Diamond Fork River

INSTREAM FLOW: A STATISTICAL APPROACH

Prepared for:
Utah Reclamation Mitigation and Conservation Commission

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August 2010

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An Innovative Approach to Developing Improved Instream Flow Recommendations

Many human activities have occurred that alter the temporal patterns and overall quantity of streamflow in rivers and streams of the western United States. These activities have led to degraded conditions in many of the affected waters.

The task of determining how much streamflow is required to sustain the aquatic ecosystems of those waters is difficult at best, and many methods have been suggested to assist resource managers in determining appropriate instream flows. This report will summarize the basic steps used to apply a statistical technique for determining instream flows for the Diamond Fork River in Utah.

The technique outlined in this report uses statistical relationships to quantify the range of natural variability that exists in less altered aquatic systems and applies those ranges to degraded systems to improve the streamflow regime. These methods are primarily useful for determining the range of low flow conditions that are found in natural streams and translating those results into meaningful estimates for degraded streams or for streams with limited or altered streamflow history data.

First Steps – Locating and Evaluating Reference Streams

USGS personnel from the Salt Lake City, Utah office, provided assistance in selecting a number of gage records from nearby rivers and streams that had limited hydrologic alteration to their flow regime. Each gage record was analyzed using the procedures outlined in steps 1-10 (below). For this study, seven gage records were selected to represent the basic streamflow variability of local streams with minimal hydrologic alteration. They include:

- Bear River near Utah/Wyoming State Line (Station # 10011500),
- Hobble Creek near Springville, UT (Station # 10152500),
- North Fork Provo River near Kamas, UT (Station # 10153800),
- Payson Creek above Diversions near Payson, UT (Station # 10147500),
- Spanish Fork above Thistle, UT (Station # 10148500),
- Weber River near Coleville, UT (Station # 10130500),
- Yellowstone River near Altonah, UT (Station # 9292500).

Although the hydrology of each of these streams has been somewhat affected by human activities, their overall timing and distribution of discharge remains largely unchanged. These streams were used as reference streams for the procedures outlined below.

Statistical Procedures and Analyses

The steps outlined below provide a characterization of the temporal variability in streamflow that is found in unaltered systems. These steps were completed for the seven reference streams listed above.

Steps 1-4 (below) are computed using the entire discharge record for each of the seven streams. These steps are used to ensure that the reference streams have similar annual distributions of hydrologic characteristics. If outliers exist after step 4, they may be eliminated from further consideration. After completion of Steps 1-4 to ensure similarity of overall hydrology from gage to gage, those data are set aside and are not used for further analyses.

Step 1 - A list of area streams that met our selection criteria was compiled. Streams had to (1) have minimal human alteration to the upstream watershed and (2) have a USGS streamflow gaging station with a reasonably long period of record.

Step 2 - The measurements of mean daily streamflow were obtained and standard flow duration curves were constructed for each gaged stream (Figure 1). A standard flow duration curve plots the mean daily streamflow against the percent of time that the streamflow has been equaled or exceeded during the period of record. Notice that streams of different size are distributed vertically along the y-axis (discharge). Although the curves appear to have similar shapes, the vertical distribution makes it impossible to use the data from one stream to guide flow recommendations on another stream, unless they happen to be of exactly the same size. In order to use these data to guide flow recommendations, a way must be found to remove the effect of stream size on the data, which could allow basins of different sizes to plot in the same space.

Step 3 - The flow duration curves, for each gaging station, were non-dimensionalized by dividing the mean daily discharge by the mean discharge for the entire period of record (Figure 2). The result is a dimensionless variable which we will call "dimensionless discharge". It is dimensionless because the units of discharge cancel out when dividing by the mean discharge. Notice that the plots which were previously distributed along the y-axis, are now grouped much more closely. This procedure causes the large and small streams to collapse onto each other, creating an envelope of streamflow variability that can be compared between streams of all sizes.

Step 4 - The flow duration curves from all stations are plotted together and visually compared to each other to identify similarities and differences. Having established that the overall streamflow variability of the streams was quite similar, these streams were deemed to be useful as "reference streams", and further analyses were completed using those records.

Steps 5-8 are computed using datasets that have been broken down by month, which provides a higher level of temporal resolution for streamflow variability. Separate flow duration relations for each month of the year, January through December, are produced and analyzed.

Step 5 - The mean discharge for each month of each year was computed for the entire gage record of each of the nine streams. For example: the mean discharge was computed for Jan. 1963, Feb. 1963, Mar. 1963, etc.

Step 6 - A duration curve was constructed for each month (Jan-Dec) using the monthly means computed in step 5. The result is twelve flow duration curves for each gage record (one for each month), that define the range of flow variability that has occurred during that month over the period of record. At this point in the process, the curves are still distributed widely along the discharge axis (y).

Step 7 – In order to remove the effect of stream size on the flow duration curves, the monthly duration curves developed in Step 6 were transformed by dividing the discharge data by the mean discharge for the period of record: the same method that was outlined previously in Step 3. Again, as in Step 3, the result is a similarity-collapse that brings the streams of all sizes into a well defined envelope of natural streamflow variability. The data that were spread along the discharge axis are now transformed into the well-grouped dimensionless discharges: example plots for a summer month (July) and a winter month (January) are shown in Figures 3 and 4, respectively. Notice that the curves are now grouped together quite closely and represent the range of discharge present in the reference streams. These monthly characterizations of streamflow variability are now represented by a dimensionless variable that can be scaled up to any size stream, simply by multiplying by the mean discharge of that stream.

Step 8 - Points were interpolated along each dimensionless flow duration curve, at 10% increments, using a Lagrange interpolation scheme. This allows us to identify important characteristics of the curves (wettest 10%, driest 20%, etc.).

Results from steps 5-8 are used to construct an overall dimensionless instream flow table (Step 9) that can be redimensionalized for other streams (Step 10).

Step 9 - The median values from the seven Utah gaging stations were determined, for each 10% increment of each month, and that value was used to establish the overall dimensionless instream flow characteristics (Figure 5 and Table 1).

Step 10 - Dimensionless discharges determined in Step 9 then can be redimensionalized for any river by multiplying the dimensionless discharges by the mean daily discharge for the period of record at whatever gage is appropriate for a given site. The result is a series of monthly mean discharge recommendations for water years, ranked by percentile.

Streamflow of the Diamond Fork River

Data from several USGS gages on the Diamond Fork River were analyzed, and flow duration curves were plotted for the associated time periods: from 1908 through 2009, with some gaps in coverage (Figure 6). A series of annual dimensionless discharge curves (Figure 7) was also constructed, by dividing the discharges in Figure 6 by the mean discharges for the various time periods, presented in Table 2. The data in Figure 7 demonstrate that the flow variability of the river has varied substantially from one time period to the next. The more recent time periods show much less flow variation than earlier time periods. The curves in Figure 7 were plotted with the seven Utah reference streams to determine the degree of alteration from natural streamflow variability that had occurred in the Diamond Fork River during the period of record (Figure 8). These data suggest that Diamond Fork currently has base flows that are proportionally much higher than would be expected in natural snowmelt streams in Utah.

Further examination of Figure 8 shows that high flows are proportionally much lower than would be expected under less-altered conditions. This apparent reduction in the magnitude of high flows, relative to mean flows, can come from a variety of impacts. One explanation concludes that peak flows may have been reduced by damming and/or storage of water, but for the case of Diamond Fork, no large water storage facilities are present, making that explanation unlikely. Another more likely reason for the reduced peak flows is an increase in mean discharge. For instance, if the mean discharge of a given stream is doubled by import of outside water, then the computed dimensionless peaks would be reduced in half. Given the import of water into the Diamond Fork system, the later explanation seems far more plausible. Higher than expected base flows are causing the mean discharge to increase, thus decreasing the relative magnitude of the high flows.

The median dimensionless values, shown previously in Table 1, can be scaled to represent the natural range of flow variability that might be expected in Diamond Fork under less-altered conditions. Table 3 shows the results of such a scaling: obtained by multiplying the median values in Table 1 by the mean discharge for the 2003-2009 time period, which was 97.8 cfs. The discharges in Table 3 represent the range of discharges that would be likely in Diamond Fork under more natural conditions, but still accounting for the imported water.

Remember that the percentile rankings in Table 3 represent the full range of water years: with low values being the drier years, and high values being the wetter years. The table is to be used in the following manner: the value for the month of March, for the 80 percentile water year, is 44.9 cfs. This means that the river would likely flow at a discharge of 44.9 cfs, during a water year that is wetter than 80 percent of the years.

As discussed previously, the data presented in Figure 8 suggest that base flows in Diamond Fork are high when compared to the median values of less altered streams in Utah. Additional dimensionless analyses can be applied to compare the flows in Diamond Fork to the highest values that were measured in the less-altered reference streams. Table 4 shows the maximum dimensionless discharge of the seven reference streams. Note that these values are substantially higher than those shown in Table 3.

The maximum values from the seven Utah reference streams, shown in Table 4, can be scaled for Diamond Fork in a similar fashion to the previous scaling. Simply multiplying the values in Table 4 by the mean discharge of 97.8 cfs, yields a new table that shows the maximum discharges that could be expected in Diamond Fork (Table 5). This table represents the highest measured discharge for the seven reference streams, by percentile, scaled for Diamond Fork. Examination of Table 5 shows that the currently mandated minimum flows on Diamond Fork (80 cfs and 60 cfs) are substantially higher than the highest of the reference streams, in all but the wettest years.

Conclusions

The statistical methods applied in this paper illustrate that the streamflow of the Diamond Fork River is substantially altered from a natural condition. When compared with the flow variability of less-altered streams, base flows are higher than expected and high flows are suppressed. The methods further demonstrate the magnitude of those departures from the expected variability. These results suggest that the currently mandated base flows may be excessively high. Lower flows would be expected to occur in most years under more natural conditions.

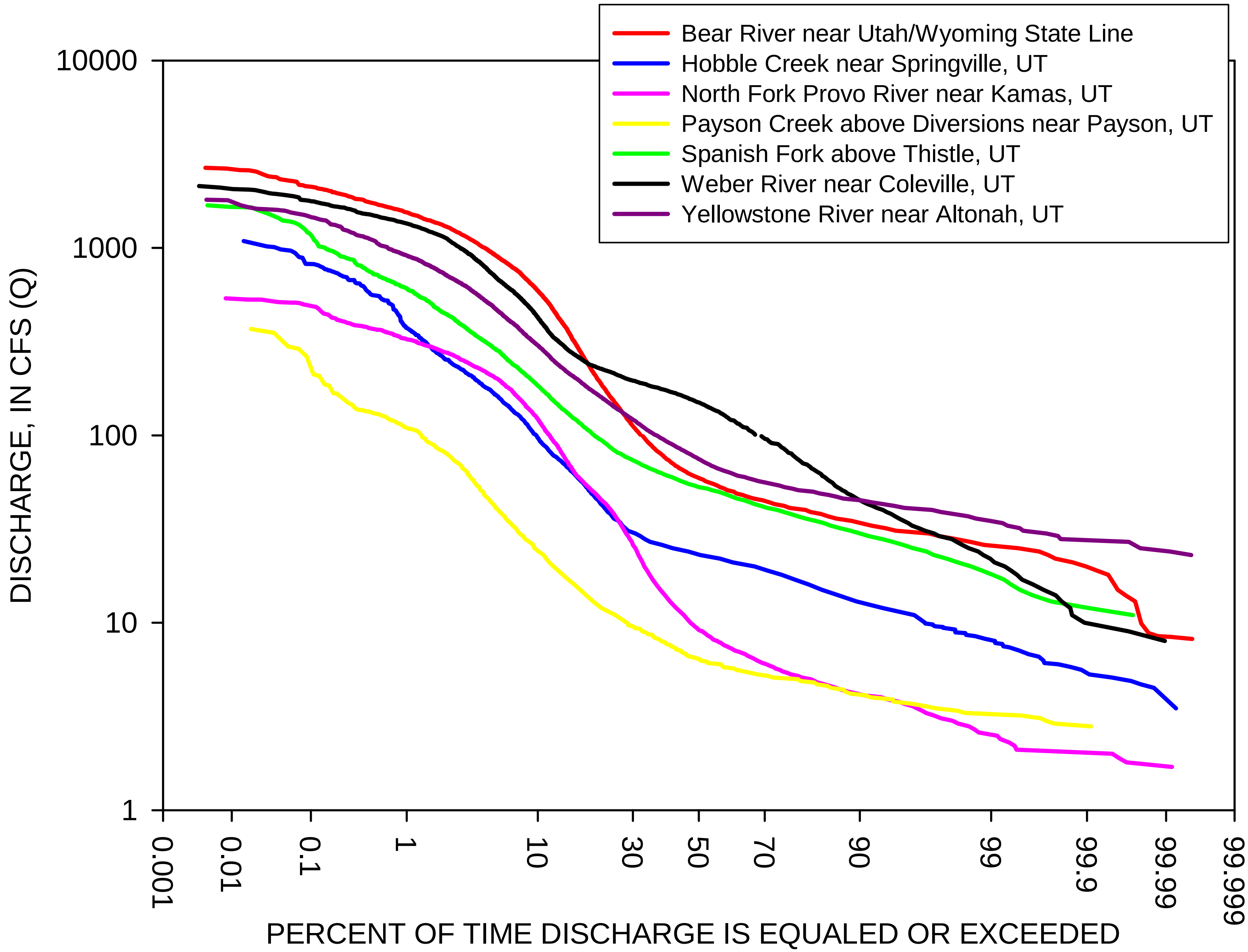

Figure 1. Standard flow duration relations for seven Utah reference streams.

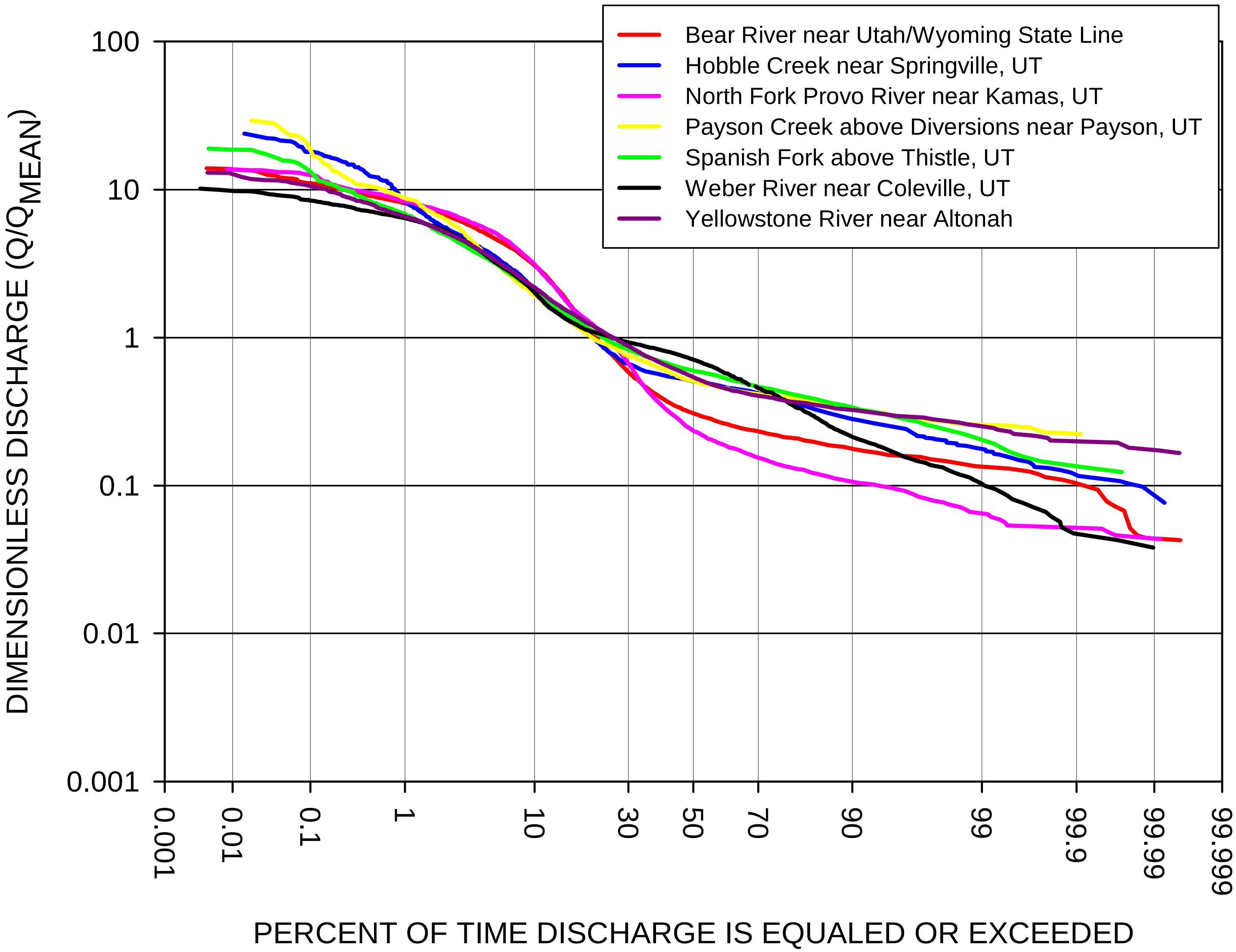

Figure 2. Dimensionless flow duration relations for seven Utah reference streams.

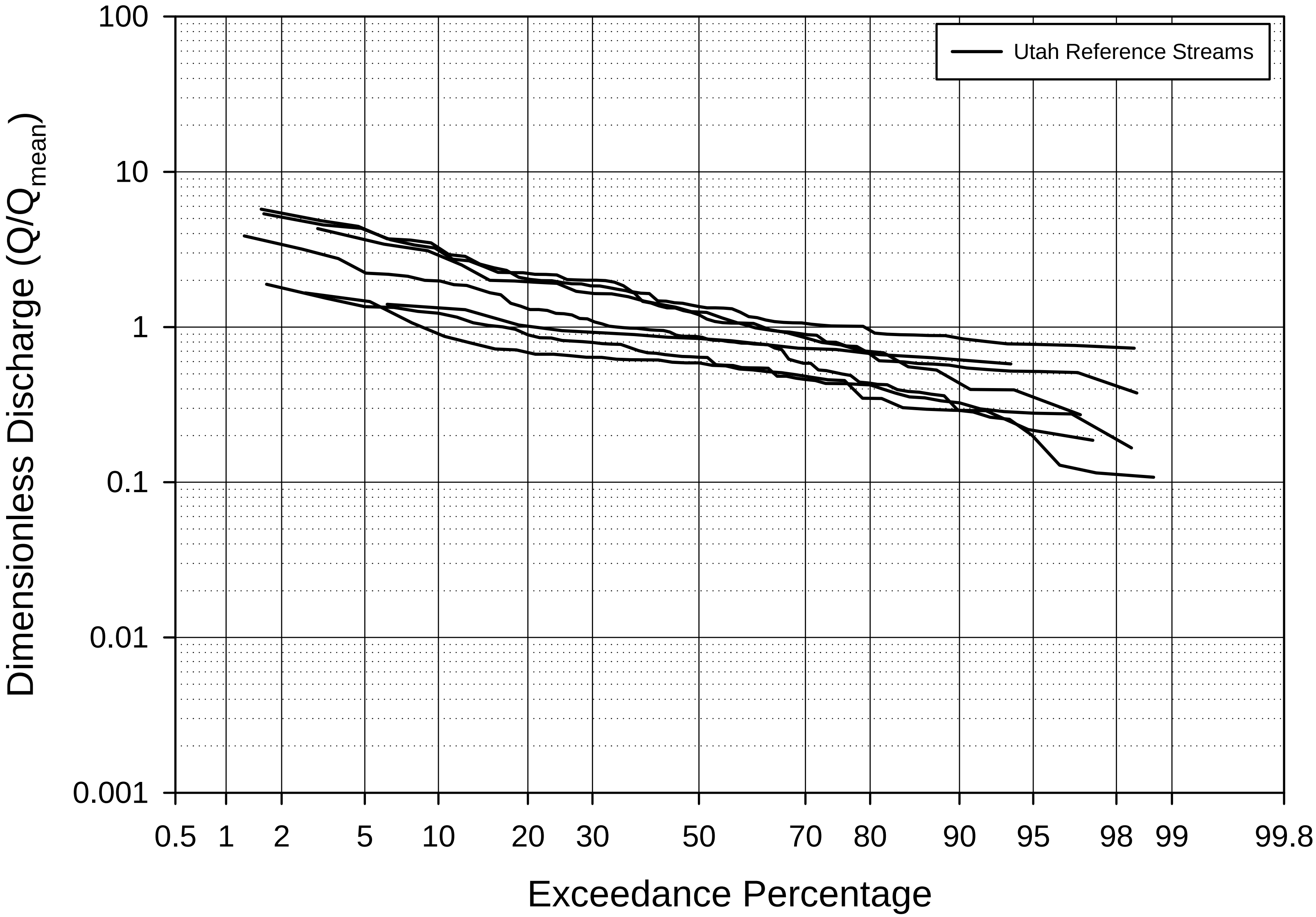

Figure 3. Monthly (July) dimensionless flow duration relations for seven Utah reference streams.

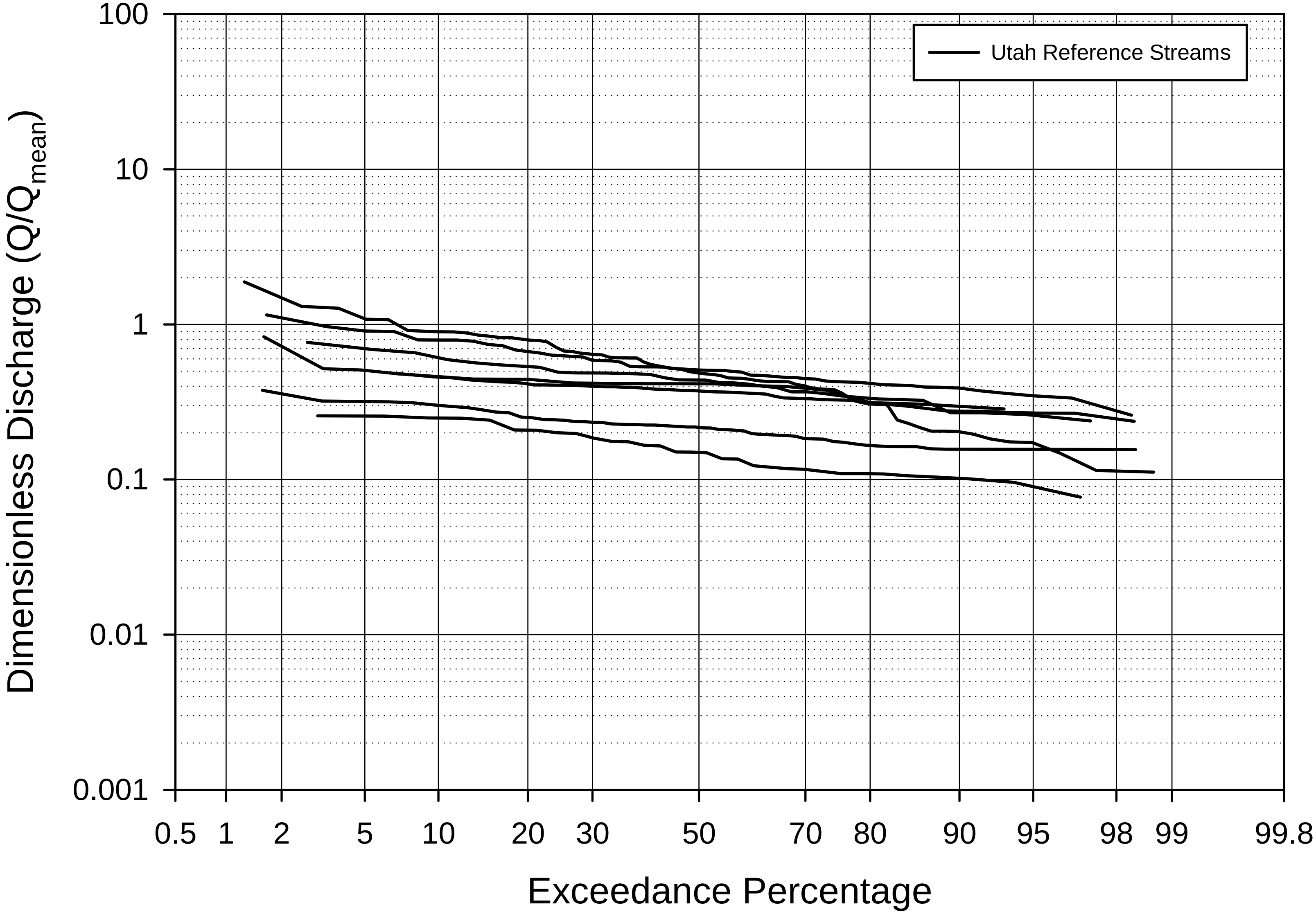

Figure 4. Monthly (January) dimensionless flow duration relations for seven Utah reference streams.

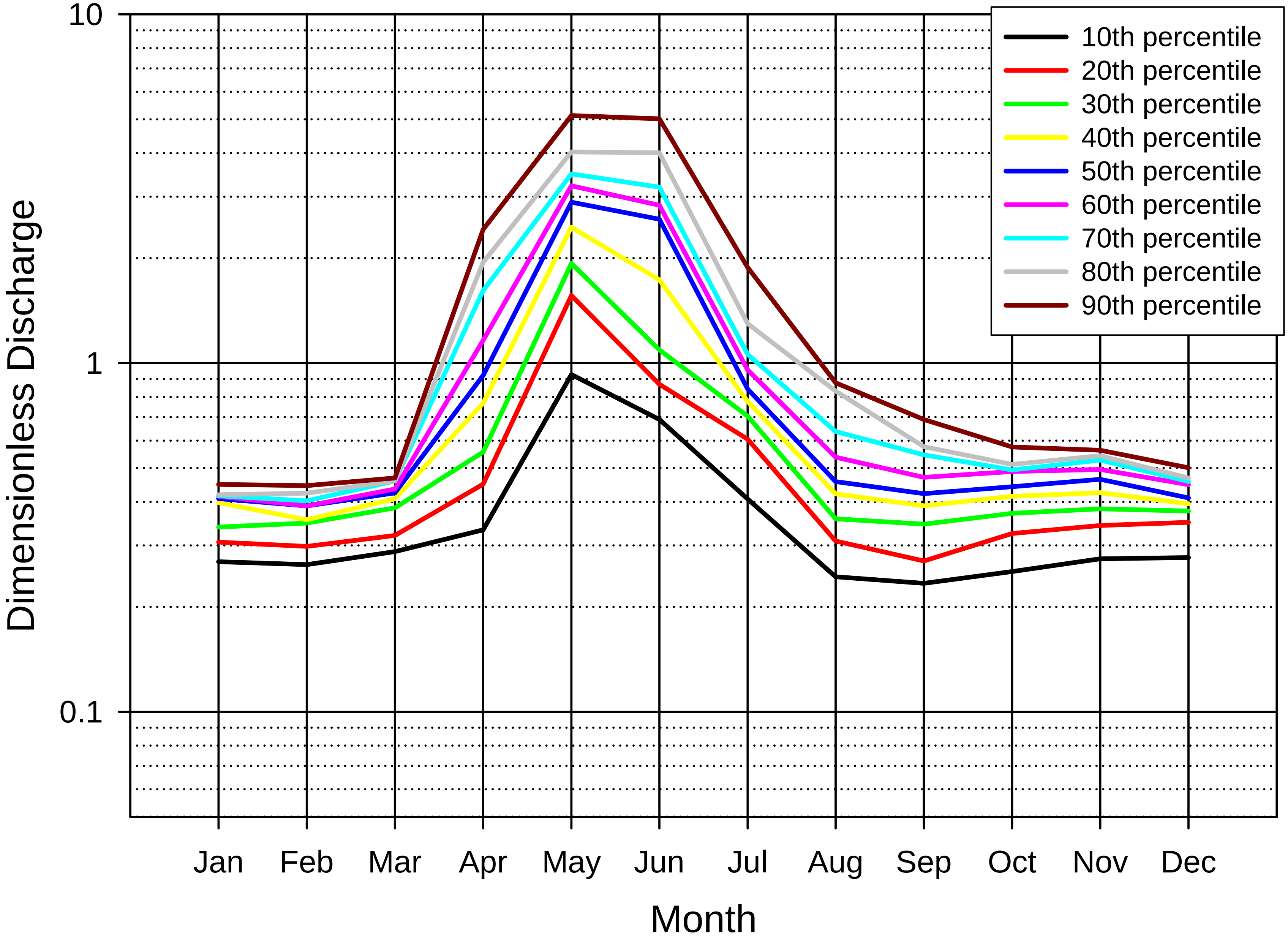

Figure 5. Dimensionless discharges for ranked water years: the median values of seven Utah reference streams.

Table 1. Dimensionless Discharges - Monthly Median Values

Month	Percentile Rank Water Year								
	10	20	30	40	50	60	70	80	90
Jan	0.269	0.306	0.339	0.398	0.408	0.415	0.416	0.419	0.449
Feb	0.264	0.298	0.348	0.355	0.389	0.389	0.403	0.424	0.445
Mar	0.288	0.321	0.385	0.408	0.424	0.435	0.459	0.460	0.468
Apr	0.332	0.449	0.556	0.767	0.923	1.163	1.615	1.947	2.419
May	0.927	1.564	1.931	2.455	2.894	3.225	3.488	4.037	5.131
Jun	0.690	0.870	1.092	1.733	2.585	2.837	3.197	4.007	5.017
Jul	0.408	0.606	0.705	0.777	0.843	0.956	1.060	1.299	1.882
Aug	0.244	0.309	0.358	0.422	0.457	0.537	0.637	0.832	0.878
Sep	0.233	0.271	0.345	0.390	0.422	0.470	0.546	0.576	0.690
Oct	0.252	0.325	0.370	0.415	0.442	0.489	0.494	0.513	0.575
Nov	0.275	0.342	0.382	0.425	0.464	0.495	0.527	0.542	0.563
Dec	0.277	0.349	0.376	0.395	0.410	0.448	0.458	0.468	0.501

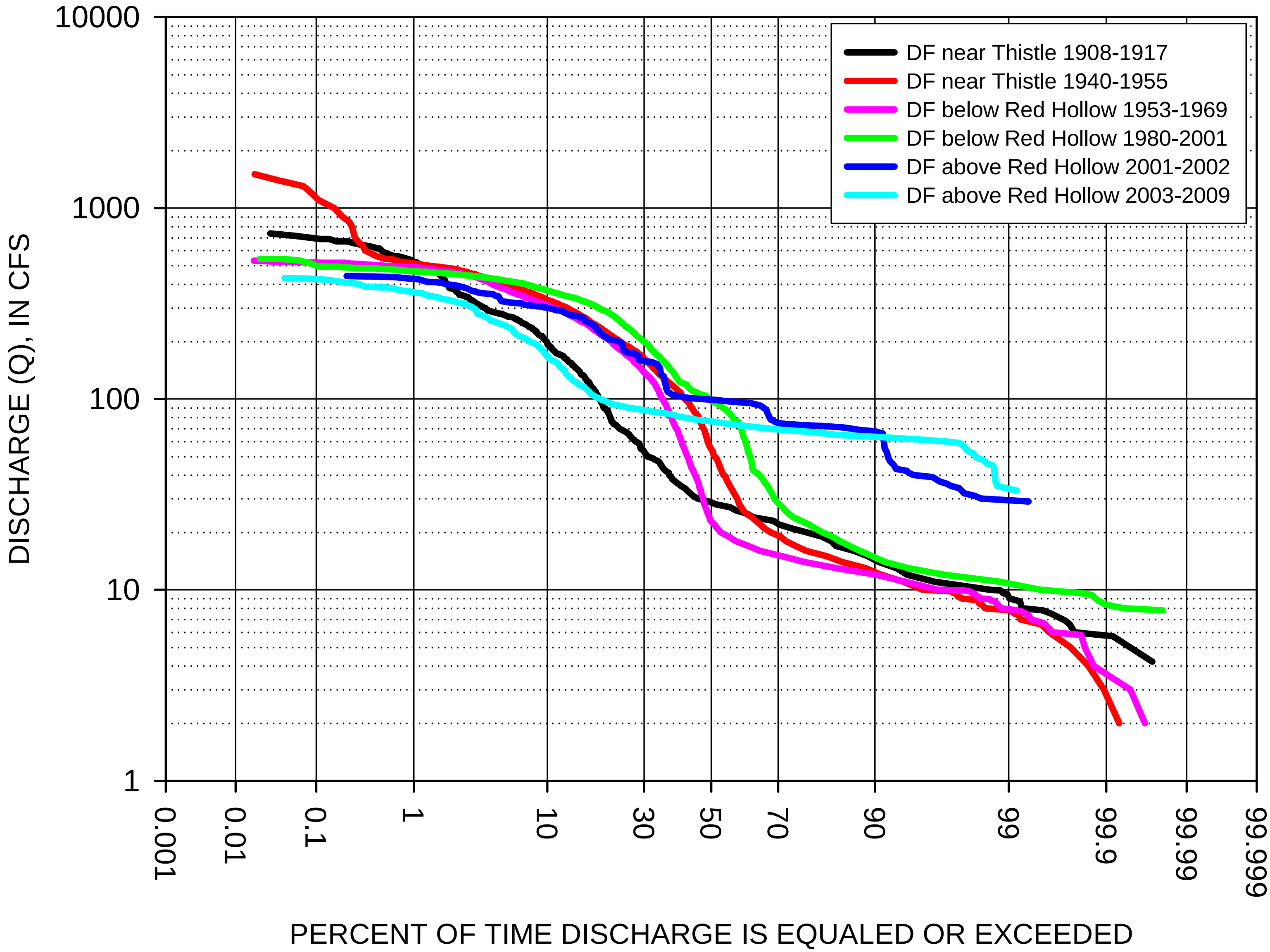

Figure 6. Flow duration relations for several gages on Diamond Fork, for time periods from 1908 to 2009.

Table 2. Mean Discharges at USGS Gages for Various Time Periods			
	Mean Q (cfs)		
Time Period	DF near Thistle	DF below Red Hollow	DF above Red Hollow
1908-1917	71.1		
1940-1955	122.9		
1953-1969		105.0	
1980-2001		145.4	
2001-2002			140.5
2003-2009			97.8

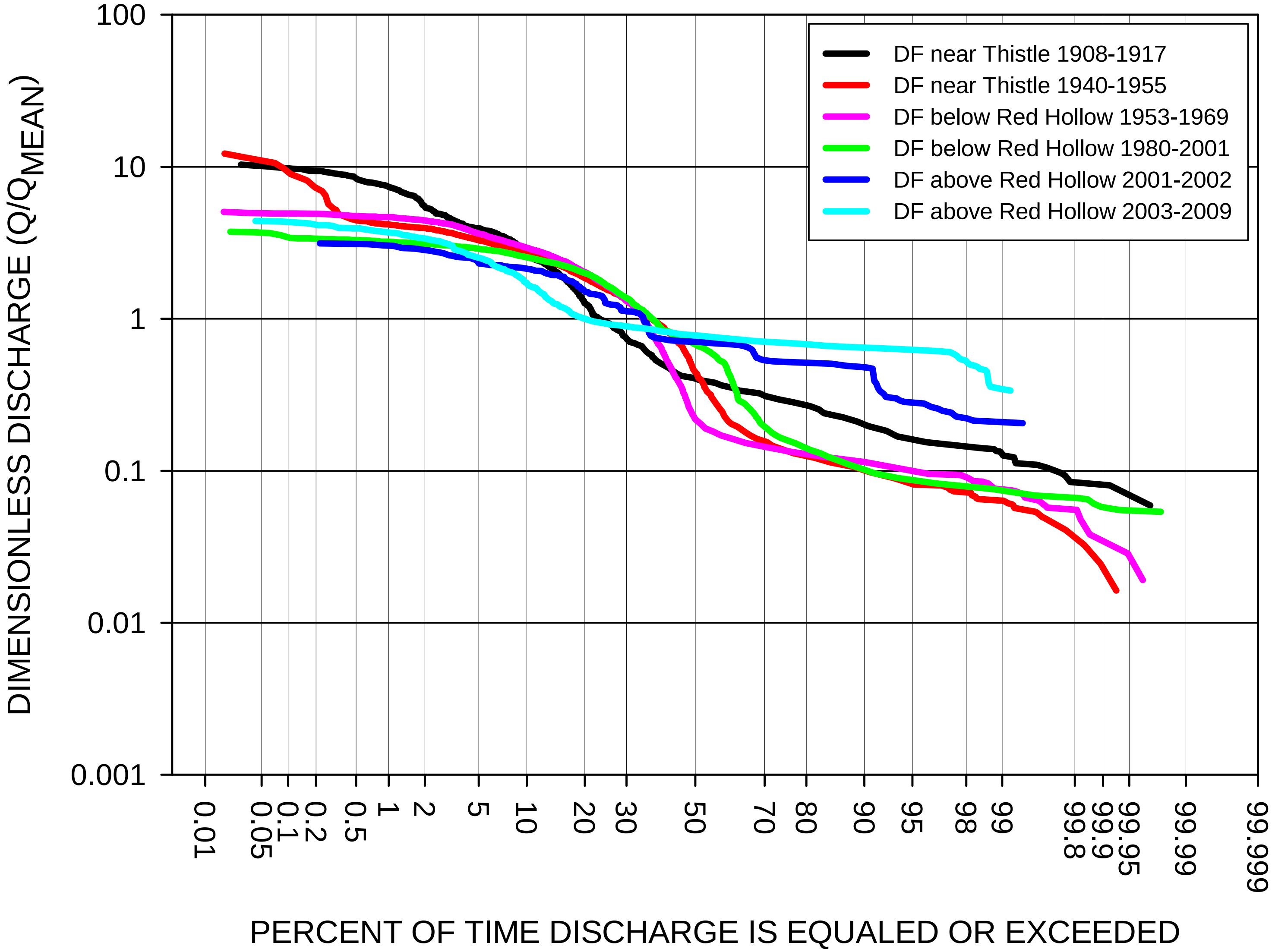

Figure 7. Dimensionless flow duration relations for Diamond Fork from three gages, for various periods of record.

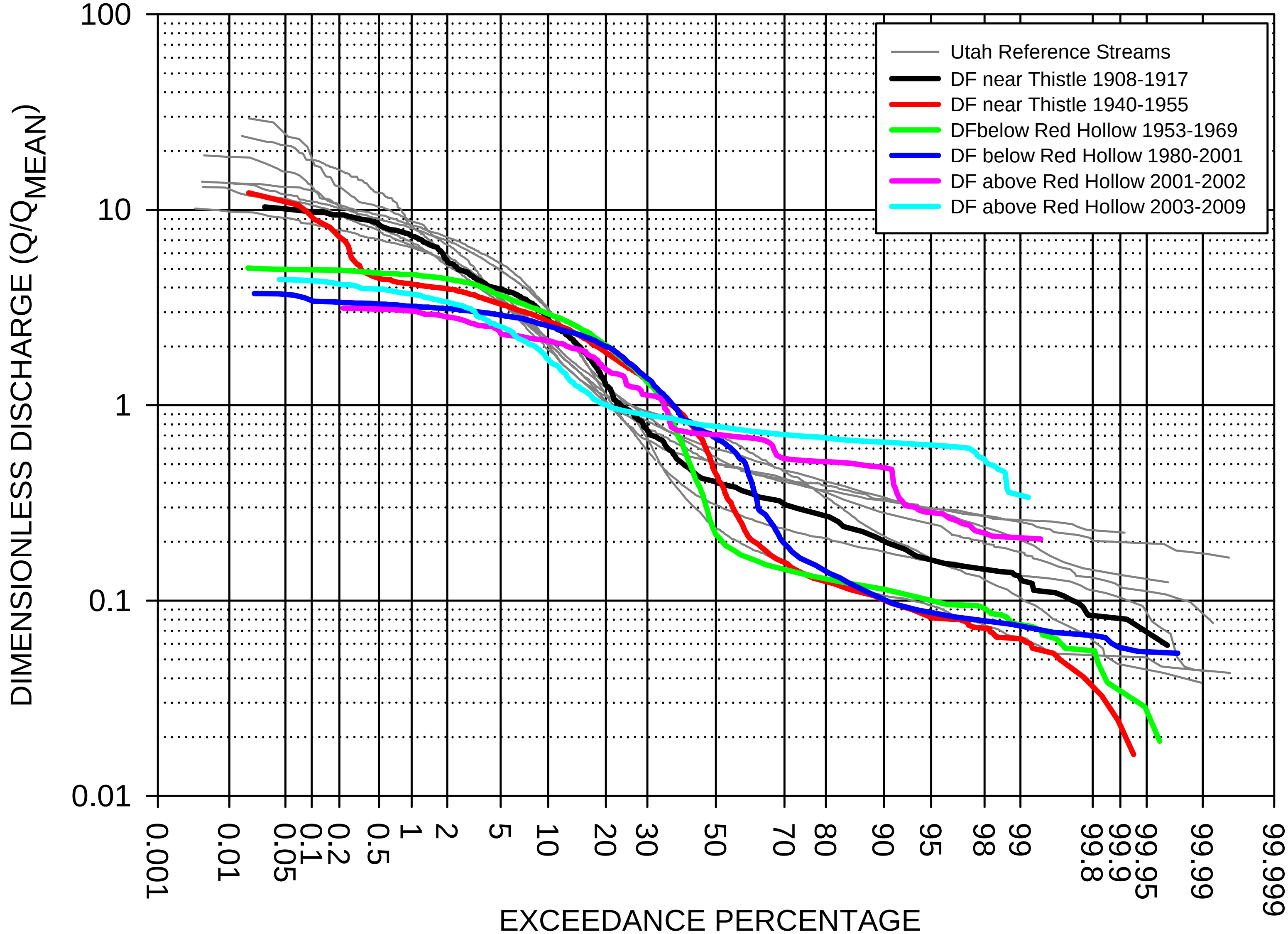

Figure 8. Plot of dimensionless discharge for several Diamond Fork gages with Utah reference streams shown in gray. Note that recent low flows in Diamond Fork are much higher than in the reference streams.

Table 3. Utah Medians, Scaled for Diamond Fork (values in cfs)									
	Percentile Rank Water Year								
Month	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**
Jan	26.3	30.0	33.1	38.9	39.9	40.6	40.7	41.0	43.9
Feb	25.9	29.2	34.0	34.8	38.1	38.1	39.4	41.4	43.5
Mar	28.2	31.4	37.6	39.9	41.5	42.6	44.9	44.9	45.8
Apr	32.5	43.9	54.4	75.0	90.2	113.8	157.9	190.4	236.6
May	90.7	152.9	188.9	240.1	283.1	315.4	341.2	394.8	501.8
Jun	67.5	85.1	106.8	169.5	252.8	277.5	312.7	391.8	490.7
Jul	39.9	59.2	68.9	76.0	82.5	93.5	103.7	127.0	184.0
Aug	23.8	30.2	35.0	41.2	44.7	52.5	62.3	81.4	85.9
Sep	22.8	26.5	33.8	38.1	41.3	46.0	53.4	56.3	67.4
Oct	24.7	31.7	36.2	40.6	43.2	47.8	48.3	50.2	56.2
Nov	26.9	33.5	37.3	41.6	45.4	48.4	51.5	53.0	55.1
Dec	27.1	34.2	36.8	38.6	40.1	43.8	44.8	45.8	49.0

Table 4. Dimensionless Discharges - Maximum of Seven Utah Streams

Month	Percentile Rank Water Year								
	10	20	30	40	50	60	70	80	90
Jan	0.374	0.409	0.445	0.470	0.506	0.533	0.641	0.792	0.895
Feb	0.409	0.463	0.521	0.565	0.609	0.649	0.685	0.840	0.963
Mar	0.477	0.643	0.702	0.757	0.777	0.866	0.926	1.076	1.270
Apr	0.758	0.979	1.240	1.491	2.141	2.524	3.082	3.696	5.619
May	2.091	2.407	3.020	3.083	3.817	4.090	4.867	5.896	6.766
Jun	1.848	2.456	3.030	3.641	4.452	4.906	5.676	6.472	7.229
Jul	0.816	0.905	1.038	1.140	1.332	1.494	2.004	2.187	2.928
Aug	0.628	0.730	0.763	0.904	0.967	1.068	1.228	1.346	1.509
Sep	0.521	0.556	0.641	0.722	0.764	0.856	0.936	1.103	1.308
Oct	0.431	0.494	0.520	0.559	0.666	0.783	0.835	0.896	1.038
Nov	0.362	0.417	0.524	0.580	0.645	0.730	0.845	0.921	1.020
Dec	0.336	0.394	0.434	0.513	0.579	0.647	0.713	0.824	0.953

Table 5. Dimensionless Discharges - Maximum of Seven Utah Streams

Month	Percentile Rank Water Year								
	10	20	30	40	50	60	70	80	90
Jan	36.5	40.0	43.5	46.0	49.5	52.1	62.7	77.4	87.6
Feb	40.0	45.3	51.0	55.3	59.5	63.5	67.0	82.2	94.2
Mar	46.6	62.8	68.6	74.0	76.0	84.7	90.5	105.2	124.2
Apr	74.1	95.7	121.3	145.9	209.4	246.8	301.5	361.4	549.5
May	204.5	235.4	295.3	301.5	373.3	400.1	476.0	576.7	661.8
Jun	180.7	240.2	296.3	356.0	435.4	479.8	555.1	633.0	707.0
Jul	79.8	88.5	101.6	111.5	130.2	146.1	195.9	213.9	286.3
Aug	61.4	71.4	74.6	88.4	94.5	104.5	120.1	131.7	147.6
Sep	50.9	54.4	62.7	70.6	74.7	83.7	91.5	107.9	127.9
Oct	42.2	48.3	50.8	54.6	65.1	76.5	81.7	87.7	101.5
Nov	35.4	40.8	51.3	56.7	63.1	71.4	82.6	90.1	99.7
Dec	32.9	38.5	42.4	50.2	56.7	63.3	69.8	80.6	93.2