21. Appendix 5

Sensitivity Analysis of Design Hydrograph Calculations

22. Overview

In review of the original Pembina Phase III study report the review committee raised a number of questions for investigation into the estimate of design hydrographs for input into the Pembina TELEMAC model. Of the issues raised the key questions were related to the influence of:

- Selection of extreme value distribution;
- The appropriateness of the selected skew coefficient for the Bulletin 17 analysis;
- The influence of the source station selection on the drainage area-ratio (DAR) methodology for design hydrographs in ungauged basins;
- The influence of the selected DAR equation of design storm hydrographs in ungauged basins; and
- The influence of the period definition and removal of snowmelt events in the calculation of summer design hydrographs.

Each of these questions was addressed through a sensitivity analysis to determine if the changes in the ultimate design hydrographs by varying the above approaches.

23. Sensitivity to Extreme Value Distribution

In order to determine the influence on the selection of the extreme value distribution and the associated methodology a sensitivity analysis was conducted comparing the Bulletin 17 (B17) methodology (USGS 1981) outlined in the original report with four other distributions: Generalized Extreme Value (GEV), Pearson Type III (PE3), Log Pearson Type III (LPE3), and Log-Normal (LN3). For the newly investigated distributions an L-moment approach was employed to estimate the fit of the distributions (Hosking 2012, Hosking & Wallis 1997).

Results indicate that the B17 technique is generally the most conservative when compared to the other distributions for the stations analyzed. Figure 62 shows the relationship between estimated maximum daily flows for the 100-year event calculated using the B17 methodology and the other distributions. The B17 estimates are generally higher than all other distributions, with the possible exception of the Log-Pearson III distribution which closely matches for some stations. The data suggests the other three distributions are generally lower than Bulletin 17, although there are not enough samples to determine if the Bulletin 17 values are generally higher to a significant degree (95% CI) as compared the other distributions using a matched-pair sign test (Helsel & Hirsch 1991). Figure 63 illustrates the effect the distribution can have on the balanced hydrographs, which shows the distribution can have an influence not only on peak values but also hydrograph shape, although to a lesser degree.

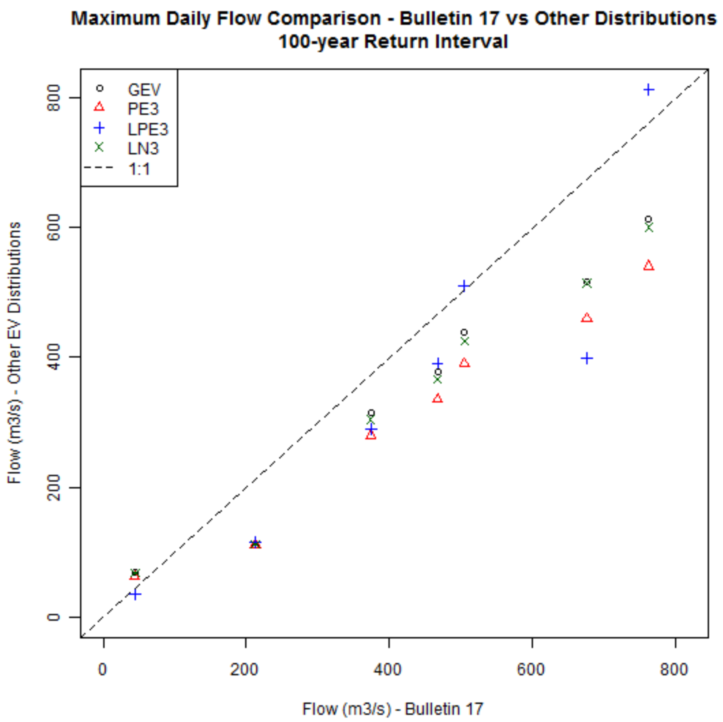
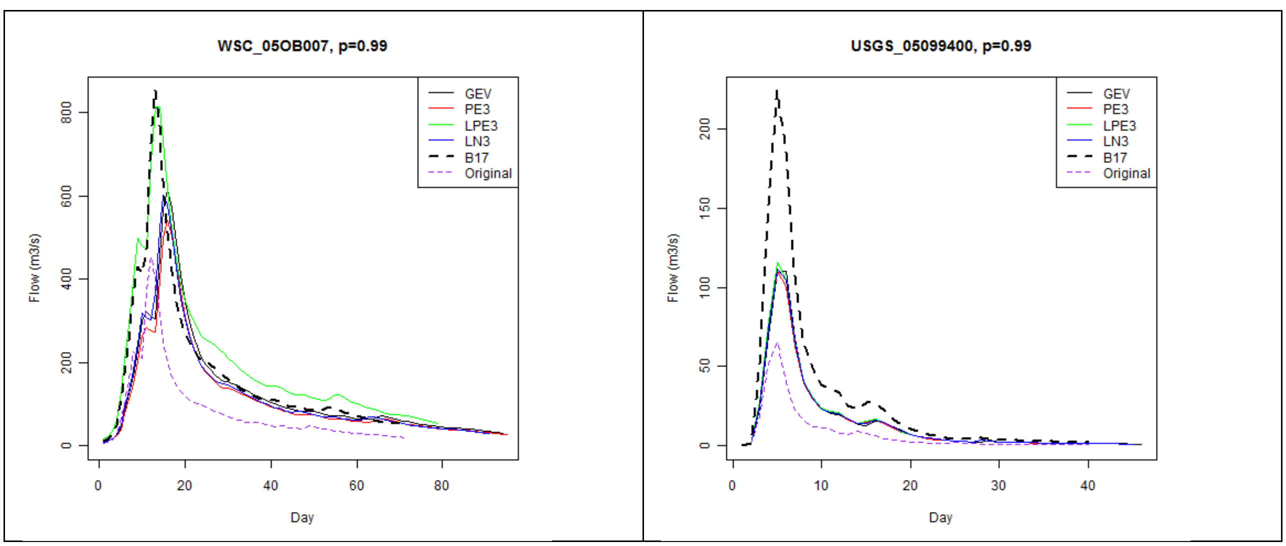


Figure 62 - Distribution Sensitivity - Comparison of Extreme Value Distributions



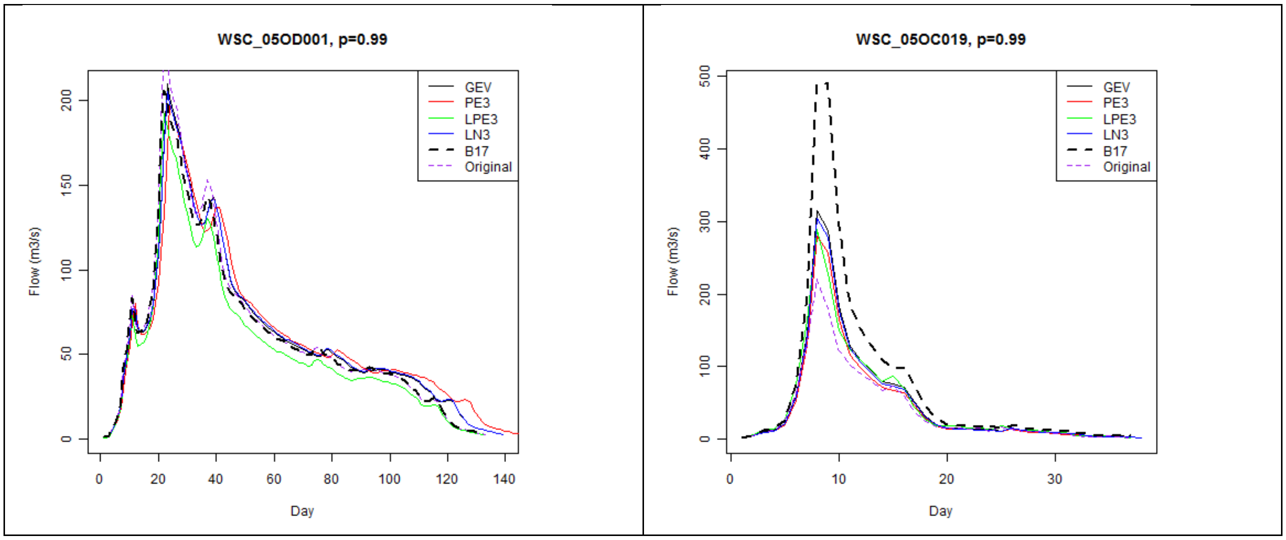


Figure 63 - Distribution Sensitivity - Design Hydrographs

24. Sensitivity to Skew Coefficient

A more recent report than the original Bulletin 17 produced by the USGS highlighted updated skew coefficients for the Pembina River basin region (Lorenz 1997). The report indicated skew values from -0.4 to -0.5 for the area around the Pembina River basin. A skew value of -0.4 was originally employed in the study. As a test of the degree of sensitivity of the results to a change in the skew coefficient, analyses were performed using skew values in a range from -0.3 to -0.5. Results show that there is some minor change in flows (see Figure 64) and the greatest observed change in 1:100 maximum daily flows from a 0.1 skew adjustment is 4.7%.

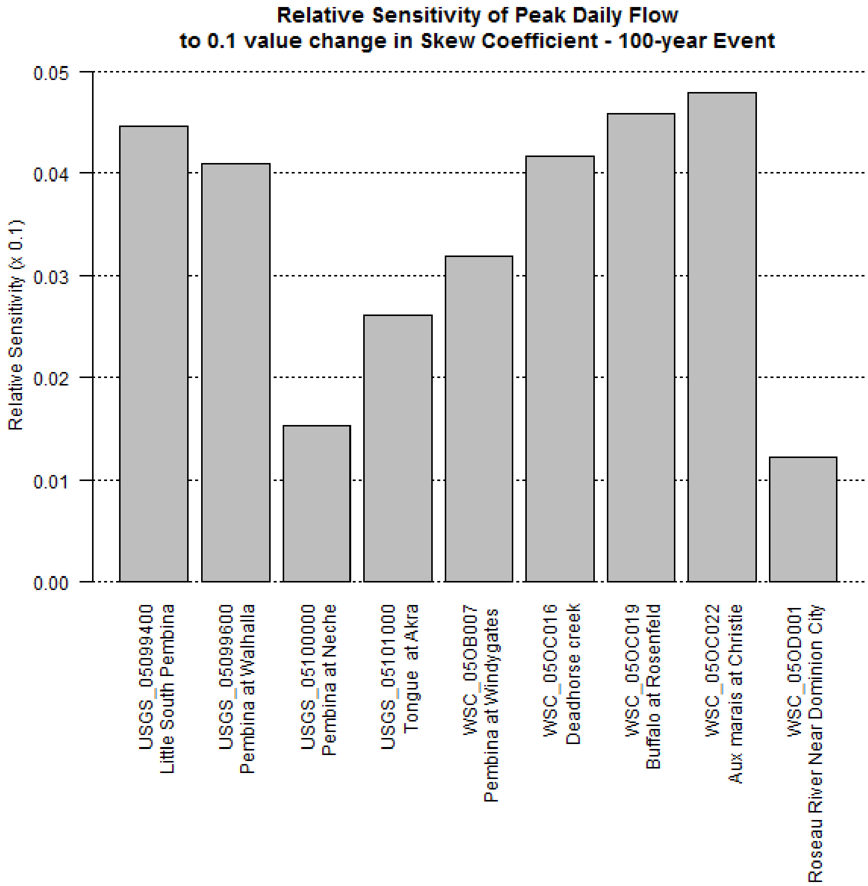


Figure 64 - Skew Coefficient Sensitivity

The higher skew values (-0.3) provide marginally higher flows as shown in Figure 65, indicating that the original skew value is likely conservative in the range reported by the USGS report.

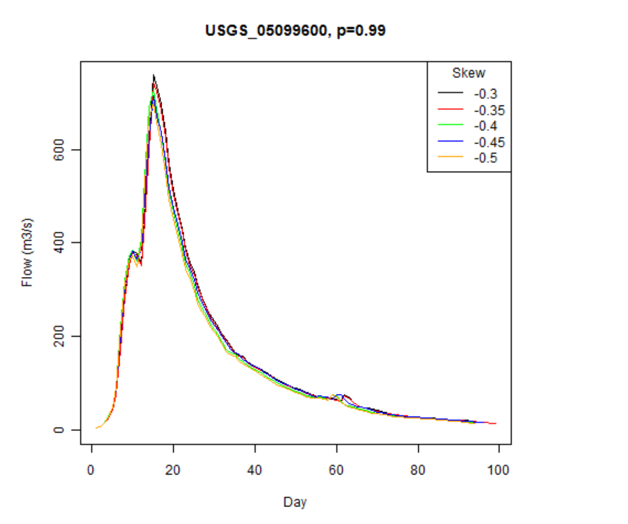
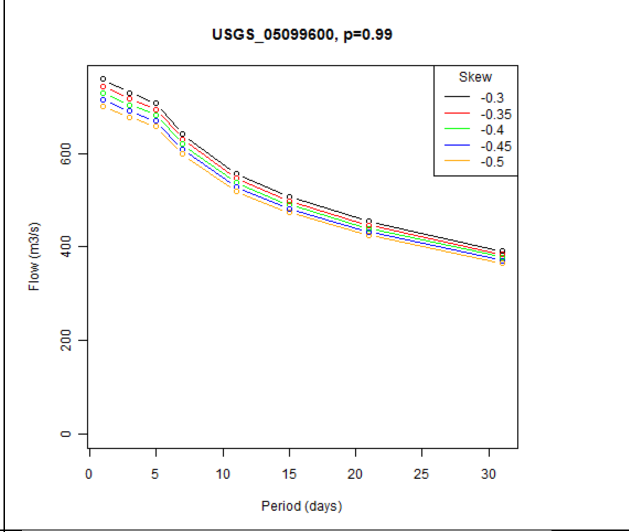
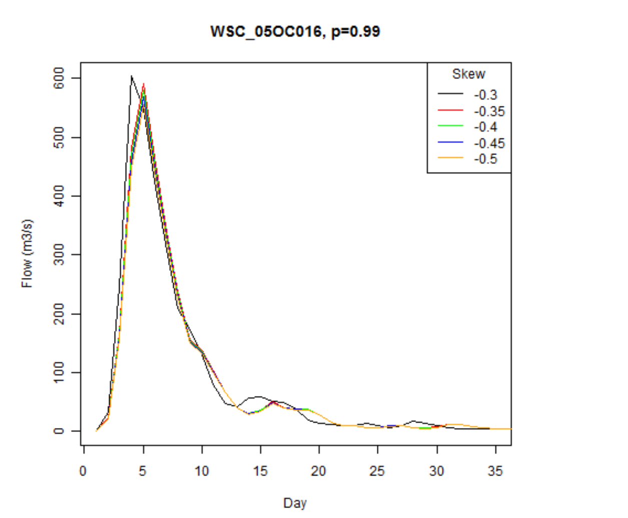
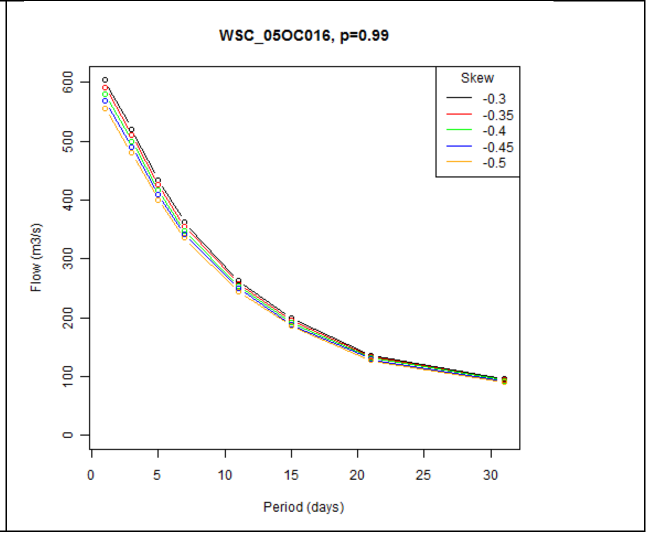
Hydrograph Sensitivity	QdF Sensitivity
	
	

Figure 65 - Skew Coefficient Sensitivity - Hydrograph and QdF plots

25. Area-Ratio – New Source Hydrometric Stations

Considering flow control of Tongue River, new stations were recommended as source hydrometric stations for drainage area-ratio methodology. Frequency and balanced hydrograph analysis were conducted on 3 new stations: Antelope Creek, Baldhill Creek, and Rush River (see Table 30). Antelope Creek had a very short observed period of record and was dropped as a candidate station. Frequency analysis and balanced hydrograph generation plots for Rush River and Baldhill Creek are included at the end of this annex.

Table 30 - Hydrometric Stations

Agency	Station Code	Latitude	Longitude	Description	Drainage Area (km2)	Record Length (years)
USGS	5101000	48.78	-97.75	Tongue at Akra	414	47
USGS	5100000	48.99	-97.55	Pembina at Neche	8832	59
USGS	5099600	48.91	-97.92	Pembina at Walhalla	8676	42
USGS	5099400	48.87	-98.01	Little South Pembina	471	33
WSC	5OB007	49.03	-98.27	Pembina at Windygates	7500	20
WSC	5OC016	49.25	-97.55	Deadhorse creek	926	32
WSC	5OC019	49.19	-97.40	Buffalo at Rosenfeld	927	28
WSC	5OC022	49.07	-97.31	Aux marais at Christie	195	29
WSC	5OD001	49.19	-96.98	Roseau River Near Dominion City	5020	61
USGS	**5052500**	**46.31**	**-96.73**	**ANTELOPE CREEK AT DWIGHT, ND**	**761**	**9**
USGS	**5057200**	**47.23**	**-98.12**	**BALDHILL CREEK NR DAZEY, ND**	**1790**	**55**
USGS	**5060500**	**47.02**	**-97.21**	**RUSH RIVER AT AMENIA, ND**	**300**	**65**

26. Drainage Area-Ratio - Sensitivity to Source Hydrometric Station

To examine the sensitivity of the source hydrograph at the ungauged areas using the drainage area ratio method, the resulting hydrographs from the original study were compared to results generated using the Rush River and Baldhill Creek source hydrographs, effectively comparing the hydrographs using the same translation equation and different source stations. The results are shown in Figure 66 (plots for all target watersheds show identical patterns), and indicate quite a bit of variability. The Baldhill Creek has the most conservative in terms of peak flow and the Rush River is the least conservative with the original hydrograph (sourced from the Tongue River) falling between for 1:100 events.

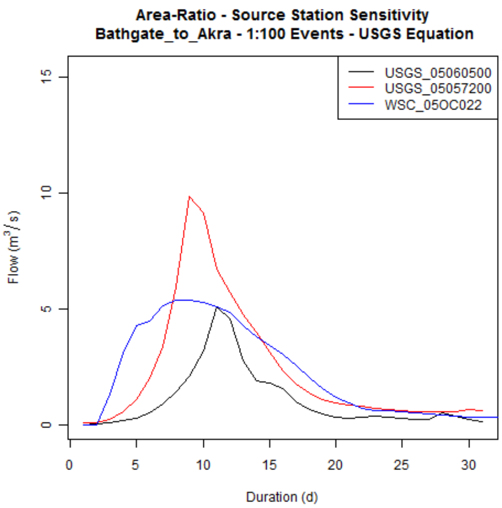


Figure 66 - Drainage Area-Ratio Method Sensitivity to Source Hydrometric Station

The source station influence for all return periods was compared. Table 31 shows the peak daily flows for the various return intervals for Rush River and Baldhill Creek relative to the same flows using Tongue River as the source station. The Tongue River falls between the other two stations for 1:100 and 1:50 return intervals, but is lower than both of the other stations for the 1:20 and 1:10 intervals. To illustrate flow magnitudes, Table 32 tabulates the estimates of the maximum daily flows for the various annual return periods and the 1:20 summer return period. The source station used in these estimates was Rush River and the summer flows were extracted using the May 1 to Sept 30 period.

Table 31 - Drainage Area-Ratio - Source Station Sensitivity Peak Flow (relative to Tongue River)

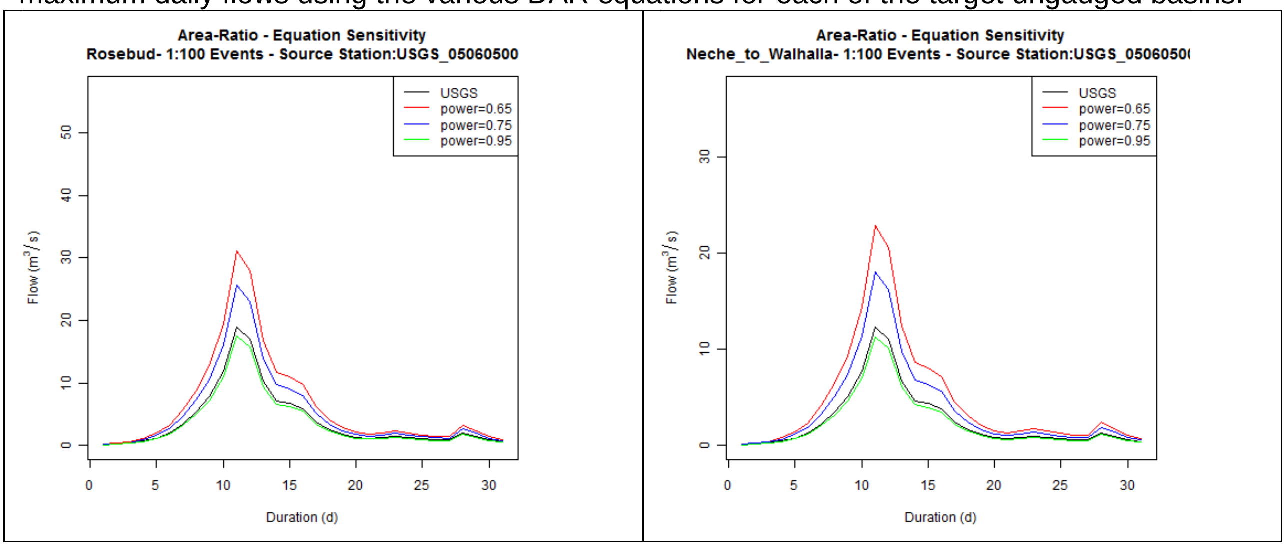
Source Station:		**Return Interval Daily Max Flow, Relative to Tongue River as Source Station**			
Station ID	**Station Name**	**1:100**	**1:50**	**1:20**	**1:10**
USGS_05060500	Rush River	0.94	0.98	1.03	1.09
USGS_05057200	Baldhill Creek	1.82	1.74	1.61	1.52

Table 32 - Drainage Area-Ratio - Maximum Daily Flow Estimates

Ungauged Basin	Drainage Area (km2)	Maximum Daily Flow (m^3/s) 1:100	1:50	1:20	1:10	1:20 Summer
Louden Coulee	57	23.7	18.6	12.7	8.9	5.6
Rosebud	266	97.8	76.9	52.5	36.7	26.8
Bathgate to Akra	64	26.4	20.7	14.2	9.9	6.3
Pembina River - Walhalla to Neche	167	63.7	50.1	34.2	23.9	16.7
Pembina River - Neche to Pembina	80	32.5	25.6	17.5	12.2	7.9
Tongue River - Louden to Pembina River	95	38.0	29.9	20.4	14.3	9.4

27. Drainage Area-Ratio - Sensitivity to DAR Equation

Employing a range of drainage area-ratio equations and exponents to look at hydrograph sensitivity. The original USGS-sourced DAR equation (Emerson et al. 2005) was employed along with standard area ratio equations with coefficients of unity exponents of 0.65, 0.75, 0.95. Sample graphical results are shown in Figure 67. The USGS equation provides lower flow values, nearly in line with 0.95 – the flows increase substantially with a decrease in the ratio exponent. Table 33 shows the relative differences in maximum daily flows using the various DAR equations for each of the target ungauged basins.



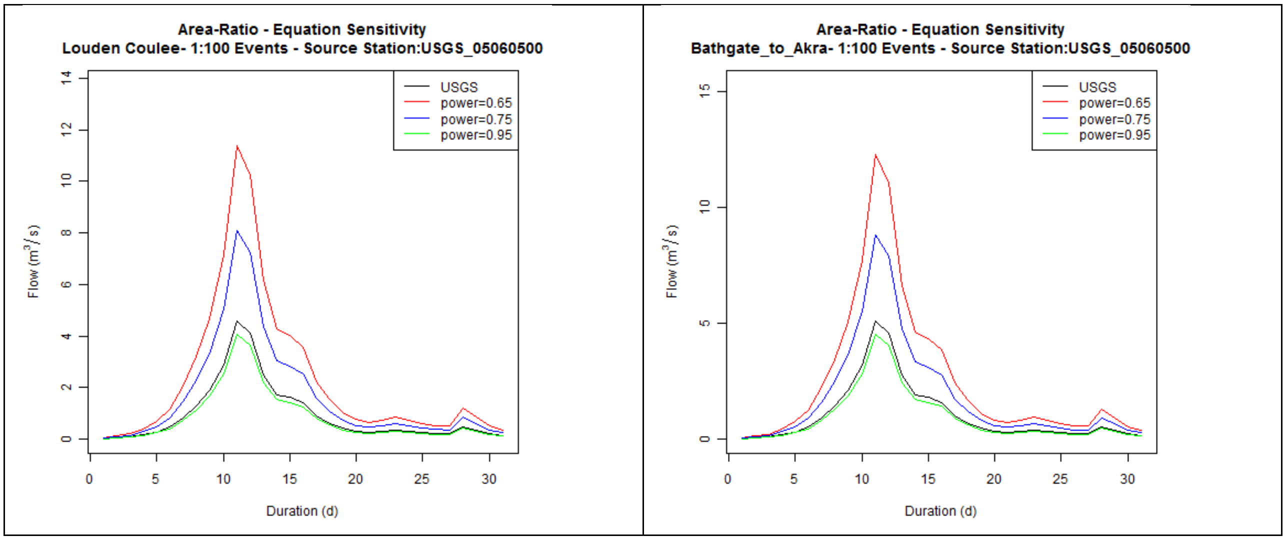


Figure 67- Sensitivity to DAR Equation

Table 33 - Flows Sensitivity by DAR Equation Relative to USGS Equation (Tongue River as Source Station)

	Ungauged Basin			
DAR Equation	**Louden Coulee**	**Rosebud**	**Bathgate to Akra**	**Neche to Walhalla**
USGS	1.00	1.00	1.00	1.00
Exp=0.65	1.54	1.01	1.49	1.15
Exp=0.75	1.30	1.00	1.28	1.08
Exp=0.95	0.93	0.98	0.94	0.96

28. Summer Events - Sensitivity Summer Period Definition

The summer events were calculated by removing the events that were deemed to be snowmelt or snowmelt-influenced in order to reduce the impact of the summer. The issue is highlighted in Figure 68 which shows an annual hydrograph with the designated summer period (May to September) highlighted in red. It can be seen that the highest flow in this period is the recession of the spring snowmelt event and the events that occur within the summer period that are not snow melt driven. The sensitivity of the summer design hydrographs to the snowmelt period designation was examined and the determination of how the design hydrographs with the snowmelt events compared.

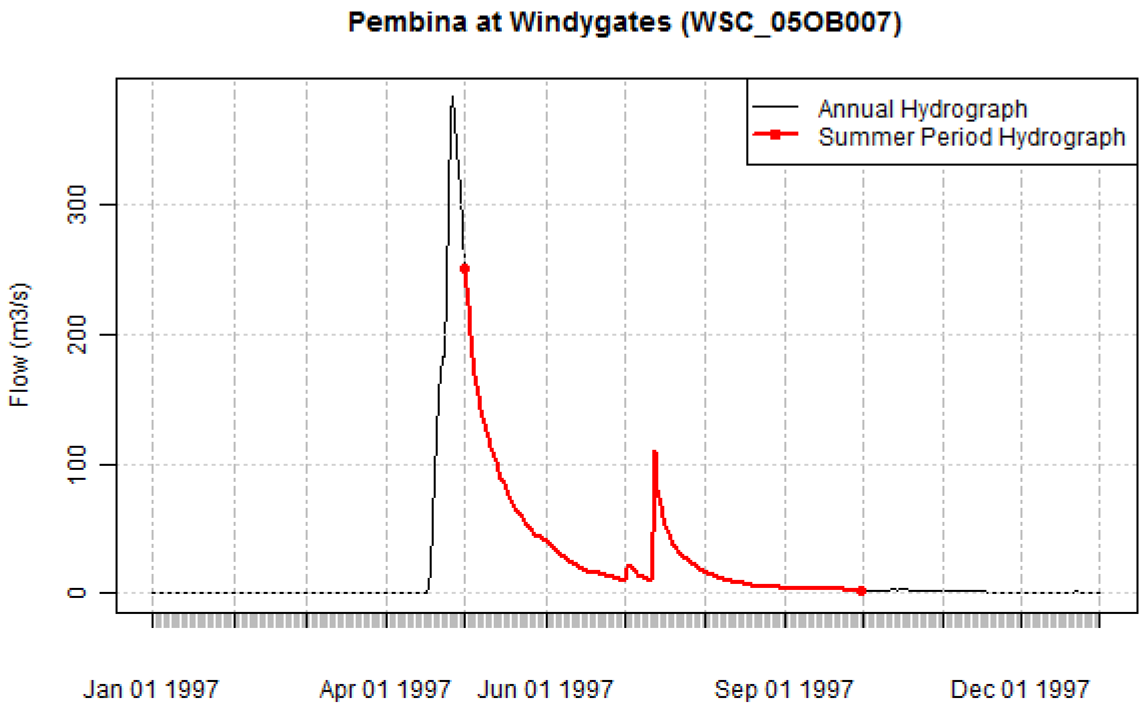


Figure 68 - Summer Period Definition - Typical Annual Hydrograph

In order to determine the influence of the summer period definition on the design hydrographs the frequency analysis was performed for the original seven stations using a number of separate seasonal periods. These periods are shown in Table 34.

Table 34 - Summer Definition Sensitivity – Analysis Periods

Period Name	Start Date	End Date
Annual	01-Jan	31-Dec
0401-0930	01-Apr	30-Sep
0415-0930	15-Apr	30-Sep
0501-0930	01-May	30-Sep
0515-0930	15-May	30-Sep
0601-0930	01-Jun	30-Sep
0615-0930	15-Jun	30-Sep
Events*	01-May	30-Sep

*- snowmelt events removed

The time series for each station was concatenated to each of the event periods and then frequency analysis was conducted against the daily flow data using the Bulletin 17 methodology for the 20-year return interval. These results were then compared to the 20-year return intervals supplied in the original report. The results are shown in Figure 69 which shows the 20-year return interval values for all of the periods and the events normalized to the annual maximum estimate of the 20-year return interval flow.

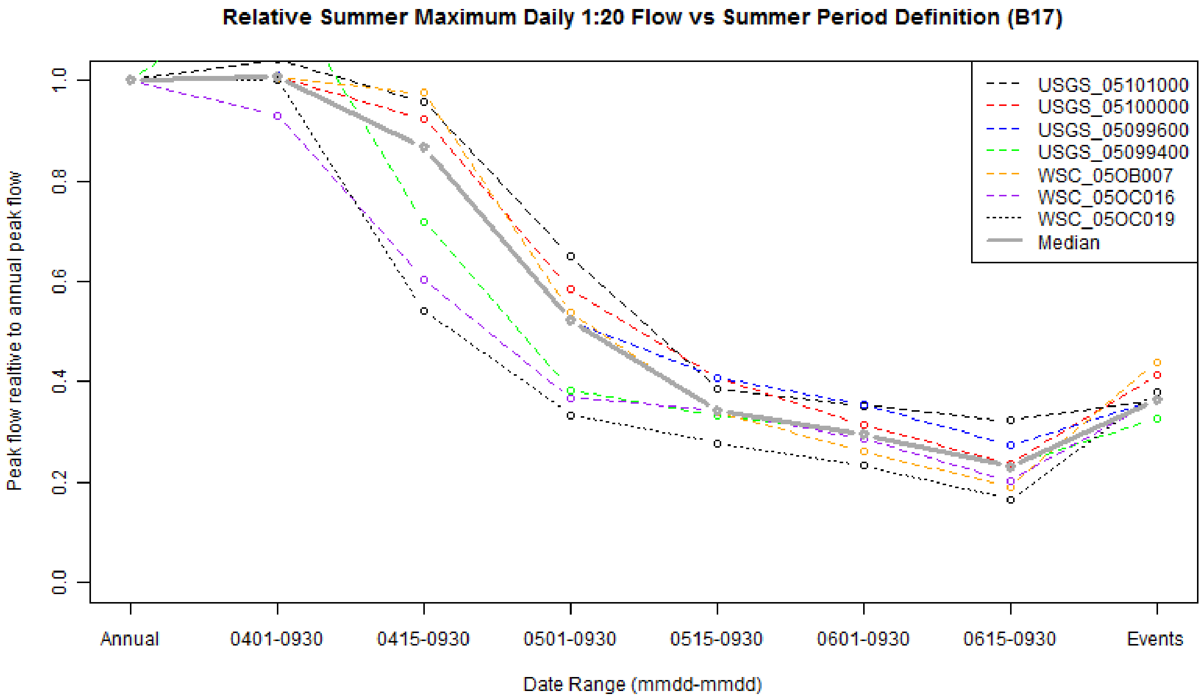


Figure 69 - Summer Period Definition Sensitivity

From this analysis it can be seen that the general trend in peak flow reduction with a reduction in reporting interval indicate that for these stations drop from an annual peak to approximately 20-40% of the peak value during the summer period. It can also be seen that the prescribed definition of summer period of May 1 to Sept 30 is somewhat higher than the summer period plateau observed later. This suggests that for many of the stations the snowmelt period has not finished at this time and high freshet runoff is still contributing high flows – which is indicated in hydrographs like those shown in Figure 68. By observing this plot is possible to estimate a more reasonable estimate of the summer period may be beginning May 15, as this is where the curve begins to plateau into the summer. The events as presented in the report are generally of lower flows than those determined based on the period beginning May 1. However, the events in the report have generally higher flows than those derived from the period begging May 15, making them in general slightly less conservative than the period beginning May 1 but more conservative than the period beginning May 15.

29. References

Emerson, D. G., Vecchia, A. V. & Dah, A. L. (2005), Evaluation of Drainage-Area Ratio Method Used to Estimate Streamflow for the Red River of the North Basin, North Dakota and Minnesota, Technical report, USGS.

Helsel, D. & Hirsch, R. (1991), Statistical methods in water resources, *in* 'Techniques in Water Resources Investigations of the United States Geological Survey', Vol. 4, USGS, chapter A3 Hydrologic Analysis and Interpretation.

Hosking, J. R. M. (2012), *L-moments*. R package, version 1.6. http://CRAN.R-project.org/package=lmom

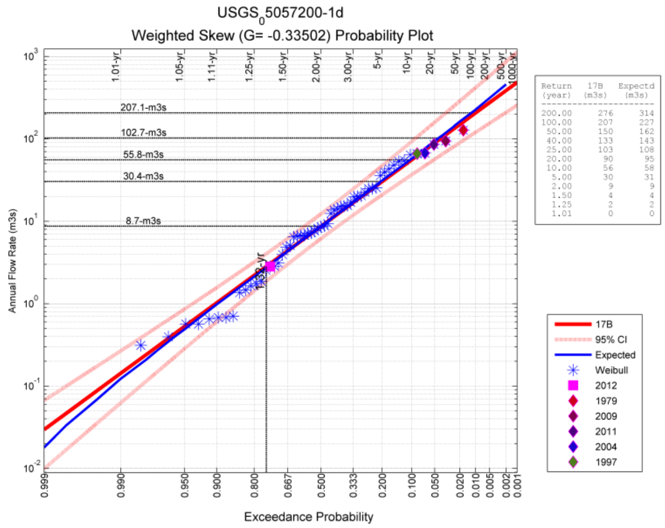
Hosking, J. & Wallis, J. (1997), *Regional frequency analysis: an approach based on L-moments*, Cambridge Univ Pr.

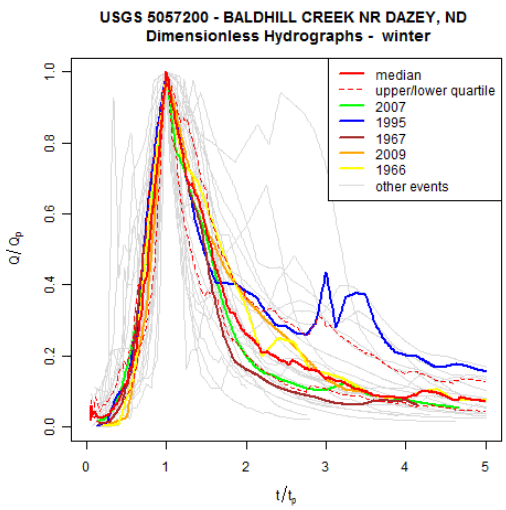
Lorenz, D. L. (1997), *Generalized Skew Coefficients for Flood-Frequency Analysis in Minnesota*, number Water Resources Investigations Report 97-4089, US Geological Survey.

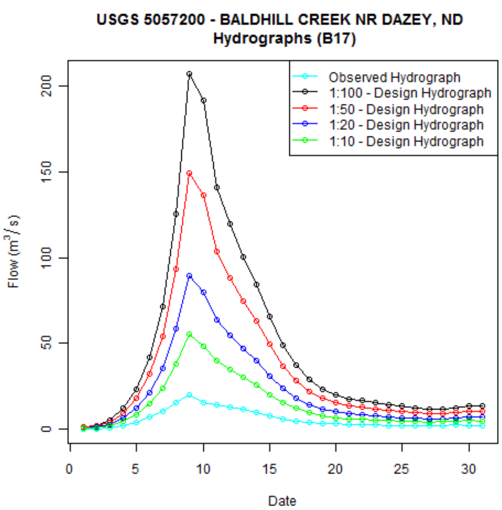
USGS (1981), Guidelines for Determining Flood Flow Frequency, Technical Report Bulletin 17B, U.S. Geological Survey, Reston, Virginia.

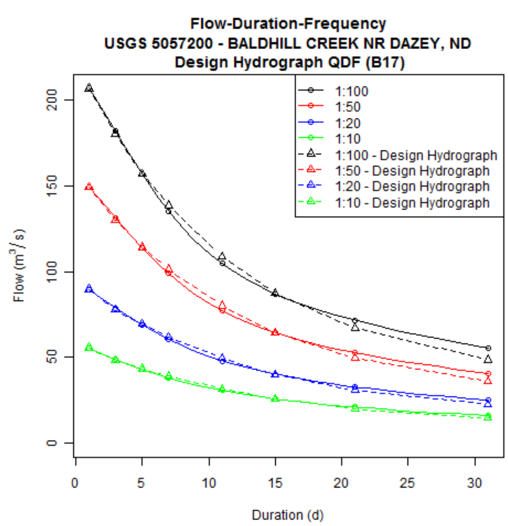
30. Frequency Analysis for Rush River and Baldhill Creek

30.1 Baldhill Creek Near Dazzy, ND – Annual Analysis

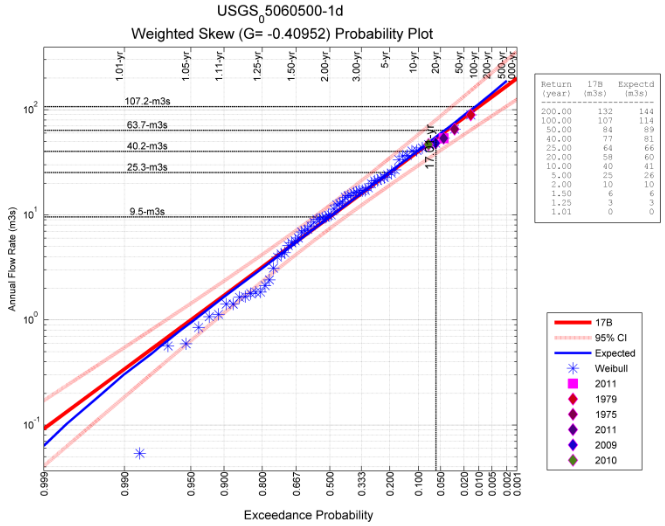








30.2 RUSH RIVER AT AMENIA, ND - Annual Analysis



Return (year)	17B (m3s)	Expectd (m3s)
200.00	132	144
100.00	107	114
50.00	84	89
40.00	77	81
25.00	64	66
20.00	58	60
10.00	40	41
5.00	25	26
2.00	10	10
1.50	6	6
1.25	3	3
1.01	0	0