Technical Memorandum

To: *South Carolina Department of Natural Resources (DNR)*
South Carolina Department of Health and Environmental Control (DHEC)

From: *CDM Smith*

Date: *July 22, 2015*

Subject: *Record Extension Testing of the Unimpaired Flow (UIF) Dataset for the Saluda River Basin*

Following receipt of DNR comments on the Draft UIF dataset for the Saluda River Basin and the subsequent discussion held on July 17th, CDM Smith conducted testing of several methods for UIF record extension. The purpose of this memorandum is to document the testing, present observations, and provide recommendations on the UIF record extension methodology to be used going forward. The memo is supported by a slide set containing graphical depictions and comparisons of calculated UIFs.

Explanation of Testing

The following conclusions for UIF record extension are based on tests in which we took two sets of paired UIFs with long records, where one UIF could be used as a reasonable reference gage for the other. We truncated one of the UIF records to simulate a condition in which a long record of a reference UIF (B) was used to extend a short record of another UIF (A), the one that was truncated. Generally, UIF A has a short period of record "1", and UIF B has a longer period of record of "1+2", where "1" represents the coincident period of record for both A and B, and 2 represents the remainder of UIF B's period of record, for which UIF A is extended. In this test, we truncated the actual record for A to just period 1, and tested the extension techniques by comparing predictions to the data for UIF A over period 2.

In this test, SLD12 was used to predict SLD10, and SLD09 was used to predict SLD04. The methods were evaluated for Period 2 in both cases, where we have UIF data for both gages, but where it was not used to develop the statistics for Gage A. We refer to Period 1 as the "training" period, since it is only these statistics that are used to develop the statistics needed for the extension methods, and Period 2 as the "testing" period, since here we are evaluating the methods that would otherwise be somewhat blind (absence of data, and hence the need for record extension). Period 2 in both cases included the severe drought of the 1950s, and Period 1 in both cases involves the recent decades.

Methods Tested

We tested the following methods for UIF record extension:

- **Method 1.** MOVE.1 with no log transform, time frame for reference gage is its entire POR (1 + 2)
- **Method 2.** MOVE.1 using log transform of data prior to computing mean and std. dev. (still using the entire POR for the reference gage)
- **Method 3.** MOVE.1, but apply time frame protocol to just the overlapping period (1) for computing the mean and std. dev. (without the log transform)
- **Method 4.** Combine 2 and 3 above: This is the unmodified version of MOVE.1 as published by Hirsch (1982).
- **Area Ratio:** For SLD10, the area ratio was also employed for comparative purposes, as this remains a fundamental option for record extension.

Observations

The following observations are based on review of the graphical comparisons of the calculated UIFs.

1. No single method is a reliable predictor over the entire flow regime. Each tends to work better than others over specific flow regimes only.
2. Log Transform: For SLD10: The log transform appears to be beneficial across the low and mid-range flow regime, but significantly under-predicts the highest flows. This is the bias that comes as a caution with the method. For SLD04, the same is true, but this time the high flow bias over-predicts the high flows.
3. Time Frame for Statistics: For SLD10: There appears to be very little difference between the time periods used for mean and std. dev: For the straight flows, using the entire period stats for the reference gage works best, and for the log-transformed flows, the preferred method changes in the mid-range flows from one to the other. For SLD04, the results are too close to make any significant distinction between these methods.
4. MOVE.2 vs. MOVE 1: We did not test MOVE.2, but its purpose was to help resolve the issue of time frame used for computing statistics, and to estimate parameters for ungaged data. Generally, it is likely that Method 2 vs. Method 4 bound the differences between MOVE.1 and MOVE.2, because MOVE.2 attempts to use more of the statistical period of record in the estimation. We see very little benefit in trying to refine the difference between the time frame being used by switching to MOVE.2, as the results are generally very close regardless of the selection of time frame. Further, as noted in the Hirsch paper, MOVE.2 tends to compress the flows toward the center at the extremes, which is undesirable.

5. Area Ratio: For SLD10, the Area Ratio and MOVE.1 with log transforms are practically the same for low flows, and definitely better than MOVE.1 with straight flows.

Recommendations

Because the tests suggest that no single method works best for an entire flow regime, we propose that we continue to use the hybrid approach on a case-by-case basis (apply area ratios for the flow regimes where they fit best, and apply MOVE.1 for flow regimes where it fits best), with one important modification, noted in red below:

a) Compare Area Ratio with MOVE.1 as strictly defined (log transform, and only the period of coincident record applied).

b) If either method works well across the full hydrologic regime and is a stronger predictor than the other, apply it.

c) If each method is clearly preferred over the other for ***different*** hydrologic regimes, and can produce a good fit to observed data, apply the hybrid approach and define the flow threshold at which we switch from one method to the other. *Note that this is what we have done to date to capitalize on the performance of the methods where one clearly dominates the other.*

d) If neither method can reproduce high flows well, consider MOVE.1 with the entire POR and straight flows without the log transform for ***high flows only*** (as originally employed for this study based on success elsewhere). Tests confirm that this method may sometimes be best for high flows.

Other UIF Considerations

We have also begun to investigate “smoothing” of the UIFs where run-of-river operations or other stream impairments have produced unnatural “noise”. We agree that moving averages can be applied in instances where it appears that run-of-river operations are creating unrealistic, single day spikes in the record. Where these spikes can be likely attributed to run-of-river, or other impairments, we will attempt to smooth the data. The smoothing of the data, where appropriate, will eliminate much of the noise that is transferred to downstream UIFs. Generally, we will only apply smoothing techniques if we can identify a likely cause of the sudden spikes or dips in UIF estimates, and assure ourselves that the causes are not otherwise captured in the UIF calculations.

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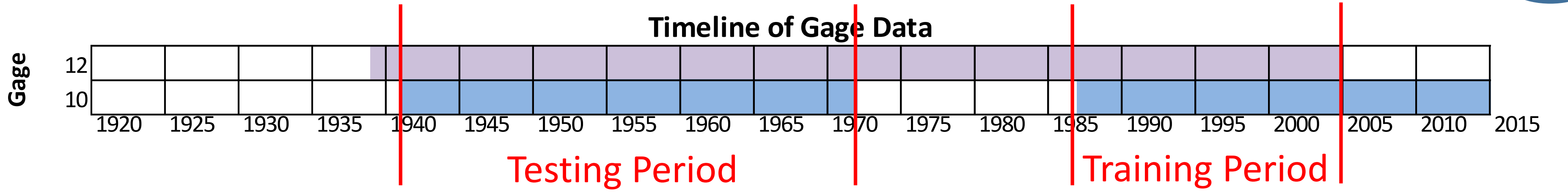
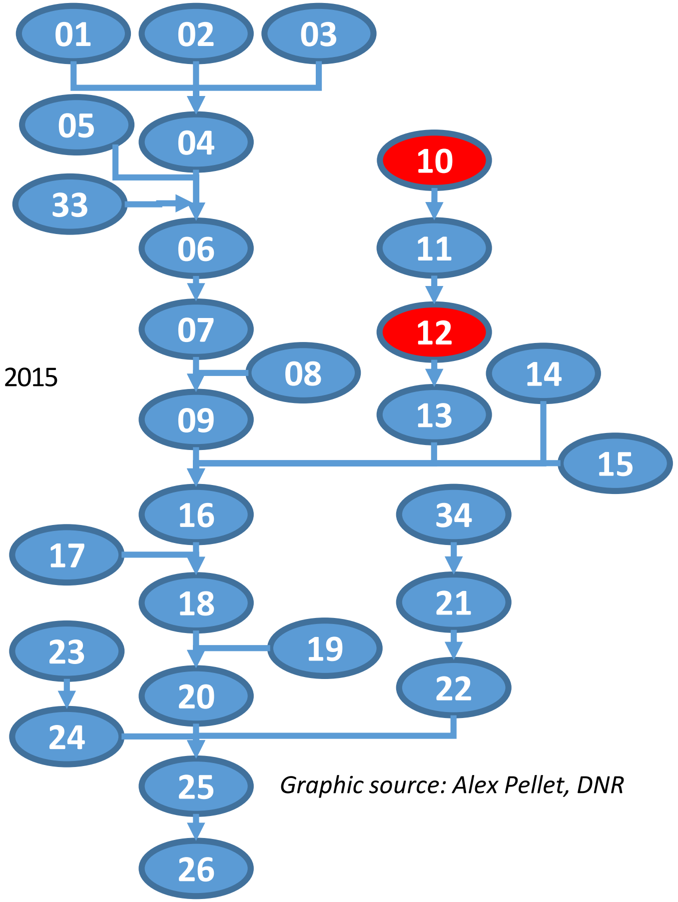
See accompanying memorandum for discussion of the results and recommendations

Extending SLD10 with SLD12 as reference

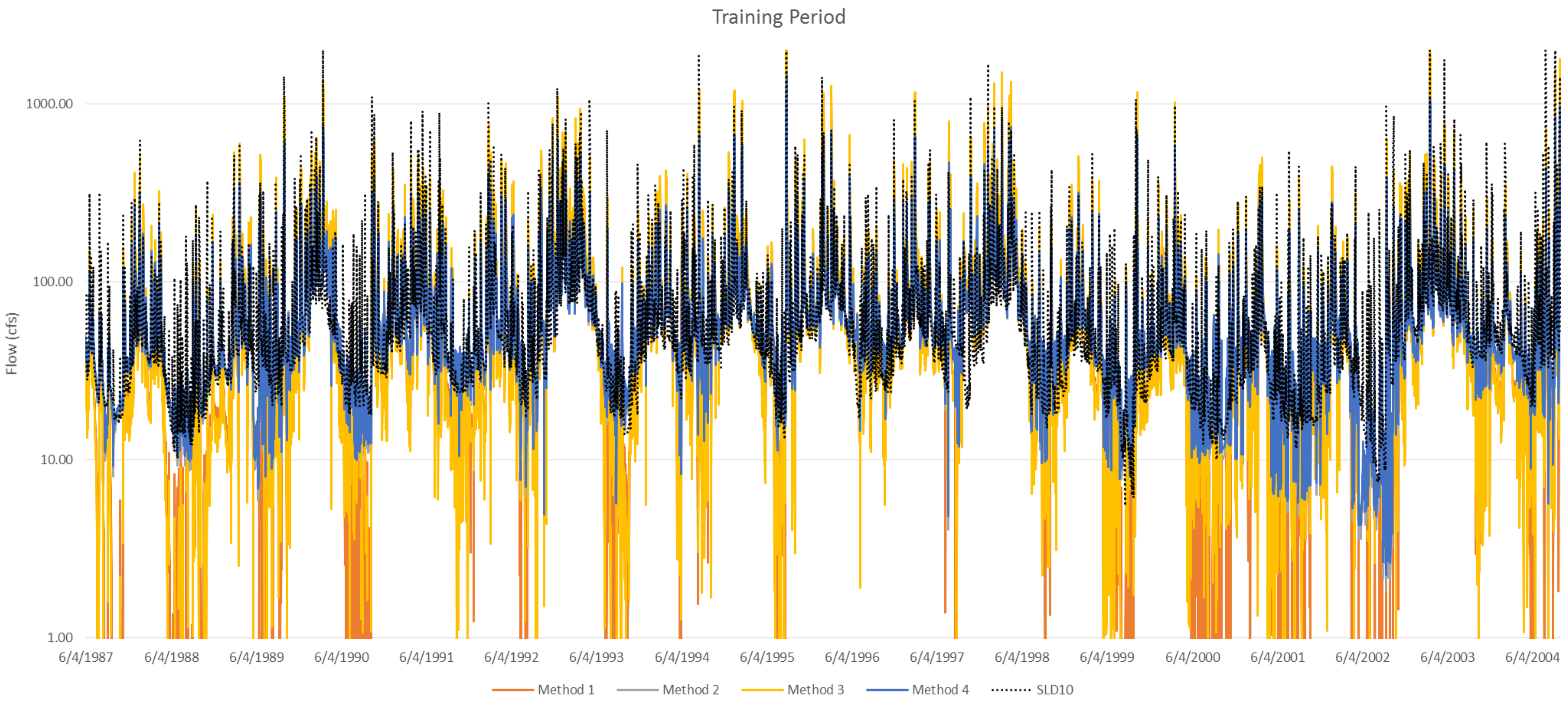
- Training Period 6/4/1987 - 9/30/2004
- Testing Period 11/21/1941 - 9/30/1971

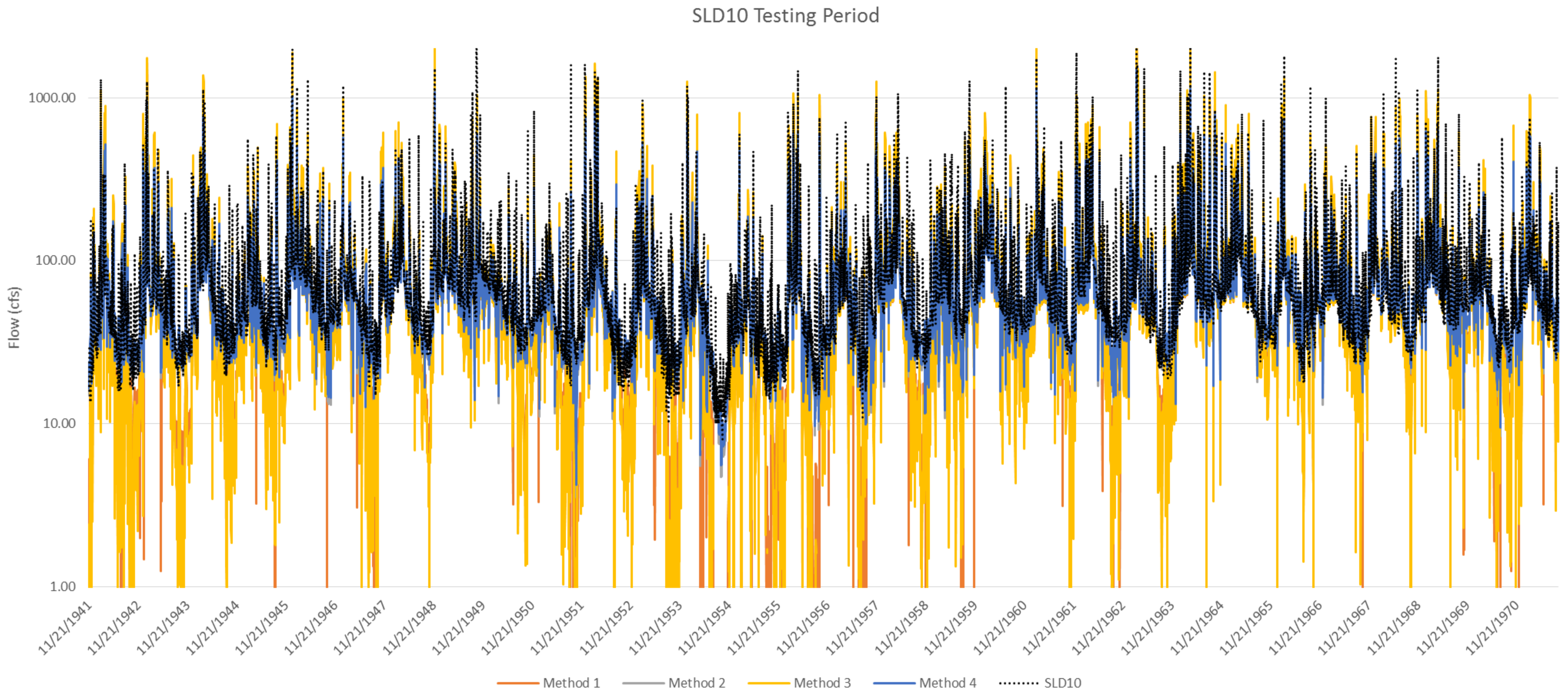


	SLD10		SLD12	
	Mean	SD	Mean	SD
Full Period	79.00	126.44	334.14	409.70
Training	76.12	136.87	319.61	411.51
Testing	83.34	124.68	327.67	400.31

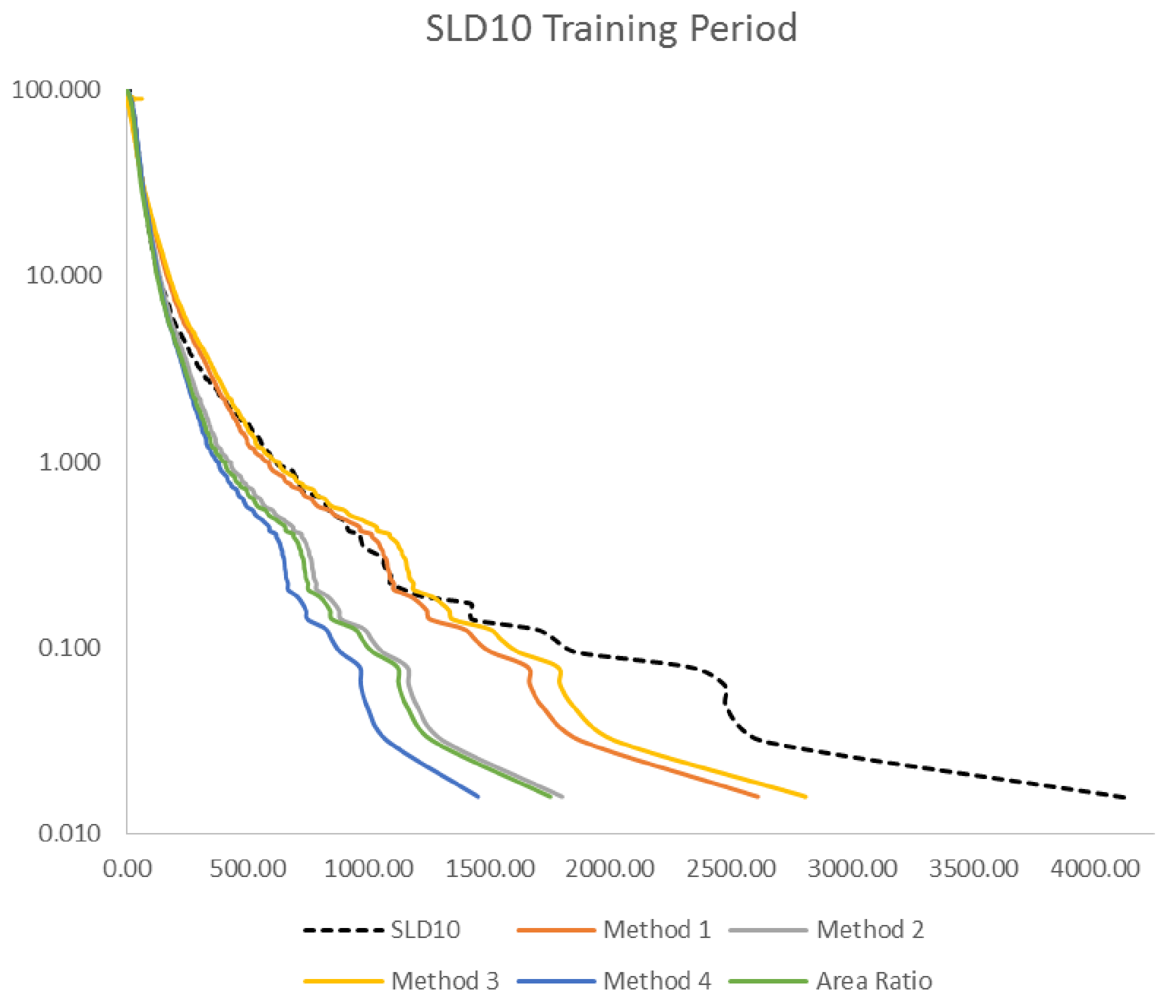


Graphic source: Alex Pellet, DNR

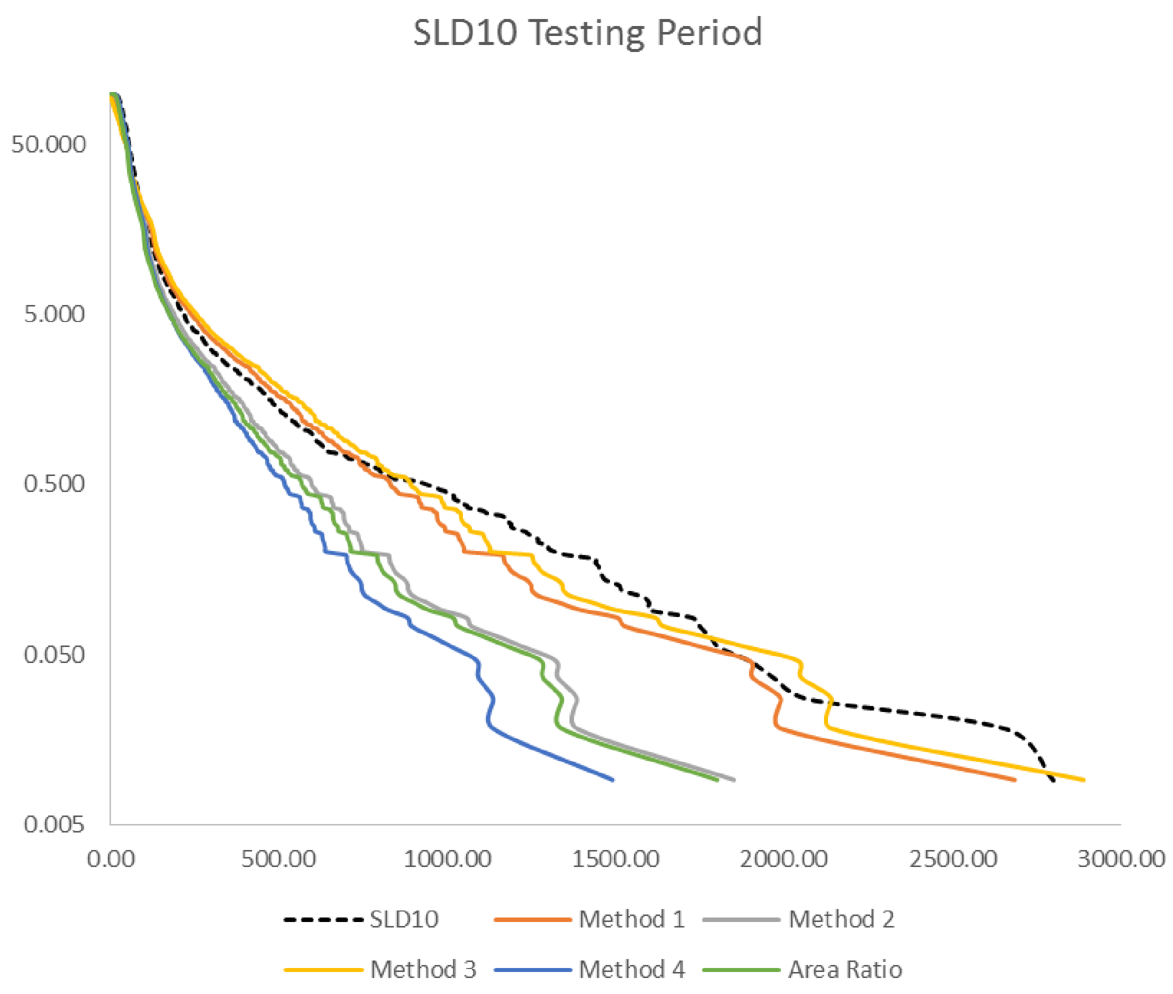

Training Period
Flow (cfs)
1000.00
100.00
10.00
1.00
6/4/1987
6/4/1988
6/4/1989
6/4/1990
6/4/1991
6/4/1992
6/4/1993
6/4/1994
6/4/1995
6/4/1996
6/4/1997
6/4/1998
6/4/1999
6/4/2000
6/4/2001
6/4/2002
6/4/2003
6/4/2004
Method 1
Method 2
Method 3
Method 4
SLD10

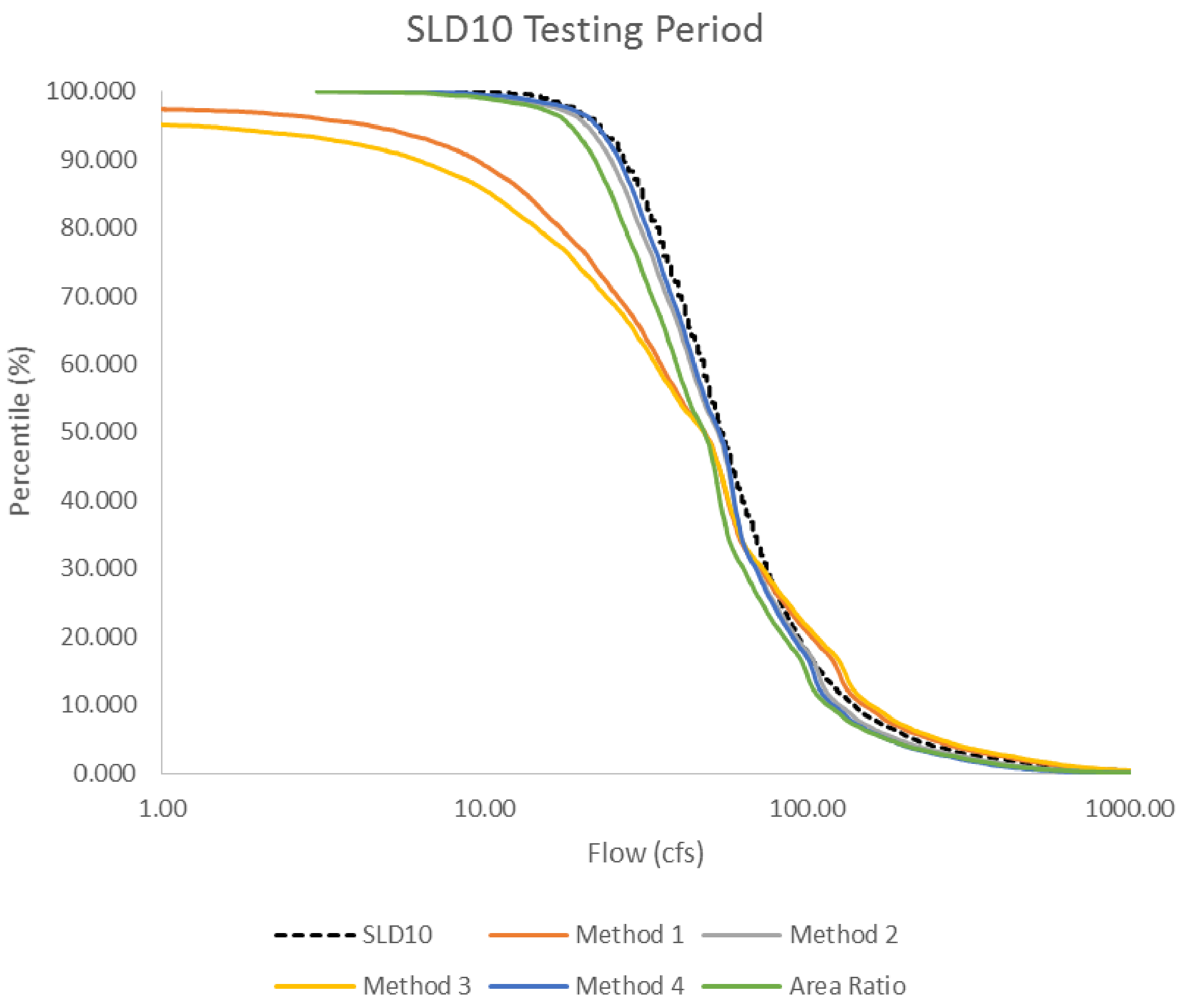

SLD10 Testing Period
Flow (cfs)
1000.00
100.00
10.00
1.00
11/21/1941
11/21/1942
11/21/1943
11/21/1944
11/21/1945
11/21/1946
11/21/1947
11/21/1948
11/21/1949
11/21/1950
11/21/1951
11/21/1952
11/21/1953
11/21/1954
11/21/1955
11/21/1956
11/21/1957
11/21/1958
11/21/1959
11/21/1960
11/21/1961
11/21/1962
11/21/1963
11/21/1964
11/21/1965
11/21/1966
11/21/1967
11/21/1968
11/21/1969
11/21/1970
Method 1
Method 2
Method 3
Method 4
SLD10

SLD10 Training Period - Exceedance Plots



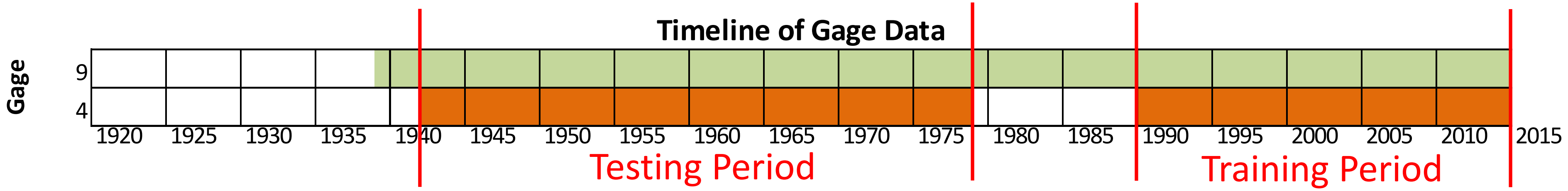
SLD10 Testing Period - Exceedance Plots

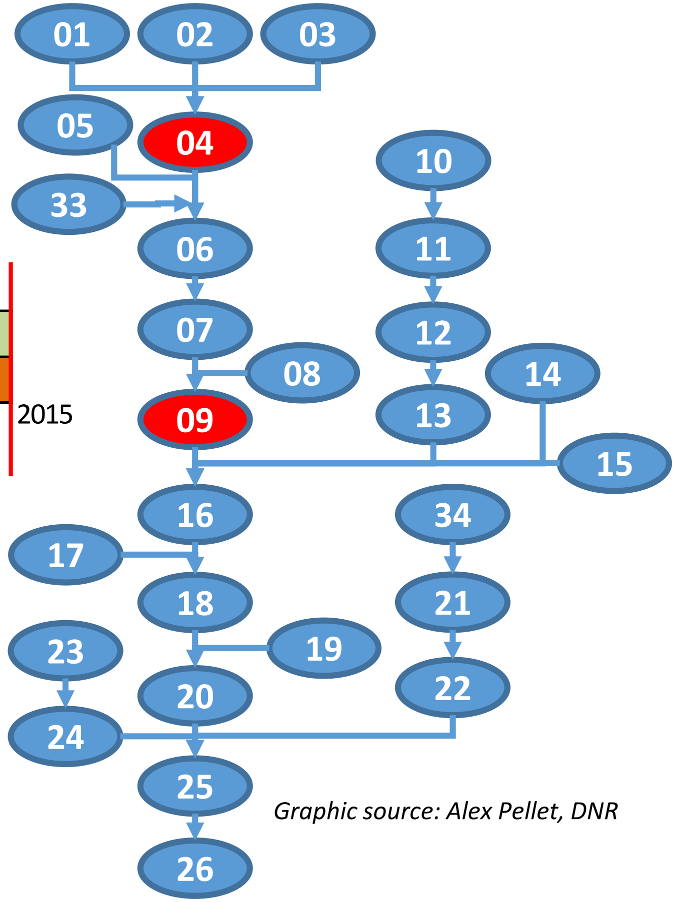




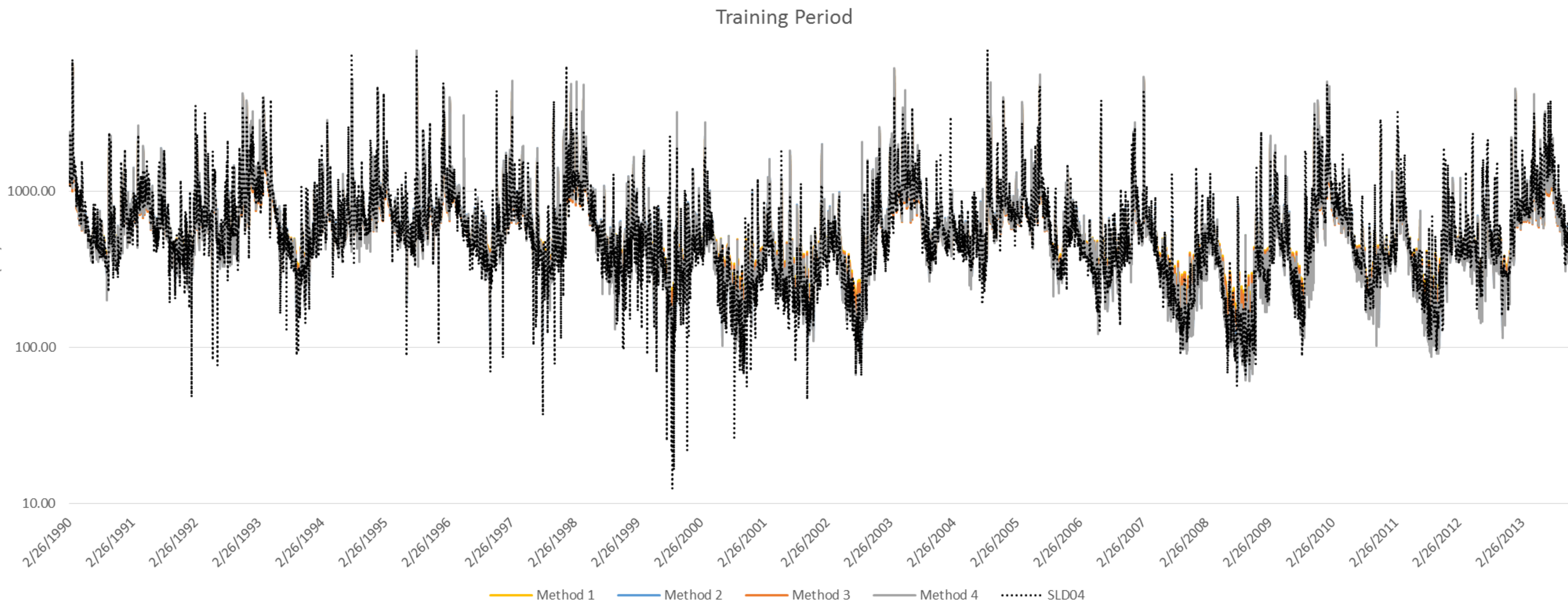
Extending SLD04 with SLD09 as reference

- Training Period 2/26/1990-12/31/2013
- Testing Period 1/9/1942-9/30/1978

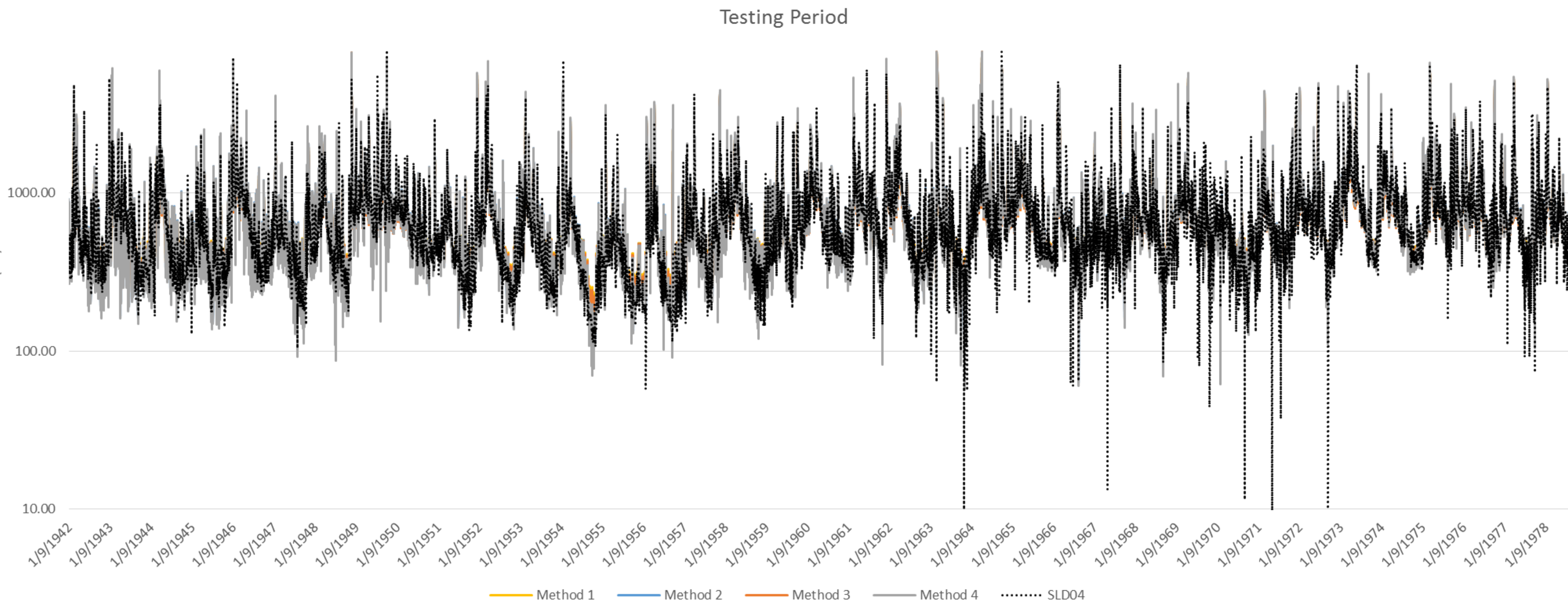




	SLD04		SLD09	
	Mean	SD	Mean	SD
Full Period	671.16	512.93	1024.43	920.59
Training	637.37	506.01	973.96	892.12
Testing	693.09	516.21	1105.78	973.32



Training Period
1000.00
100.00
10.00
2/26/1990
2/26/1991
2/26/1992
2/26/1993
2/26/1994
2/26/1995
2/26/1996
2/26/1997
2/26/1998
2/26/1999
2/26/2000
2/26/2001
2/26/2002
2/26/2003
2/26/2004
2/26/2005
2/26/2006
2/26/2007
2/26/2008
2/26/2009
2/26/2010
2/26/2011
2/26/2012
2/26/2013
Method 1
Method 2
Method 3
Method 4
SLD04


Testing Period
1000.00
100.00
10.00
1/9/1942
1/9/1943
1/9/1944
1/9/1945
1/9/1946
1/9/1947
1/9/1948
1/9/1949
1/9/1950
1/9/1951
1/9/1952
1/9/1953
1/9/1954
1/9/1955
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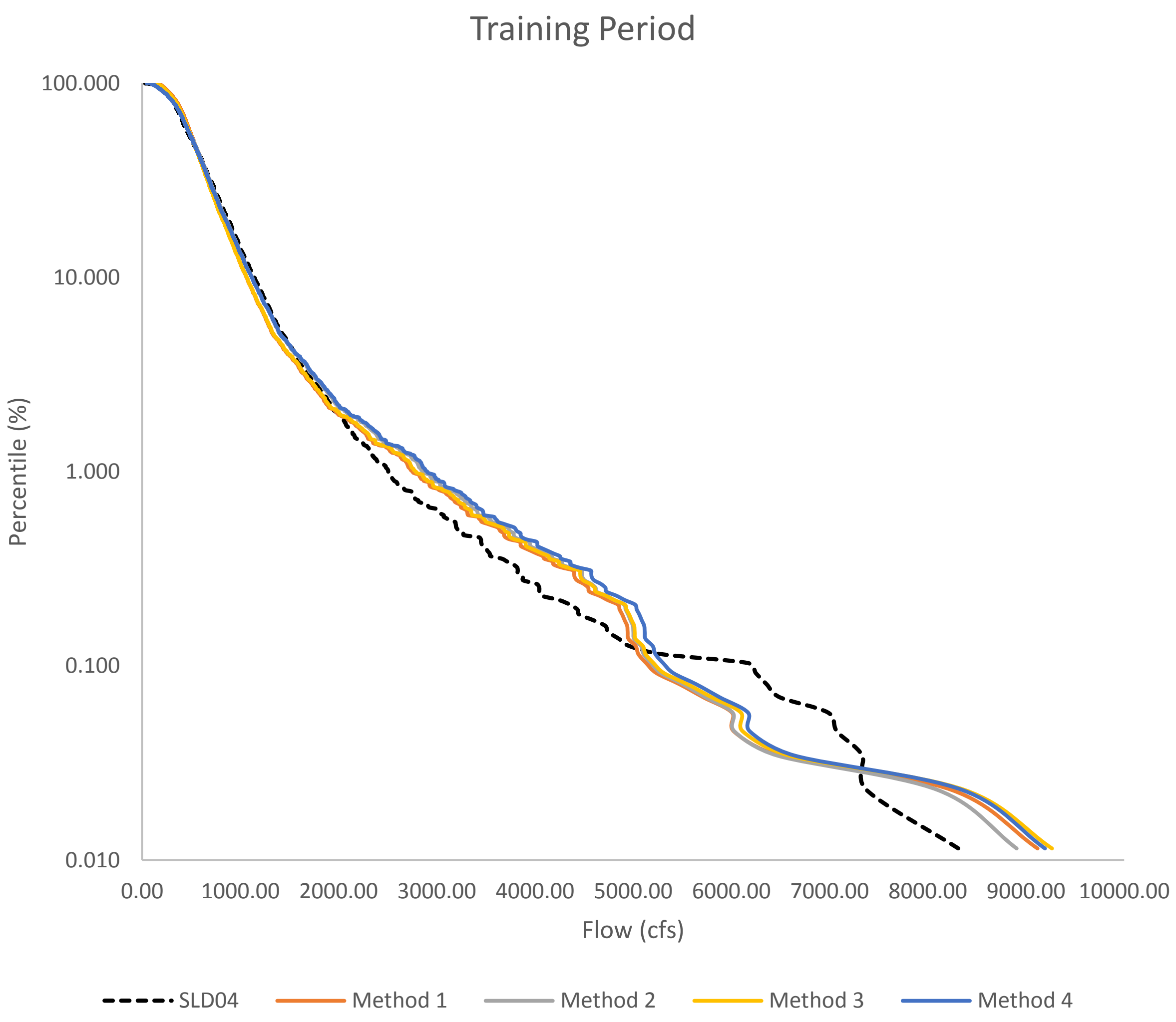
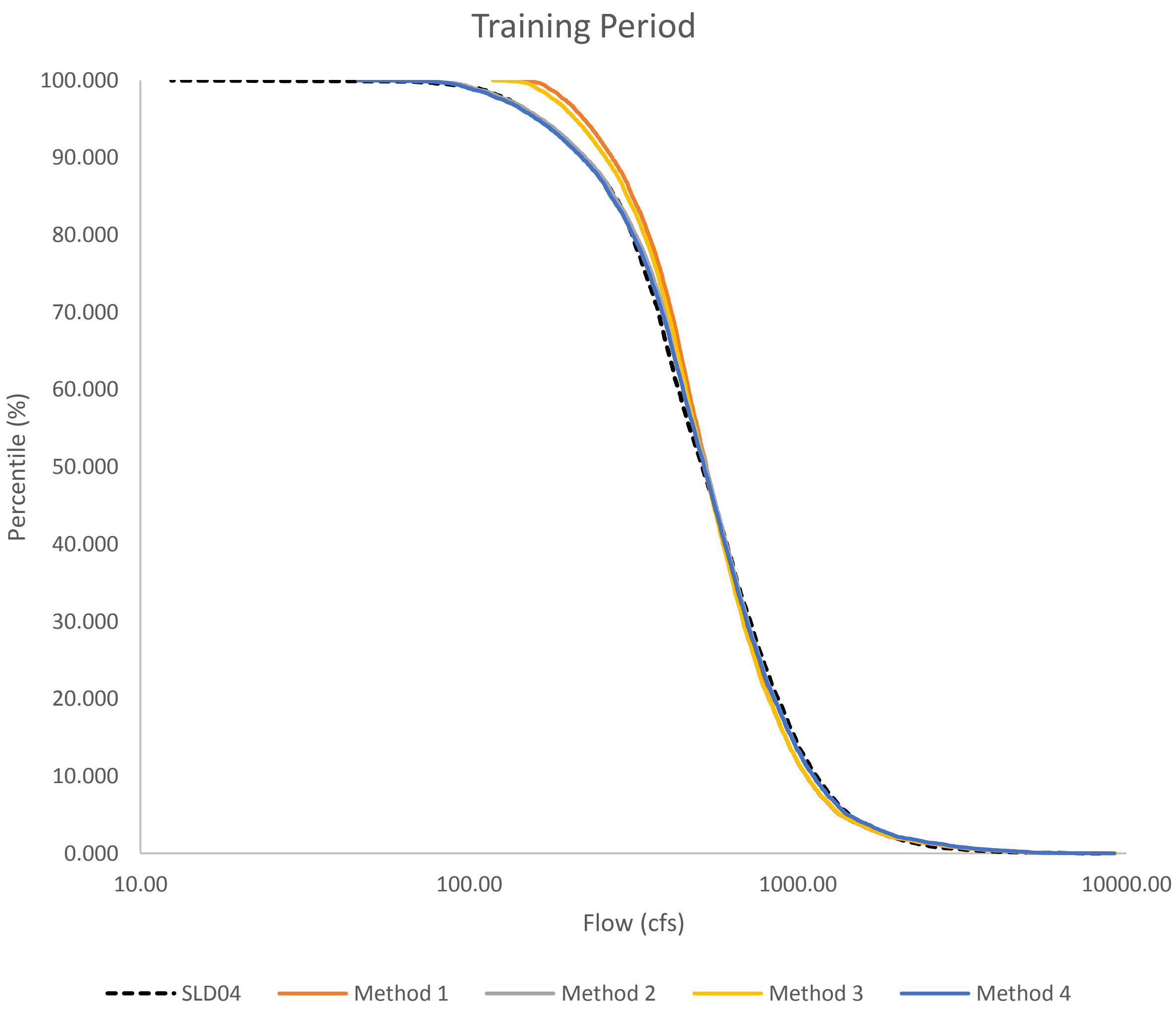
1/9/1966
1/9/1967
1/9/1968
1/9/1969
1/9/1970
1/9/1971
1/9/1972
1/9/1973
1/9/1974
1/9/1975
1/9/1976
1/9/1977
1/9/1978
Method 1
Method 2
Method 3
Method 4
SLD04

SLD04 Training Period - Exceedance Plots





SLD04 Testing Period - Exceedance Plots