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Fountain Creek Gage Analysis

Homework 6

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Introduction:

The CIVE 717 class members, Nate Clifton, Susan Cundiff, Ali Reza Nowrooz Pour, Robbie Queen and Scott Zey studied the gage records on Fountain Creek and tributaries individually as Homework assignments 4 and 5. A case study of all the gages and how they compare to one another is the culmination of Homework Assignment 6. This paper is the collection of the flow duration curves, calculated $\hat{b}$ values, sediment rating curves, the cumulative distribution function of the sediment rating curve method and the total sediment load.

Methodology:

The gages along Fountain Creek were identified on a map (**Figure 1**) as a first step in studying the hydrology and sediment transport of this system. To study how the amount of flow and how often that flow occurs is changing in the downstream direction the flow duration curves for the study sites have been compiled in **Figure 2**. The flow duration curve is developed when the data is ranked from highest to lowest and then assigned a Weibull plotting position. The Weibull plotting position is determined by dividing the rank number by the total number of values plus one:

$$E(x) = \frac{rank}{N+1}$$

A value that describes the flow duration curve, $\hat{b}$, can be helpful for extrapolating data at higher discharges. The method from section 5.6 of the River Mechanics (Julien, 2002) text book was used to determine the $\hat{b}$ for the flow duration curve. The ln(x) is plotted against the ln[-ln(E(x))] in **Figure 3** for all of the data and then a line is fit to the higher values of the ln(x) as demonstrated in **Figure 4**. For demonstration purposes, the slope of the line, b, for Fountain Creek at Colorado Springs, CO is 0.3859. From section 5.6, the relationship between b and $\hat{b}$ is:

$$\hat{b} = \frac{1}{b} = \frac{1}{0.3859} = 2.59$$

The method to find the sediment rating curve that was done for all gages in this summary is by taking the data in individual intervals (for flow)and determining the average of each of those intervals. The average of the discharge for the intervals was determined and then the average of the sediment discharge for each interval was determined. The intervals were so that they were equal on a log-log plot. The ranges were typically as follows: 1-10, 10-20, 20-40, 40-80, 80-160, 160-320, 320-640, 640-1280, and so on. This data was then plotted on a graph and a line was fitted to it as seen on **Figure 5**. Looking at Figure 5, the best way to fit the data appears to be a power function. The power function for the Monument Creek sediment rating curve is given by $y = 0.00286Q^{1.802}$. The sediment rating curve equations are in **Table 1** as well as several other basin characteristics that will be used in later discussions. The cumulative distribution function of the sediment load as a function of Q/Q_{av} was calculated and plotted in **Figure 6**.

To determine the mean annual discharge (in cfs) and the mean annual sediment load (in short tons per year) the flow-duration/sediment-rating curve method was used. The method is best applied when the period of record is long, sufficient data across all flows that provide a good scatter, and good data at high flows. This method is applied by breaking up the data into percentage of time exceeded intervals. The flow discharge was determined for each interval from the flow duration curve for each of the interval. The sediment discharge was then calculated using the equation determined from the sediment rating curve. The flow discharge is then multiplied by each interval range, Δp, and then summed up for all of the intervals provides the mean annual discharge. **Table 2** is an example table summarizing the techniques as described in Julien (2010) to calculate the mean annual discharge and annual sediment load. **Table 3** summarizes Fountain Creek near Colorado Springs. The same calculations were performed with the sediment discharge provided a mean annual sediment load of approximately 14,500 short tons per year. The intervals used and the values of each of these variables are displayed in the following table.

Tabular Results and Figures:

Table 1. Summary of basin characteristics.

USGS Gage	Gage Name	Drainage Area (miles^2)	$\hat{b}$	Sediment Rating Curve Equation
7103700	Fountain Creek above Colorado Springs	102	2.65	$0.0286*Q^{1.802}$
7103970	Monument Creek at Woodmen	180	2.61	$0.004*Q^{2.4}$
7105500	Fountain Creek at Colorado Springs	392	2.59	$0.037*Q^{1.8464}$
7105800	Fountain Creek at Security	500	2.5	$0.017*Q^{1.8215}$
7106500	Fountain Creek at Pueblo	925	2.5	$0.00399*Q^{2.12175}$

Table 2. Example calculations for determining mean annual discharge and annual sediment load for Fountain Creek near Colorado Springs, CO

Time Interval (%)	Interval midpoint (%)	Interval Δp (%)	Q_{cfs} (ft^3/s)	Q_s (short tons/day)	$Q_{cfs}*\,\Delta p$ (ft^3/s)	Sediment Load $Q_{cfs}*\,\Delta p$ (short tons/year)
0.00-0.02	0.01	0.02	813	38572	0.16	2816
0.02-0.1	0.06	0.08	469	10301	0.38	3008
0.1-0.5	0.3	0.4	263	2570	1.05	3752
0.5-1.5	1	1	144	606	1.44	2210
1.5-5.0	3.25	3.5	71	111	2.49	1417
5-15	10	10	35	20	3.5	742
15-25	20	10	21	6	2.1	218
25-35	30	10	16	3	1.6	113
35-45	40	10	13	2	1.3	69
45-55	50	10	11	1	1.1	46
55-65	60	10	9.8	1	0.98	35
65-75	70	10	8.4	1	0.84	24
75-85	80	10	6.8	0	0.68	15
85-95	90	10	5.1	0	0.51	7
95-100	97.5	5	3.6	0	0.18	2
Total		100			**18**	**14473**

Table 3. Summary of mean annual discharge and annual sediment loads.

USGS Gage	Gage Name	Drainage Area (miles^2)	Mean Annual Flow (cfs)	Sediment Load (short tons/year)
7103700	Fountain Creek above Colorado Springs	102	18.3	14473
7103970	Monument Creek at Woodmen	180	28.2	13486
7105500	Fountain Creek at Colorado Springs	392	101.4	168743
7105800	Fountain Creek at Security	500	120.6	84674
7106500	Fountain Creek at Pueblo	925	153.2	276378

	drainage	DA	mean flow	sed load	SD
	mi2	km2	cfs	tons/yr	tons/km2yr
FC above CS	102	264.1	18.3	14473	49.71112
Monument	180	466	28.2	12486	24.30222
FC at CS	392	1015	101.4	168743	150.8117
Security	500	1294	120.6	84674	59.33013
Pueblo	925	2395	153.2	276378	104.6784

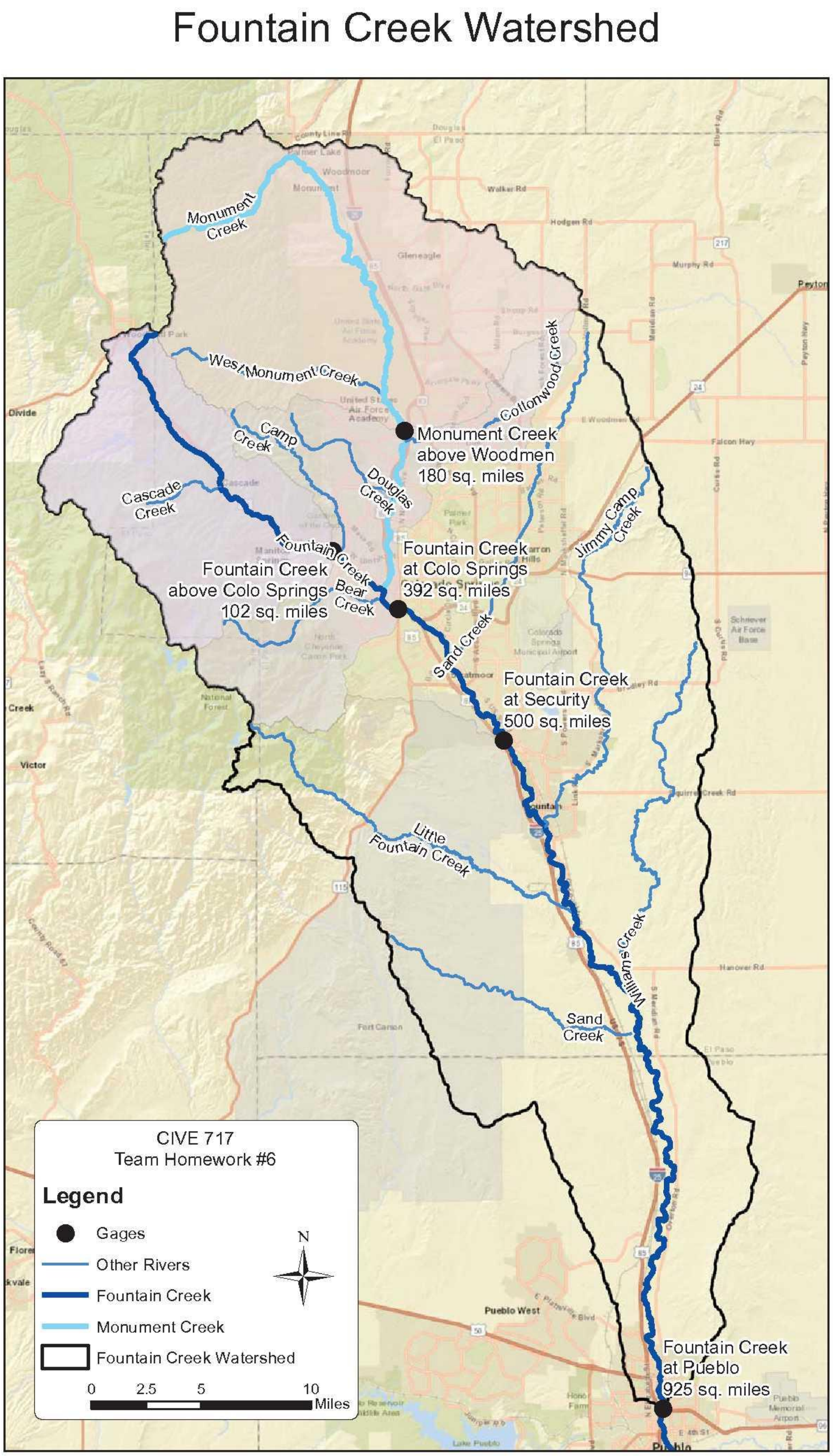

Figure 1. The five Fountain Creek and tributary gages and drainage areas in plan view.

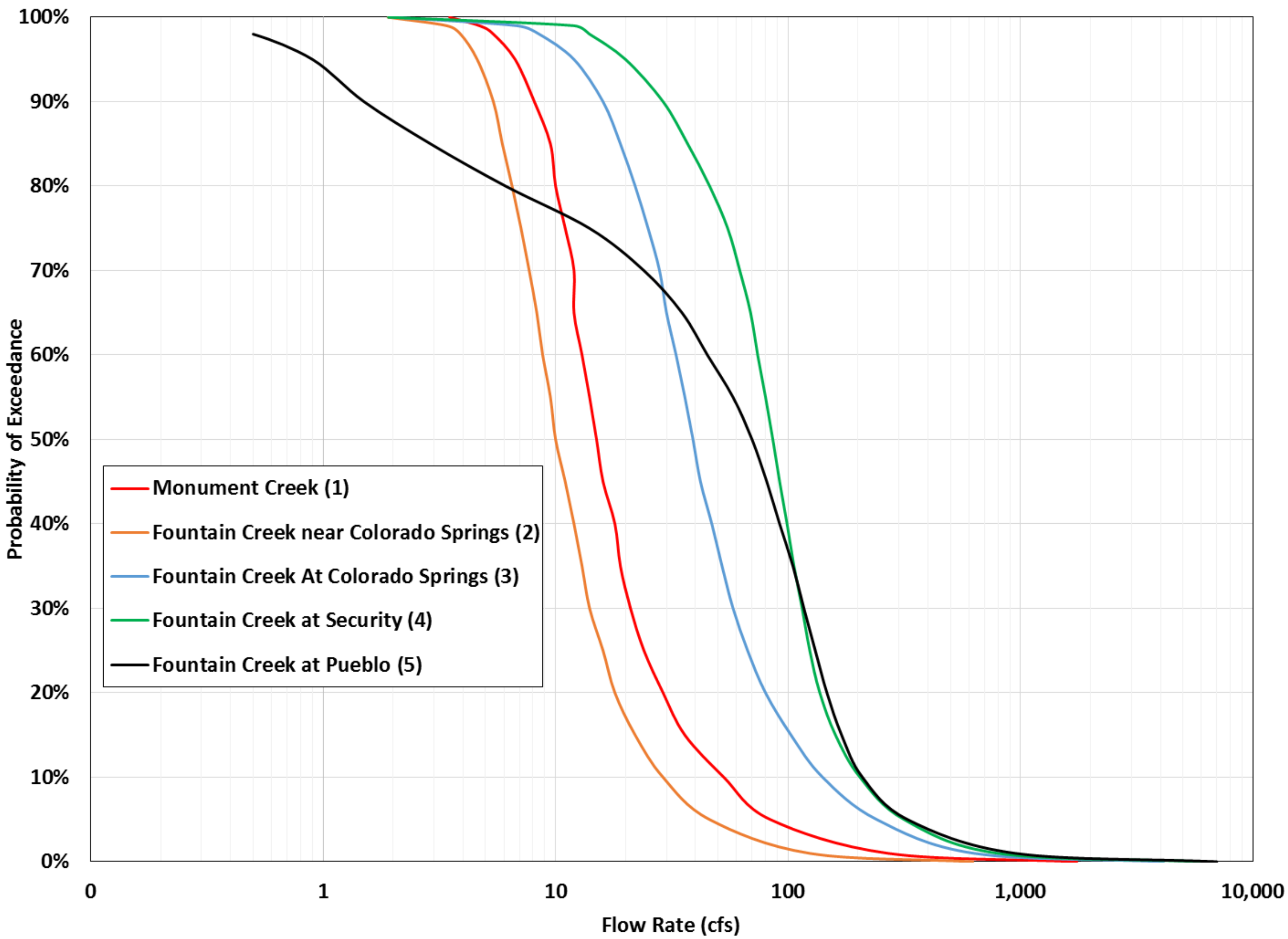

Figure 2. Flow duration curves for all gages.

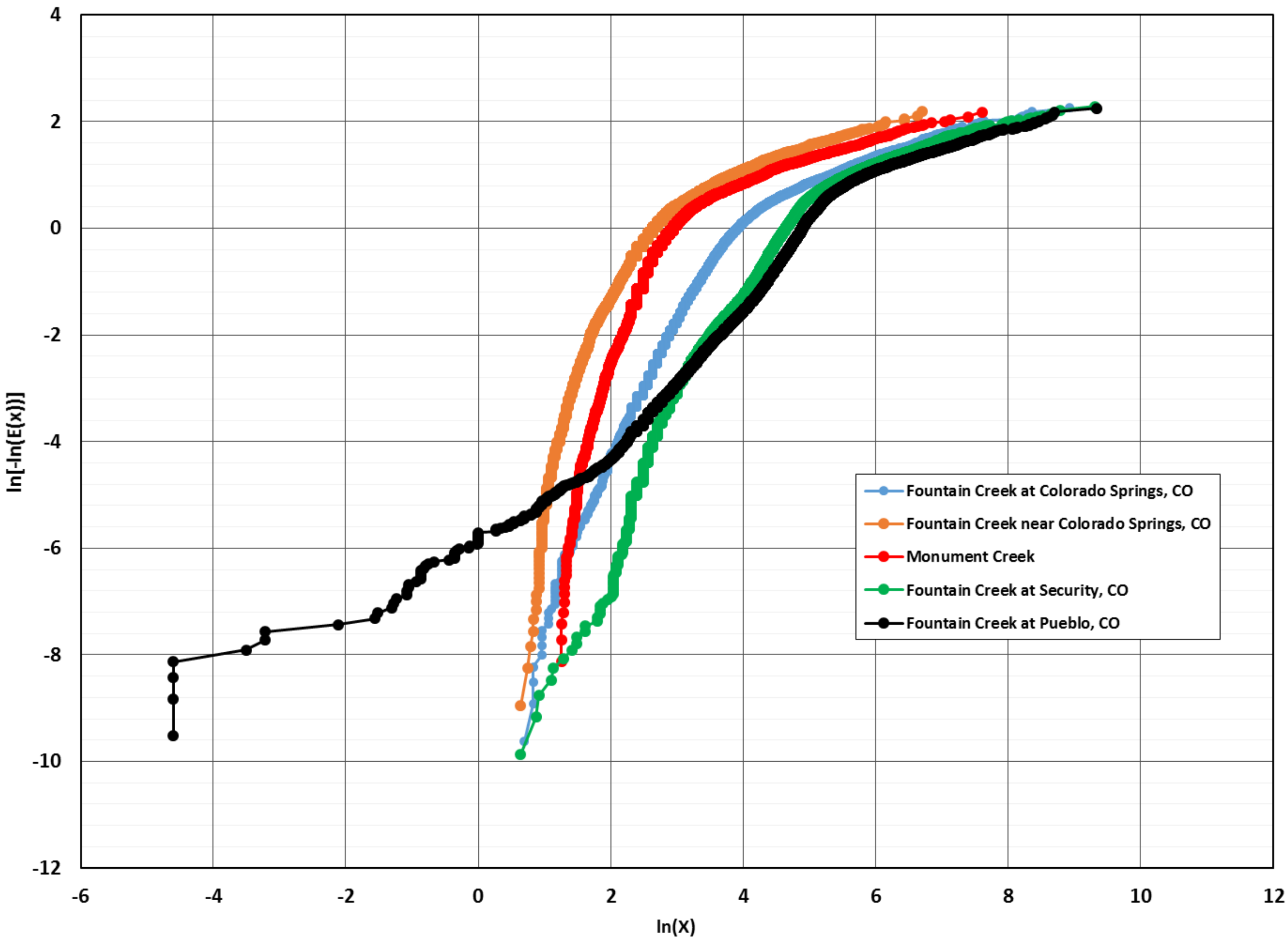

Figure 3. Relationship of ln (x) and ln[-ln(E(x))] plotted to get the slope and intercepts for calculating the $\hat{b}$ parameters.

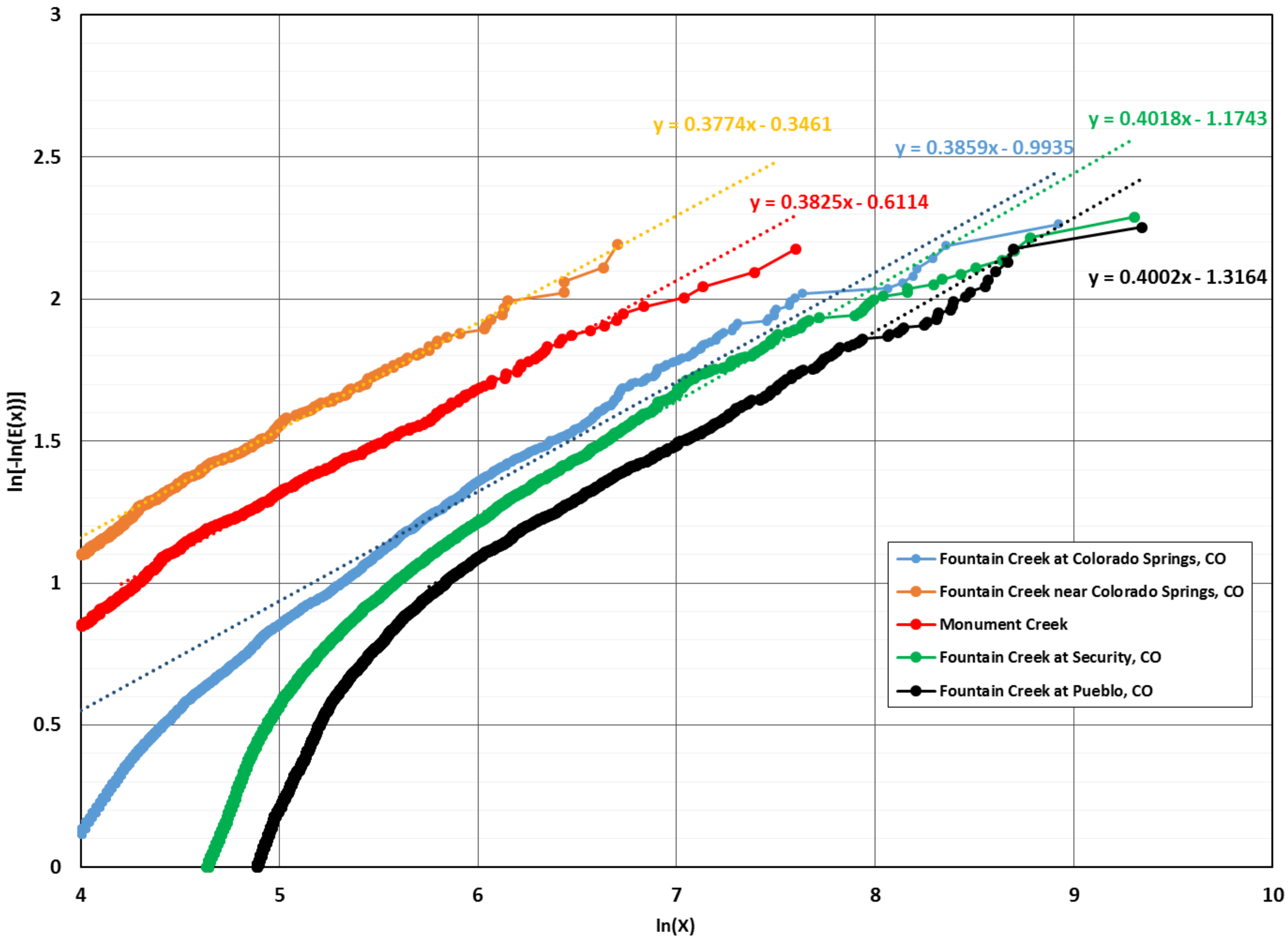

Figure 4. Close up of the best fit line for the ln (x) and ln[-ln(E(x))] of the flow duration curve.

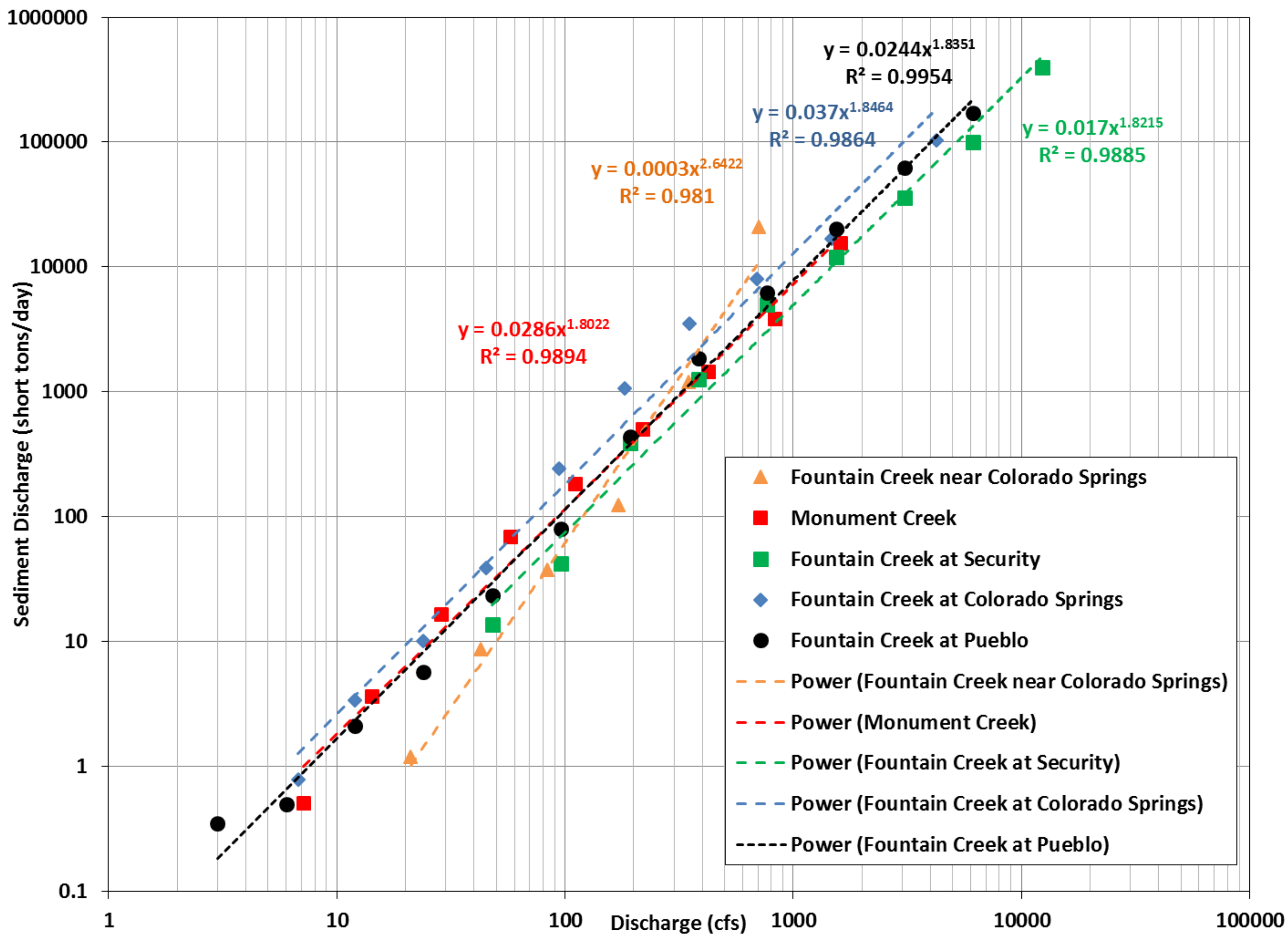

Figure 5. Sediment rating curves for all gages based on the averaged bin method.

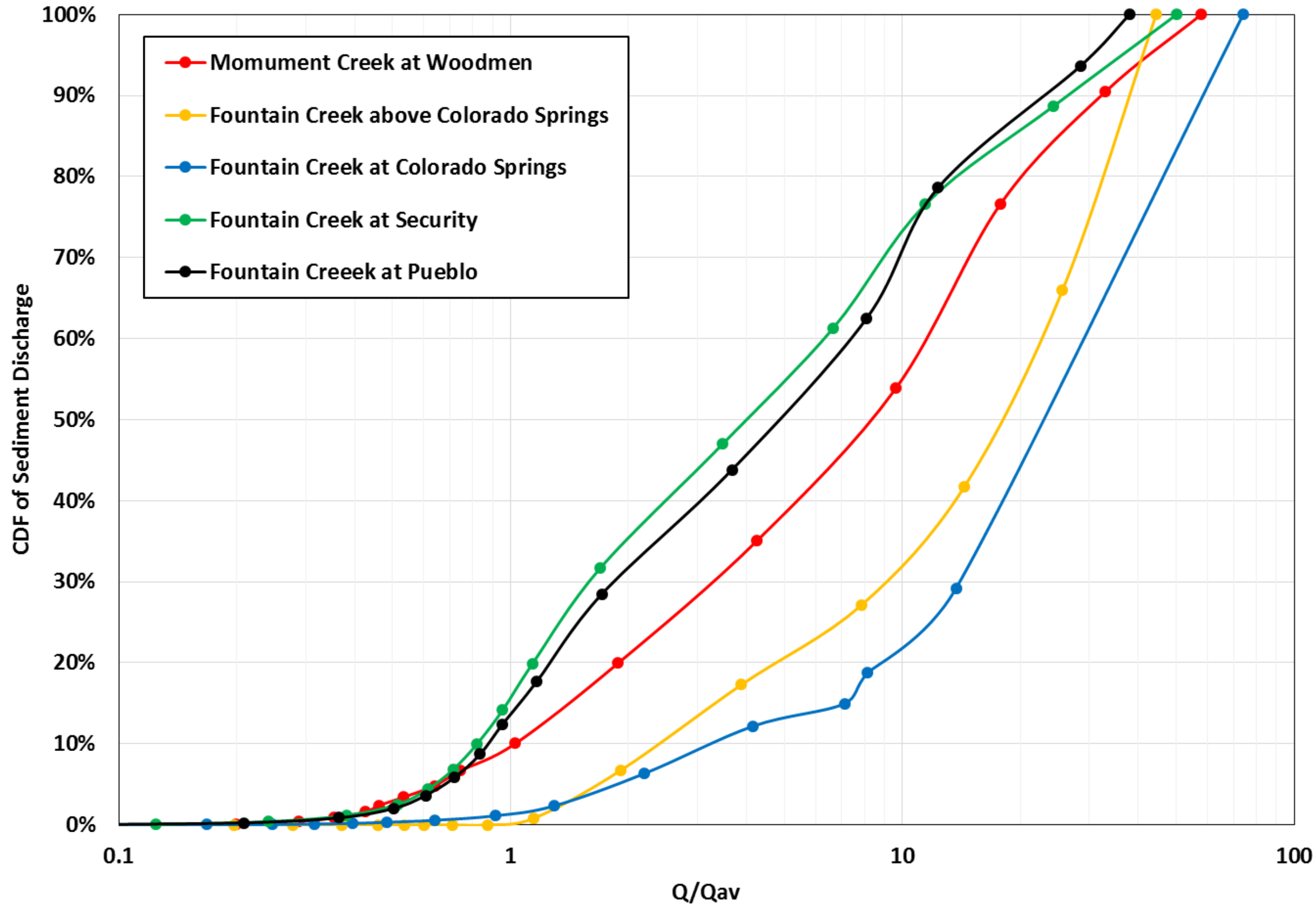

Figure 6. Summary of cumulative distribution function of sediment discharge as a function of Q/Q_{av}.

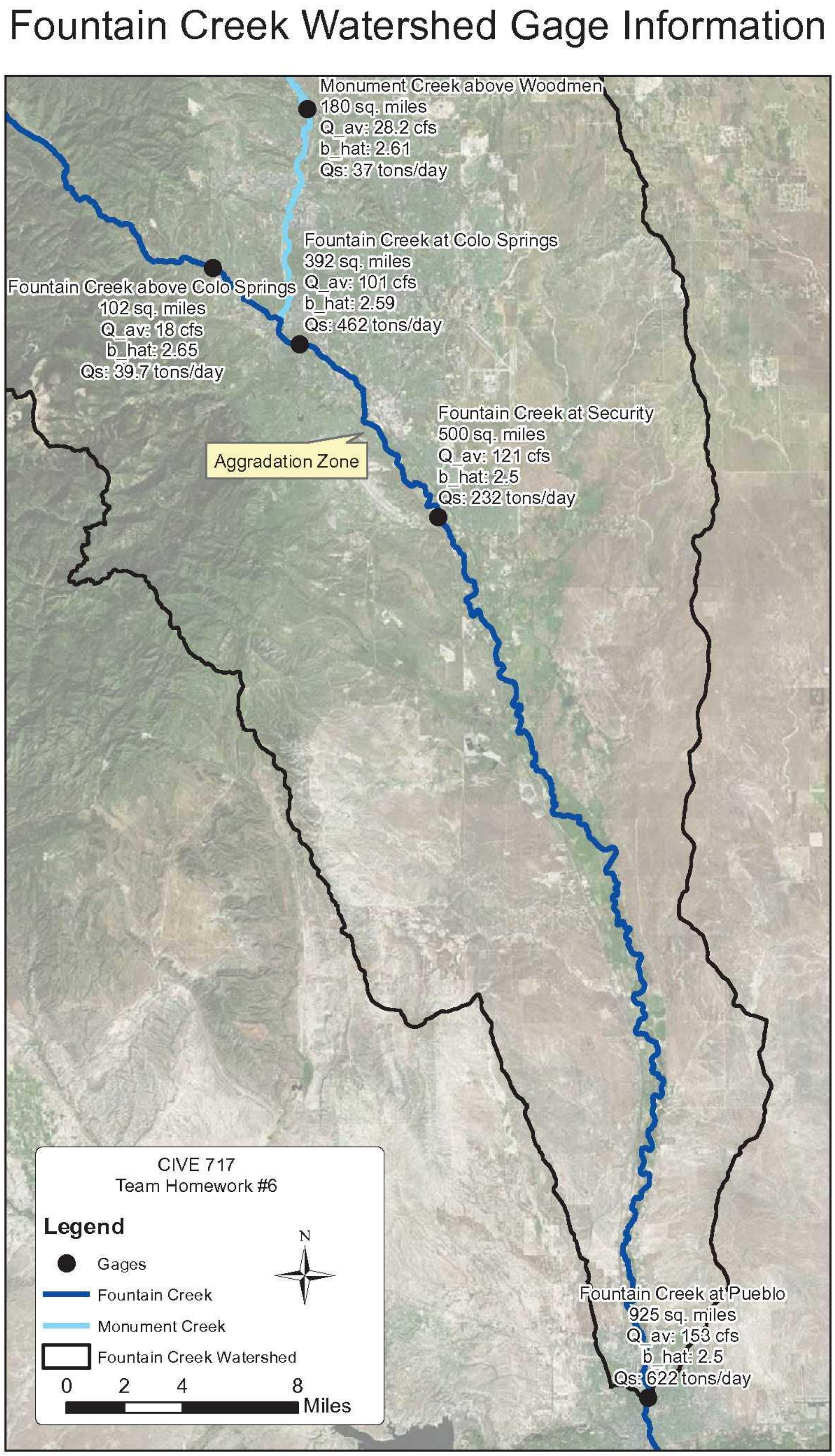

Figure 7. Plan view map of the study area with all five gages with the drainage area, mean annual flow, $\hat{b}$ and annual daily sediment load.

Summary and Conclusions:

When compiling all of the individual analyses for these gages it is interesting to see how the flow duration, sediment rating curves and characteristics that describe the flow and sedimentation change. The following discussions are the summary and conclusion of the group.

The flow duration curves generally shift towards greater discharges as the location progresses downstream. This trend makes sense when one considers the increasing drainage area in the downstream direction. With the exception of Pueblo, all of the locations seem to have similar variations in flow rates. However, Pueblo's flow duration curve exhibits both the lowest flows at the 90 percent and the highest flows at the 10 percent of exceedance. We can only speculate that irrigation practices between Colorado Springs and Pueblo may explain this data.

The $\hat{b}$ parameter can be used to describe the flow duration curve or the sediment duration curve. This is valuable for determining what an expected sediment load may be for any given exceedance probability. The collection of all of the $\hat{b}$ parameters for this study area shows that in general, increasing drainage area produces a smaller $\hat{b}$ (Table 1). Figure 4 shows the lines fit to the higher end of the data and shows that as the drainage area increases the slopes of those lines flatten and thus result in a smaller $\hat{b}$.

The average sediment rate for discharge intervals at each station is shown in Figure 5. The sediment rating curve for all the stations, i.e. sub basins, almost fall on the same line as shown with the regression line for the Fountain Creek at Pueblo gage. However, the rating cure for Fountain Creek above Colorado Springs gage has a steeper slope in comparison with the other station. The mountainous basin of Fountain Creek above Colorado Spring station is probably the reason for this increase in sediment transport rate. The high-peak, low-duration discharges of this mountainous basin probably produce higher sediment discharges.

Looking at the CDF of the sediment discharge for each stream gage, a trend emerges among the various streams. The most upstream reach with the smallest drainage area (Fountain Creek above Colorado Springs) has the curve shifted towards the extreme events. It takes about 18 times the average flow for 50% of the sediment to pass. The terrain for this is largely mountainous and most likely susceptible to flashy storms that cause this large sediment load at extreme events. Looking at the gage on the other watershed (Monument Creek at Woodmen) it takes about 8 times the flow for the 50% of the sediment to pass. This could make sense as this watershed transports more of the flow during less extreme methods possibly due to its more urban character.

Going downstream to the next gage (Fountain Creek at Colorado Springs) where both of the above watersheds meet, this trend appears to diverge a bit and this part of the stream has more sediment transport at the extreme events. It takes about 22 times the average flow for 50% of the sediment to pass. This might possibly be due to additional watersheds that enter this reach not studied that add sediment during extreme events.

Continuing downstream, the trend changes quite dramatically. At the next downstream gage at Security, it takes about four times the mean discharges to pass 50% of the sediment. This is approximately equal to the gage at Pueblo in which it takes about five times the mean discharge to pass 50% of the sediment. This shows consistency between the two gages in the downstream direction in the distribution of how they pass the sediment. These two also pass more of the sediment more frequently based on the average flow than the three gages upstream.

In the upper region of the watershed, Monument Creek at Woodmen (07103700) and Fountain Creek (07103970) produce similar sediment loads of around 14,000 short tons per year (Table 3). However, Monument Creek produced a larger mean annual flow by approximately 10 cubic feet per second. After convergence of the two channels the mean annual flows and sediment load increased greatly. The data show for this study region that with increasing drainage area the mean annual flow increases. This generally is true for the annual sediment load with the exception of the Fountain Creek at Security gage. Some thoughts as to why this may be true is that there is an agricultural diversion that might impede some of the ability of the sediment to be carried downstream and a large aggradation zone (Figure 7). The gage at Pueblo produces the highest sediment loads and keeps with the notion that increasing drainage area produces higher mean annual flows and sediment load.

This case study of several gages along the same river allowed the team to understand the big picture of how hydrology and sediment transport relate to one another and to appreciate the importance of conducting a detailed stream gage analysis as the beginning of any study.

References:

Julien, P.Y. (2010). *Erosion and Sedimentation, 2nd Edition*. United Kingdom: Cambridge University Press.

Julien, P.Y. (2002). *River Mechanics*. United Kingdom: Cambridge University Press.