Appendix G-1: Target Drawdown Analysis

PF2 – Supplemental Technical Analysis

1 Objective

The objective of this assessment is to gain a better understanding of how drawing down the reservoirs impacts flood and water supply operations in the basin. Plan of Study, Phase III operating scenarios 308 and 311 consist of proposed changes to the normal and spring drawdowns, respectively. This analysis will be applied to aid in the optimization of the targeted 01 February normal drawdown elevation and the pre- spring runoff flood drawdown. This assessment is being used as a starting point to minimize the number of optimization trials necessary in ResSim and as a means of better framing the results produced by the ResSim trials.

2 Assumptions

Several assumptions are made at all the reservoirs sites to facilitate this screening level analysis:

- The 90-day inflow volume used to define the March (spring flood) drawdown takes in account the forecasted flow between February 1 and June 1. This is to ensure there is enough flood control space in the reservoir to accommodate inflows that have a snowmelt component during this period.
- It is assumed that operators want the reservoirs to be at their respective full supply/normal summer pools by the 15th of May to support water supply operations. To evaluate if water supply objectives are being met, the maximum 90-day inflow volume to the reservoirs between February 1st and May 15th is analyzed.
- It is assumed that streamflows are being adequately managed when releases can be kept below the following critical channel restraints:
    - 706 cfs below Grant Devine Reservoir
    - 883 cfs below Rafferty Reservoir
    - 1,400 cfs below Lake Darling Reservoir
- It is assumed that operators will try to minimize having to release flows at the thresholds listed above for durations of over 45 days.

To better understand when spring drawdown is necessary, as currently prescribed by Annex A, a screening level volume frequency assessment is carried out. Note that we are using an approximation of the 90 day volume frequency curve because a 90-day frequency curve cannot be generated using observed streamflow data because the assumption of event independence, required to apply B17C would be violated for a significant portion of the historic record. The 60-day frequency curve is adopted based on observed data because the 60-day frequency distributions appear to nest reasonably well with the other durations. Note that we are trying to come up with a rough approximation of the frequency distribution associated with the 90-day 90% forecasted flows. If a more in-depth volume-frequency analysis was to be carried out, the validity of the assumption of event independence would have to be thoroughly evaluated for the 60-day duration to ensure that the rising limb of subsequent event hydrographs was not contributing to the maximum 60-days of flow for a given event. This is not meant to be an exact, detailed, or comprehensive frequency analysis.

3 Grant Devine Reservoir

Inflow to Grant Devine Reservoir were computed as part of HH1 – Reconstructed Hydrology for 1946 to 2017. The normal drawdown target elevation at Grant Devine Reservoir is 1840.55 feet. This elevation is targeted by 01 February of each year. If a flood event is forecasted, Grant Devine Reservoir is drawdown further in order to store excess spring runoff. The drawdown at Grant Devine is specified by Plate A-3 of Annex A and is based on the 90%-90-day inflow volume forecasted for the reservoir. The maximum allowable drawdown at Grant Devine Reservoir is 1823.65 feet. The model currently assumes that the maximum allowable drawdown will be reached by 15 March if additional drawdown is required.

3.1 Normal Drawdown

It takes 9,130 acre-feet of inflow to fill Grant Devine Reservoir from its normal, 01 February Pool Elevation to its desired full supply level of 1843.83 feet. Between 1946 and 2017 there are 26 years (36% of years) where the maximum 90-day inflow volume to Grant Devine Reservoir between February 1 and May 15th is not enough to bring the pool up to full supply (Figure 1). This suggests that during some years, the normal drawdown target should be higher to support water supply operations. To ensure that there is still enough storage space for potential spring runoff, the normal drawdown elevation should be dependent on antecedent conditions. Raising the normal drawdown target could make it more difficult to reach spring drawdown targets before the onset of runoff. Additionally, a higher normal drawdown target will need to be assessed while taking in consideration the time and quantity of releases it will take to bring the pool back to its full supply level after spring runoff.

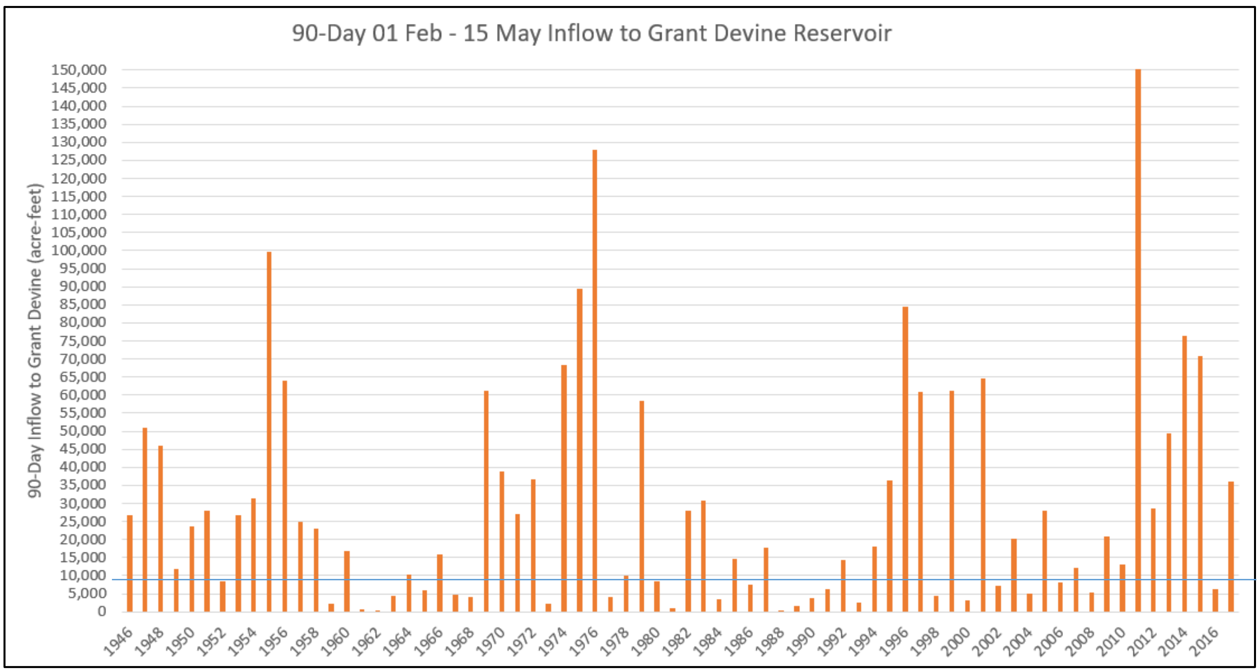

Figure 1. 90-day inflow volume to Grant Devine Reservoir – blue line indicates quantity necessary to fill from normal drawdown to full supply

To optimize the normal drawdown target and to better understand the impact of modifying the normal drawdown target it is suggested that four changes to normal drawdown be considered relative to the baseline (Table 1):

Table 1. Normal Pool Elevation Sensitivity Analysis – Grant Devine Reservoir

	Target Normal Pool Elevation Sensitivity Analysis			
Alternative #	% of Years Where FSL will be reach (approximately)	Target Pool Elevation (feet)	Target Storage (acre-feet)	Notes
0	64%	1840.55	76,500	Current Operations – Normal Drawdown Target
1	75%	1841.86	80,062	
2	81%	1842.26	81,155	
3	90%	1842.99	83,205	
4	100%	1843.83	85,530	No Drawdown - FSL

During non-flood operations, operators typically try to keep outflows from Grant Devine Reservoir below 706 cfs to prevent fish stranding. It is assumed that operators will want to get back to FSL by 15-May and that the top 90-days of inflow to Grant Devine during the spring runoff period reflects the bulk of the inflow between 01 February and 15-May. It is assumed that operators will want to get back to full supply within a 45 day period. Based on a preliminary assessment Alternative 3 might offer the optimum change to the normal drawdown target. This alternative is unlikely to cause additional flood issues, while offering significant water supply benefits. Relative to current operations, for non-flood events releases would have to be made for longer than 45-days or at an average magnitude of above 706 cfs for one additional event. However, full supply would have been reached over 90% of the years instead of 64% of the years.

3.2 Spring Drawdown

It appears that the reservoir is drawn down to its maximum drawdown when projected inflows are occurring at about a 13% annual exceedance probability (Figure 2). Additional springtime drawdown takes place when projected inflows are occurring at about a 45% annual exceedance probability (Figure 2). It appears that the 2011 event could have benefited from some additional drawdown to prevent releases from becoming too high.

To fully contain the 2011 event to releases below 706 cfs the reservoir would have had to be drawn down to provide over an additional 150,000 acre-feet of storage. This would not be feasible. Even if the reservoir was drawn down to 1817.59 feet prior to the 2011 event the reservoir would still have to release an average flow of 2,400 cfs to bring the pool back to full supply. This only provides an incremental difference in release compared to if the current drawdown was applied (2,900 cfs). Thus, increasing the drawdown within a realistic range to accommodate extreme events like the 2011 event isn't likely to provide significant flood control benefits. When the pool is below 1823.65 feet drawing the pool down further doesn't provide a significant amount of additional storage space (less than 1,500 acre-feet of additional storage per every additional one foot of drawdown).

To fully contain the 1976 event, preventing releases from rising above 706 cfs, the reservoir would have had to been drawn down to provide for an additional 20,600 acre-feet of storage. This would imply drawing the reservoir down an additional 18 feet/5.5 meters. This is also not likely feasible. However, with the current prescribed drawdown releases could be managed to under 1,000 cfs. This implies that with the current drawdown the 1976 event was sufficiently contained.

In general, the specified spring drawdown appears to provide adequate storage for spring runoff without compromising the pool's ability to get back to full supply level by 15 May. A range of spring runoff events generated by the stochastic model should be applied to ensure this holds true for events in between the 10% and 0.5% annual exceedance probability event.

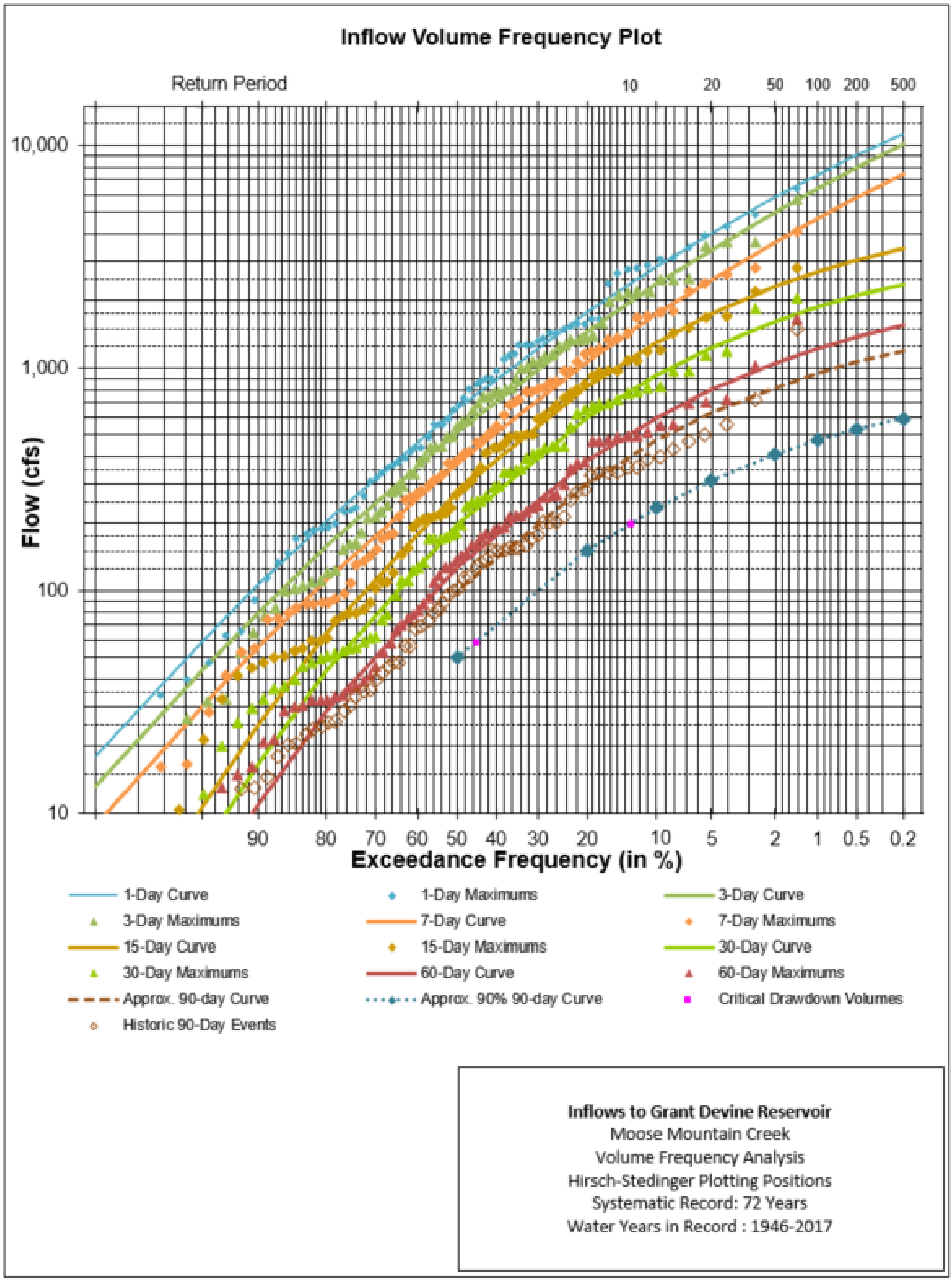

Figure 2. Inflow Volume Frequency Analysis – Grant Devine Reservoir

4 Rafferty Reservoir

Inflows to Rafferty Reservoir were computed as part of HH1 – Reconstructed Hydrology for 1946 to 2017. The normal drawdown target elevation at Rafferty Reservoir is 1802.82 feet. This elevation is targeted by 01 February of each year. If a flood event is forecasted, Rafferty Reservoir is drawdown further in order to store excess spring runoff. The drawdown at Rafferty Reservoir is specified by Plate A-1 of Annex A and is based on the 90%-90-day inflow volume forecasted for the reservoir. The maximum allowable drawdown at Rafferty Reservoir is 1796.26 feet.

If a drawdown is necessary at Boundary Reservoir the additional storage gained by the required drawdown is added to the targeted drawdown elevation at Rafferty, unless it would drive Rafferty reservoir below its maximum allowable drawdown elevation of 1796.26 feet. In the case where accommodating Boundary's storage would result in Rafferty falling below its maximum drawdown target, Boundary is drawn down independently. This occurred in 2011 and 1976. Inflows to Boundary are passed to Rafferty Reservoir via the Rafferty-Boundary diversion until Rafferty reaches its full supply level of 1806.10 feet. In the past the Saskatchewan Water Security Agency preferentially used the diverted outlet because Boundary's main spillway outlet needed repair. Boundary's spillway has recently been rehabilitated so operators no longer use the diverted outlet as frequently. The model is setup to represent post-2011 operations.

4.1 Normal Drawdown

During any given year it takes 38,300 acre-feet of inflow to fill Rafferty Reservoir from its normal, 1 February Pool Elevation to its desired full supply level of 1806.10 feet. For this assessment it is assumed that Boundary Reservoir is already at its Full Supply Level on Feb 1 so any additional runoff into Boundary would be passed to Rafferty to help it reach full supply.

Between 1946 and 2017 there are 37 years (51% of years) where the maximum, historic (computed) 90-days of inflow volume to Rafferty and Boundary Reservoirs between February 1 and May 15th is not enough to bring Rafferty's pool back up to full supply (Figure 3). This suggests that at least during some years, the normal drawdown target should be higher to support water supply operations. To ensure that there is still enough storage space for potential spring runoff the normal drawdown elevation should be dependent on antecedent conditions. Raising the normal drawdown target could make it more difficult to reach spring drawdown targets before the onset of runoff. Additionally, a higher normal drawdown target will need to be assessed while taking in consideration the time and quantity of releases it will take to bring the pool back to its full supply level after spring runoff.

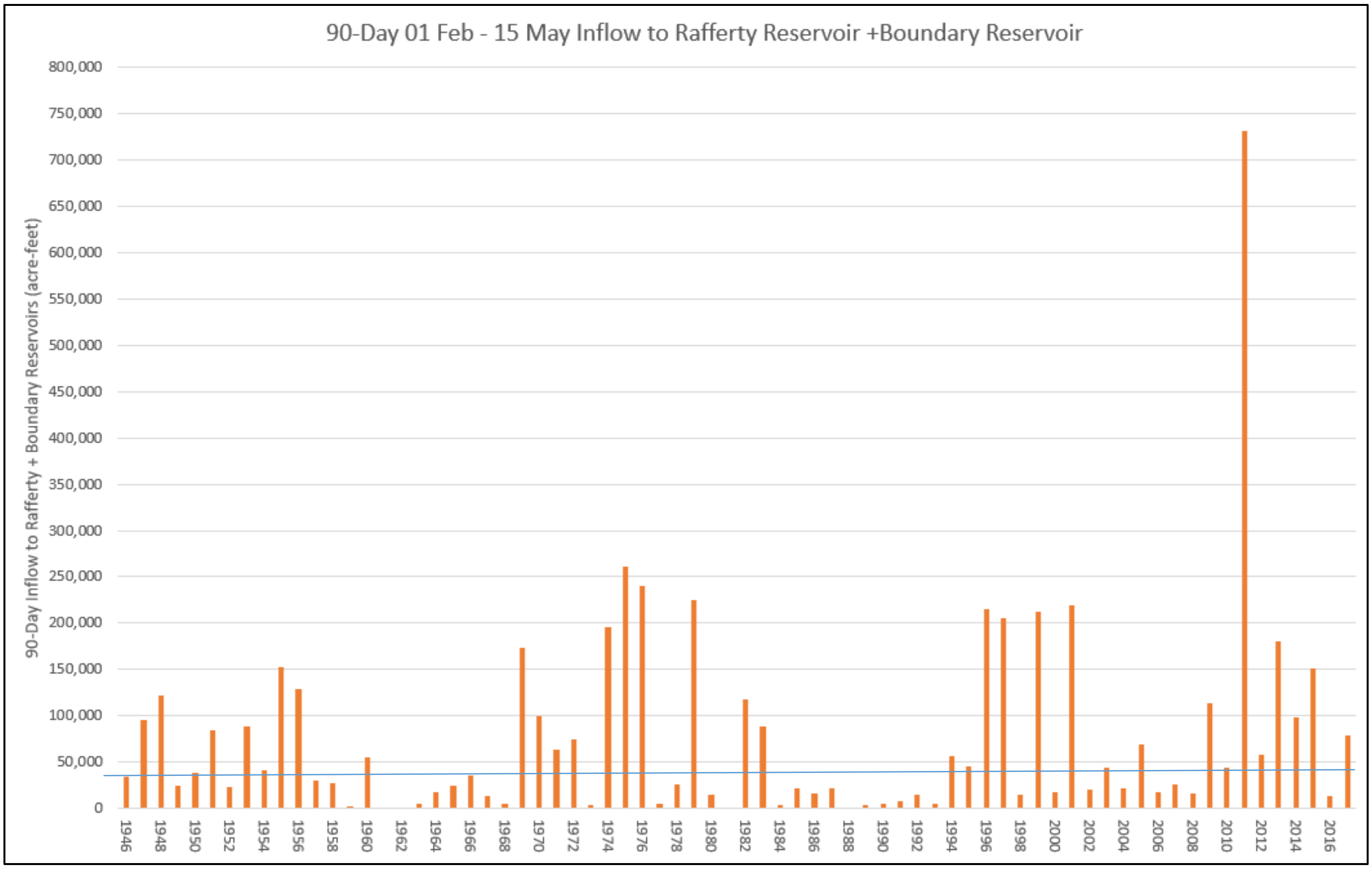

Figure 3. 90-day inflow volume to Rafferty Reservoir – blue line indicates quantity necessary to fill from normal drawdown to full supply

To optimize the normal drawdown target and to better understand the impact of modifying the normal drawdown target it is suggested that four changes to normal drawdown be considered relative to the baseline:

Table 2. Normal Pool Elevation Sensitivity Analysis – Rafferty Reservoir

	Target Normal Pool Elevation Sensitivity Analysis			
Alternative #	% of Years Where FSL will be reach (approximately)	Target Pool Elevation (feet)	Target Storage (acre-feet)	Notes
0	50%	1802.82	318,100	Current Operations – Normal Drawdown Target
1	60%	1804.13	333,772	
3	80%	1804.90	342,723	
4	90%	1805.74	352,279	
5	100%	1806.10	356,400	No Drawdown - FSL

During non-flood operations, operators typically try to keep outflows from Boundary and Rafferty Reservoirs below 883 cfs (25 cms) to prevent the low level coal haul road from becoming inundated. It is assumed that operators will want to get back to FSL by 15-May and that the top 90-days of inflow to

Rafferty and Boundary during the spring runoff period reflects the bulk of the inflow between 01 February and 15-May. It is assumed that operators will want to get back to full supply within a 45 day period. Based on a preliminary assessment Alternative 3 might offer the optimum change to the normal drawdown target. This alternative is unlikely to cause additional flood issues, while offering significant water supply benefits. Relative to current operations, for non-flood events releases would have to be made for longer than 45-days or at an average magnitude of above 883 cfs for three additional event. However, full supply would have been reached approximately 80% of the time instead of approximately 50% of the years.

4.2 Spring Drawdown

It appears that the reservoir is drawn down to its maximum drawdown when projected inflows are occurring at about a 9% annual exceedance probability. Additional springtime drawdown takes place when projected inflows are occurring at about a 27% annual exceedance probability (Figure 4). With the current spring drawdown targets, a number of flood events would have likely resulted in releases that would have made the lower level, coal haul road inaccessible and exceeded the bankfull channel capacity at Estevan: 1,236 cfs (25 cms). Only the 2011 event would have exceeded the capacity of high level coal haul road crossing: 2,470 cfs (70 cms).

There is one event where the pool may have had issue getting back to full supply: 1960. Consequently, care should be taken when adjusting the drawdown target at Rafferty so as not to reduce water supply benefits. Although the reservoir could manage flows for all historic events, some of the more intermediate events would have benefited from additional drawdown. If the pool was drawn down about 0.5 meters (1.64 feet) more the number of events exceeding channel would have been reduced from nine to four. Attempting to draw the pool down further in response to more moderate events could place water supply in jeopardy. To fully contain the 2011 event to releases below 1,236 cfs the reservoir would have had to be drawn down to provide over an additional 511,785 acre-feet of storage. This would not be feasible. A summary of the spring drawdown evaluation results is included in Table 4.

Table 3. Evaluation of Spring Drawdown at Rafferty Reservoir

Spring Drawdown Target	Number of Flood Events that Can't Reach FSL	Number of Flood Events that would Overtop Low Haul Coal Road	Number of Flood Events Exceeding Channel Capacity	Number of Flood Events that would Overtop High Haul Coal Road
Baseline	0	12	9	1
1 m (3.28 feet) below baseline	5	9	1	1
0.5 m (1.64 feet) below baseline	1	12	4	1
0.25 m (0.82 feet) below baseline	1	12	7	1
0.15 m (0.49 feet) below baseline	1	12	8	1

Two events that occurred during non-flood years could have likely benefited from additional drawdown including the 1956 event and the 2015 event. Although their respective inflow volumes had exceedance probabilities of less than 27% (>36,500 acre-feet) no additional drawdown took place in 1956 and 2015, because the basin was not considered in flood. It may be advisable for reservoir drawdown to take place regardless of whether or not the basin is in flood if the volume of water projected above a particular site warrants it.

Because Rafferty is a lager reservoir increasing the spring drawdown target offers considerable gains in storage. For every foot the pool is drawn down below the current, normal drawdown target of 1802.82 feet the reservoir gains about 10,000 acre-feet of additional storage. It is suggested that the pool be drawn down an additional 0.5 m (1.64 feet) relative to current prescribed operations. An assessment should be made to evaluate whether this would best be accomplished by shifting the values in the plate to the left versus just dropping the values in the plate vertically. Both approaches should be tested and results should be evaluated in terms of which change has the least impact on water supply, while maximizing flood control benefits. A range of spring runoff events generated by the stochastic model should be applied, as well as historic events to optimize the target drawdown and ensure that water supply is not compromised.

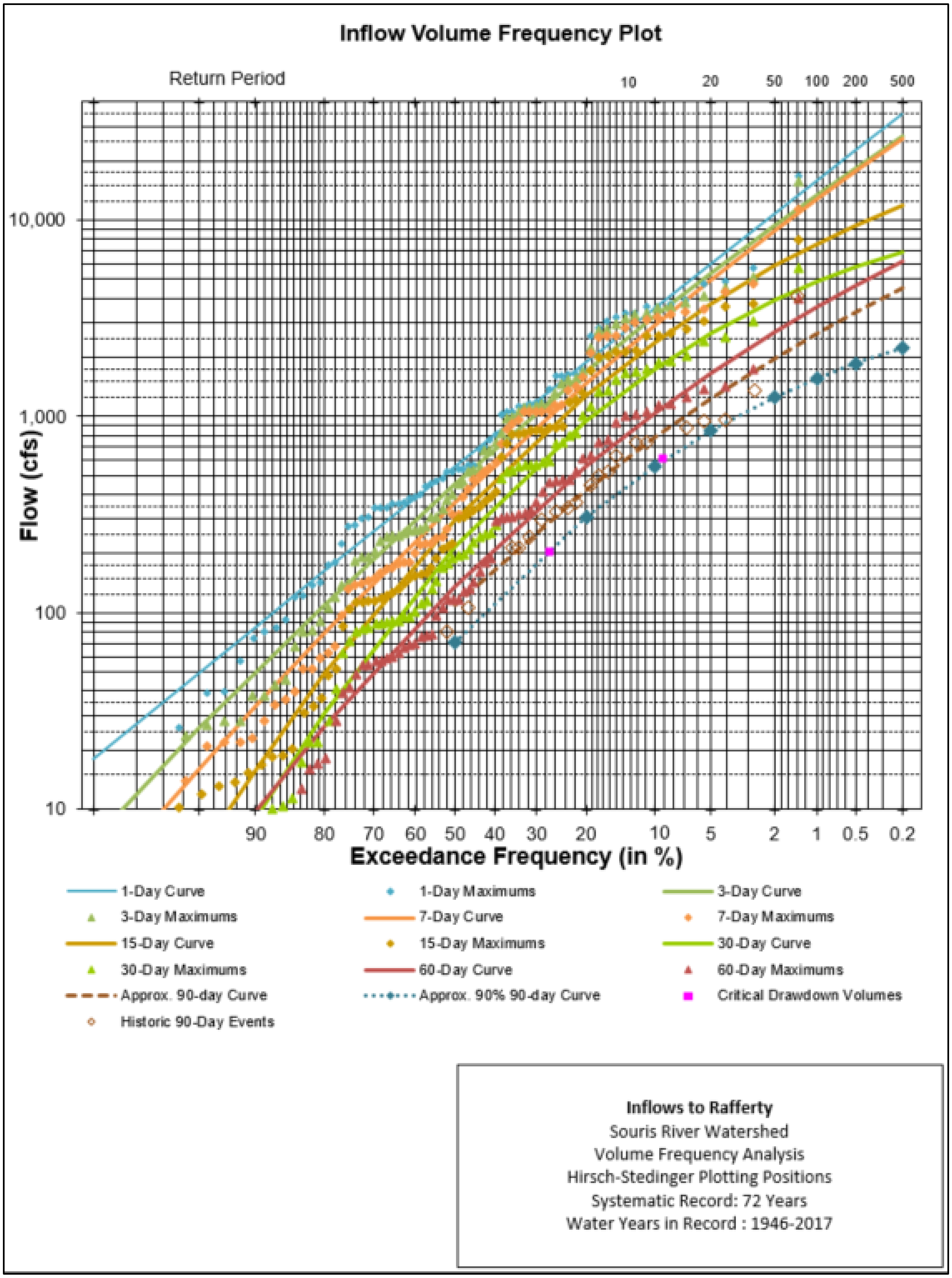

Figure 4. Inflow Volume Frequency Analysis – Rafferty Reservoir

5 Lake Darling Reservoir

Inflows to Lake Darling are dependent on inflows resulting from releases from the Canadian reservoirs and any local inflow between the Canadian reservoirs and Lake Darling. Target, spring drawdown elevations at Lake Darling Reservoir are dependent on the estimated Sherwood Crossing uncontrolled runoff volume and a sliding scale relating runoff volume to a Lake Darling target pool elevation. Uncontrolled, inflows to Lake Darling Reservoir from the Canadian reservoirs are assumed to be equivalent to the sum of inflows into the upstream reservoirs in excess of their maximum storage levels.

Inflows to the Canadian Reservoirs and intervening, local flow inputs were computed as part of HH1 – Reconstructed Hydrology for 1946 to 2017. The normal drawdown target elevation at Lake Darling Reservoir is 1596 feet. This elevation is targeted by 01 February of each year. If a flood event is forecasted, Lake Darling Reservoir is drawdown further in order to store excess spring runoff. The drawdown at Lake Darling is specified by Plate A-4 of Annex A and the expected (50%), 30-day maximum forecasted uncontrolled volume at Sherwood Crossing. The maximum allowable drawdown at Lake Darling Reservoir is 1591 feet.

5.1 Normal Drawdown

During any given year it takes 10,083 acre-feet of inflow to fill Lake Darling Reservoir from its normal, 1 February Pool Elevation to its desired normal summer pool level of 1597.0 feet. Between 1946 and 2017 there are 16 years (22% of years) where an approximation of the maximum 90-days of inflow volume to Lake Darling Reservoir between February 1 and May 15th is not enough to bring the pool back up to full supply (Figure 5). This suggests that during some years, the normal drawdown target should be higher to support water supply operations. To ensure that there is still enough storage space for potential spring runoff the normal drawdown elevation should be dependent on antecedent conditions. Raising the normal drawdown target could make it more difficult to reach spring drawdown targets before the onset of runoff. Additionally, a higher normal drawdown target will need to be assessed while taking in consideration the time and quantity of releases it will take to bring the pool back to its full supply level after spring runoff.

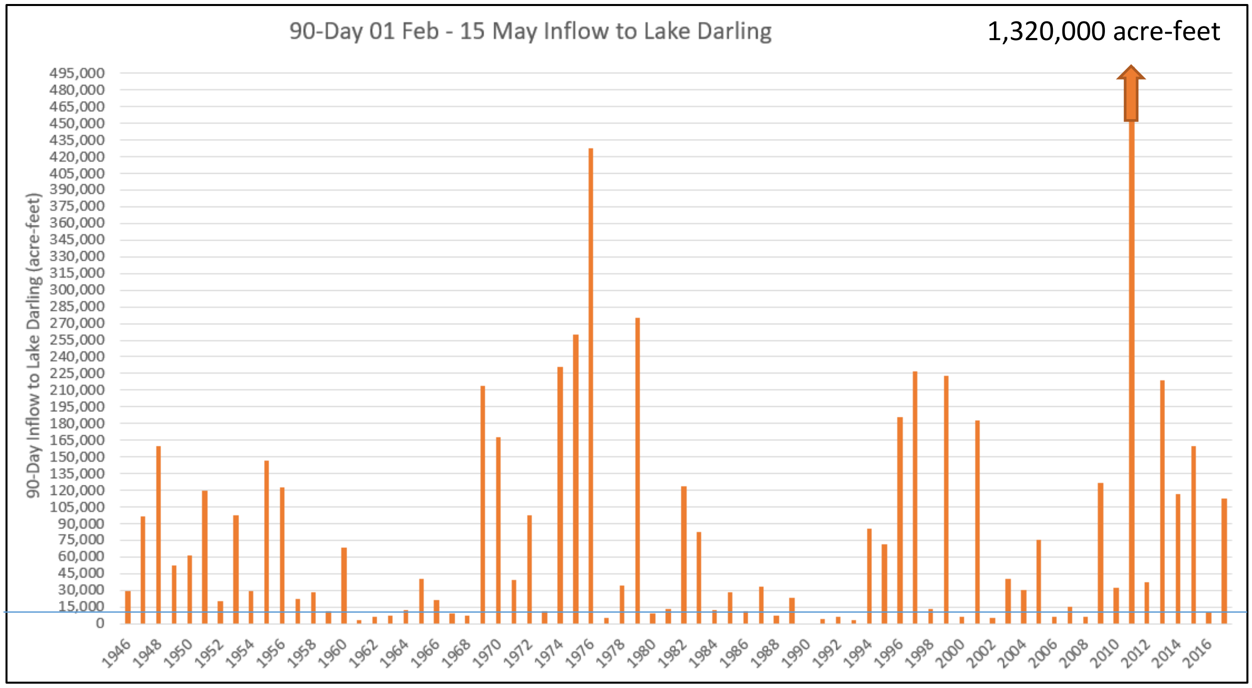

Figure 5. 90-day inflow volume to Lake Darling Reservoir – blue line indicates quantity necessary to fill from normal drawdown to full supply

To optimize the normal drawdown target and to better understand the impact of modifying the normal drawdown target it is suggested that four changes to normal drawdown be considered relative to the baseline (Table 5):

Table 4. Normal Pool Elevation Sensitivity Analysis – Lake Darling Reservoir

	Target Normal Pool Elevation Sensitivity Analysis			
Alternative #	% of Years Where FSL will be reach (approximately)	Target Pool Elevation (feet)	Target Storage (acre-feet)	Notes
0	78%	1596.00	99,682	Current Operations – Normal Drawdown Target
1	81%	1596.23	102,001	
2	90%	1596.41	103,787	
3	96%	1596.66	106,317	
4	100%	1597.00	109,765	No Drawdown - FSL

It is assumed that during non-flood operations operators try to keep outflows from Lake Darling below 1,400 cfs (channel capacity between Logan and Verendrye as per Annex A). It is assumed that operators will want to get back to FSL by 15-May and that the top 90-days of inflow to Lake Darling during the spring runoff period reflects the bulk of the inflow between 01 February and 15-May. It is assumed that operators will want to get back to full supply within a 45 day period. Inflows are approximated as the quantity of local flow into Lake Darling plus the quantity of inflow into the Canadian Reservoirs in excess of their respective full supply levels.

Based on a preliminary assessment it appears that during most years drawing the reservoir down below its full supply level is unnecessary and that the reservoir can be managed without a fall drawdown. During non-flood years the reservoir can be managed with releases under 2,000 cfs without carrying out a fall drawdown. Choosing not to carry out a fall drawdown may have resulted in approximately one additional year where releases were in excess of 1,400 cfs. By not carrying out a drawdown during non-flood year's operation of Lake Darling Reservoir can be optimized for water supply.

5.2 Spring Drawdown

It appears that the reservoir is drawn down to its maximum drawdown when projected inflows are occurring at about a 16% annual exceedance probability (Figure 6). Additional springtime drawdown takes place when projected inflows are occurring at about a 46% annual exceedance probability (Figure 6).

It is critical that the maximum channel capacity of 5,000 cfs at Minot, ND is not exceeded during flood events. To prevent downstream agricultural damages releases from Lake Darling should be less than 3,000 cfs. The Des Lacs River reaches its confluence with the Souris River just upstream of Minot, North Dakota so operators have to take into consideration contributions from the Des Lacs when making release decisions. Only the 2011 event would necessitate releases over 5,000 cfs from Lake Darling. The 1976 event could be managed using releases around 4,200 cfs. The 1975 and 1979 events required releases of about 3,000 cfs (2,800 cfs and 2,900 cfs, respectively). All other events could have likely been managed with releases under 2,500 cfs.

Drawing the pool down an additional foot incrementally results in an additional 7,400 acre-feet of storage (on average). Preventing releases over 3,000 cfs would not be feasible for either the 2011 or 1976 events. Releases could potentially be limited to 4,000 cfs if the drawdown prior to the 1976 event was two feet lower, but the added flood control benefits associated with maintaining releases at 4,000 cfs versus 4,200 cfs are likely minimal. Also, the maximum allowable drawdown elevation of 1591 feet is already being targeted if current operating guidelines are being applied during the 2011 and 1976 events. The U.S Fish and Wildlife Service may not approve of a change in operation that would allow Lake Darling to be drawn down below 1591 feet.

Based upon current operating guidelines, Lake Darling's target pool is about 1595.63 feet in 1975 and 1595.43 in 1979. An additional two feet of drawdown may have enabled operates to keep releases at about 2,600 cfs during the 1975 event and 2,700 cfs during the 1979 event. It appears that each additional foot of drawdown would enable operators to reduce releases by about 100 cfs. This isn't a significant enough reduction in outflow to warrant additional drawdown.

In general, the specified spring drawdown appears to provide adequate storage for spring runoff without compromising the pool's ability to get back to full supply level by 15 May. A range of spring runoff events generated by the stochastic model should be applied to ensure this holds true for events in between the 10% and 0.5% annual exceedance events.

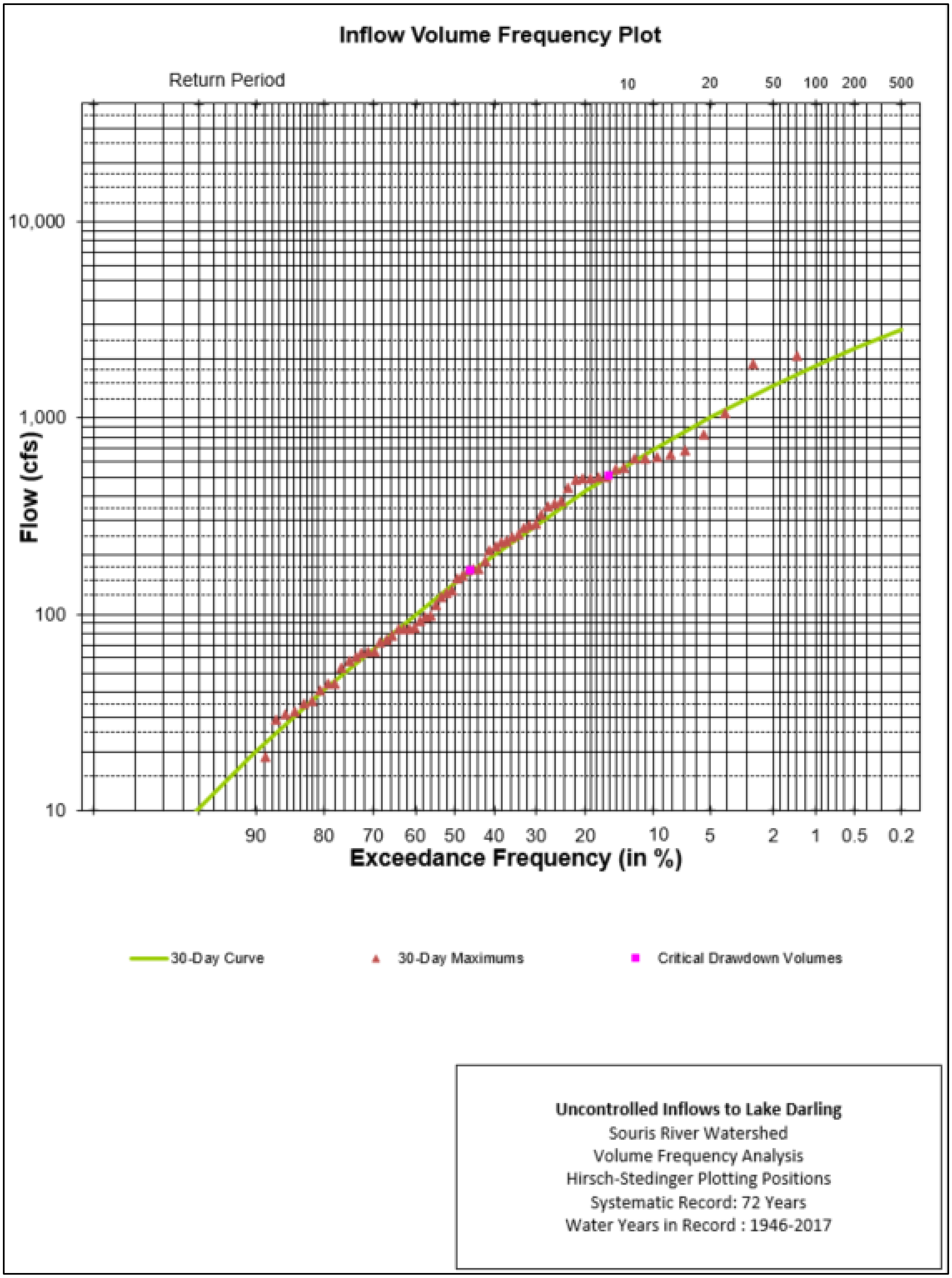

Figure 6. Inflow Volume Frequency Analysis – Lake Darling Reservoir