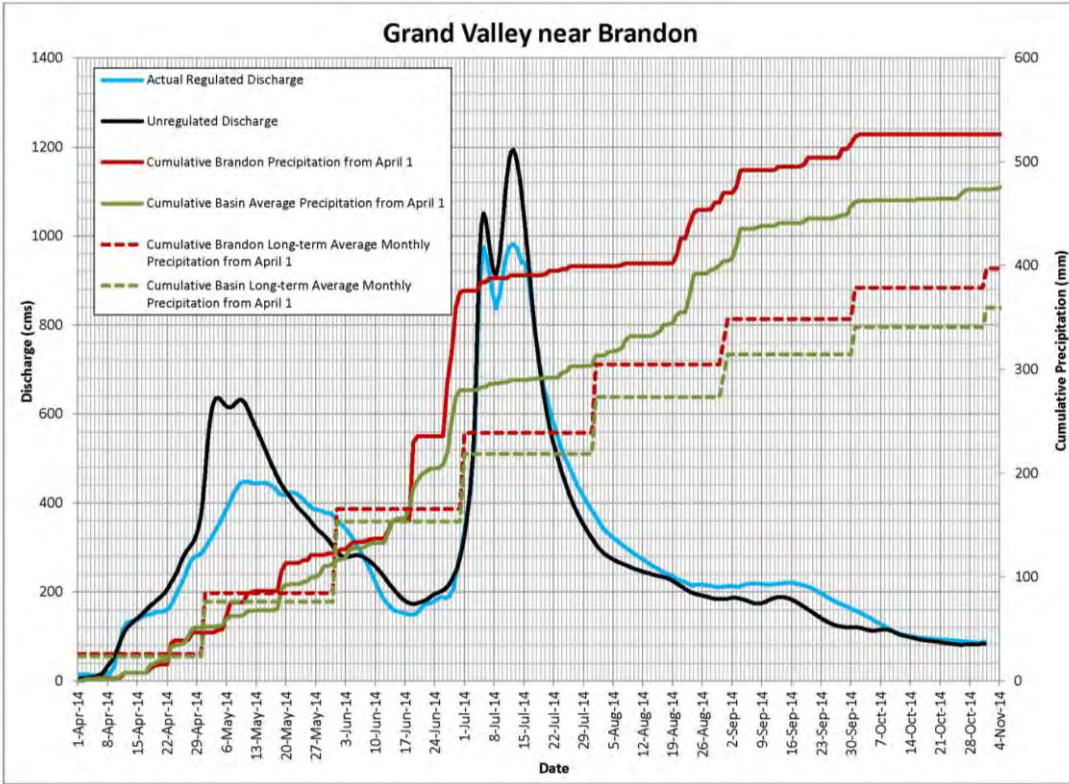


Figure 34: Hydrograph showing regulated and unregulated discharge at Brandon (cms)

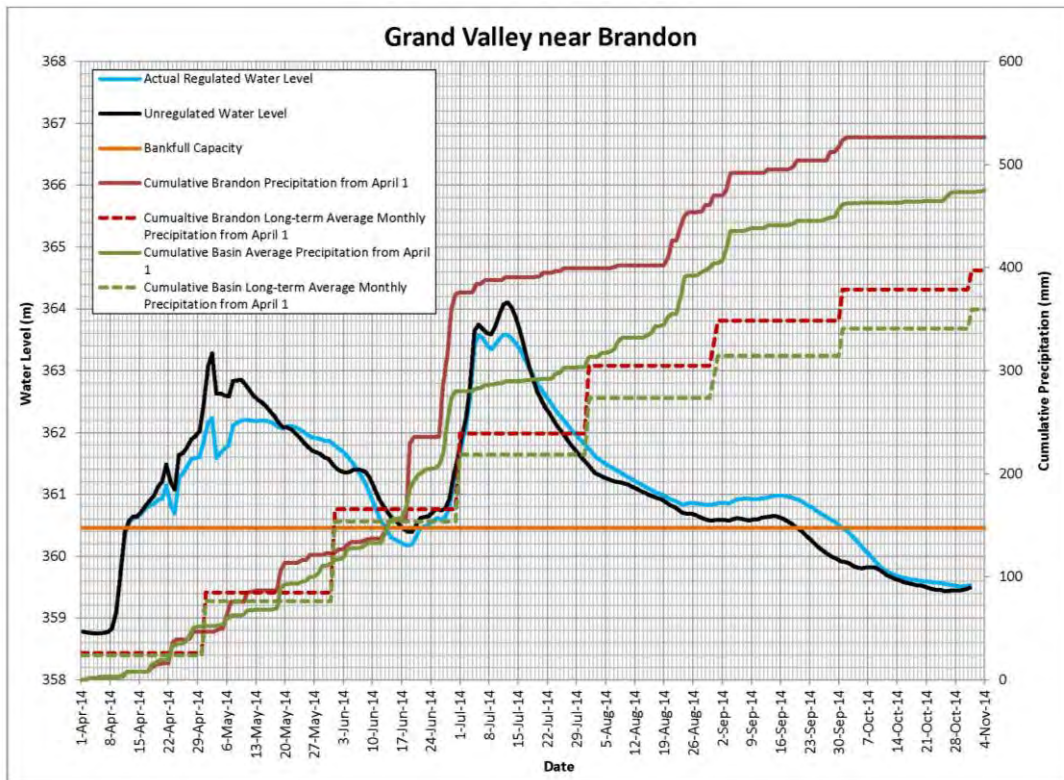


Figure 35: Hydrograph showing regulated and unregulated water levels at Brandon (m)