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Flood-Frequency Analysis Report for Willow Creek

Job Number: Co0103
Short Job Description: Willow Creek
Location: In and near Creede; Mineral County, Colorado

Description of Job:

A number of discharge-frequency estimates have been computed at the Willow Creek at Creede, Colorado USGS gaging station. These estimates have a wide range, with 100-yr discharges ranging from 1120 to 2300 cfs. The Natural Resources Conservation Service, in cooperation with the Colorado Water Conservation Board, performed an additional discharge-frequency analysis for the Willow Creek watershed to reduce the uncertainty of these estimates.

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Summary

The US Geological Survey (USGS) operated a streamgage on Willow Creek at Creede, Colorado from 1951 through 1982. This streamgage recorded annual flood peaks ranging from 66 cfs to 430 cfs. Due to the reported occurrence of a number of high flow events before the installation of this gage, it is generally believed that a frequency analysis based upon only these 32 years of record will lead to significantly underestimated discharge frequencies.

Six large events reportedly occurred prior to the gage installation for the 1951 water year (see Table 2). Estimates of the peak discharge during each of these events, computed by the US Army Corps of Engineers (COE), ranged from 1200 to 1800 cfs. The reliability of these estimates can't be determined since the computations supporting these values have not been found.

Using the gage data as well as the additional historic data for flood events that occurred before the gage installation, a few sets of discharge-frequency estimates have been computed by the Colorado Water Conservation Board (CWCB) and the COE for the Willow Creek watershed at Creede. These estimates have a wide range, with 100-year discharges ranging from 1120 cfs to 2300 cfs. The uncertainty that is apparent from these diverse estimates encouraged the Natural Resources Conservation Service (NRCS), in cooperation of the CWCB, to perform an additional hydrologic analysis.

A regional discharge-frequency analysis was performed. This regional method provided results that were consistent within the watershed and agreed at the gaging station with the results from the CWCB's study, as well as an additional frequency analysis. The recommended values that resulted from this study (at a number of Willow Creek catchments) are provided in Table 1 and Figure 1. Figure 2 provides a plot of the Willow Creek watershed, with the points of discharge-frequency computation. A detailed discussion of the methodology is also provided.

Table 1: Recommended discharge-frequency values at various points within the Willow Creek watershed.

ID	Description	Discharge Frequencies						
		100-yr (cfs)	50-yr (cfs)	25-yr (cfs)	10-yr (cfs)	5-yr (cfs)	2-yr (cfs)	1.25-yr (cfs)
6480	Willow Crk at confluence with Rio Grande	1213	1046	888	689	546	353	232
6490	Willow Crk at Railroad Crossing	1131	969	817	627	493	313	203
6500	Willow Crk at Creede gaging station	1073	915	769	586	458	288	185
6520	W Willow Crk at confluence with E Willow Crk	532	457	386	296	232	144	90
6530	W Willow Crk at Nelson Creek (inclusive)	382	325	273	206	159	96	58
6540	E Willow Crk at confluence with W Willow Crk	942	807	681	523	412	264	172
6550	E Willow Crk at road crossing near Phoenix Mine	733	623	522	398	311	196	127

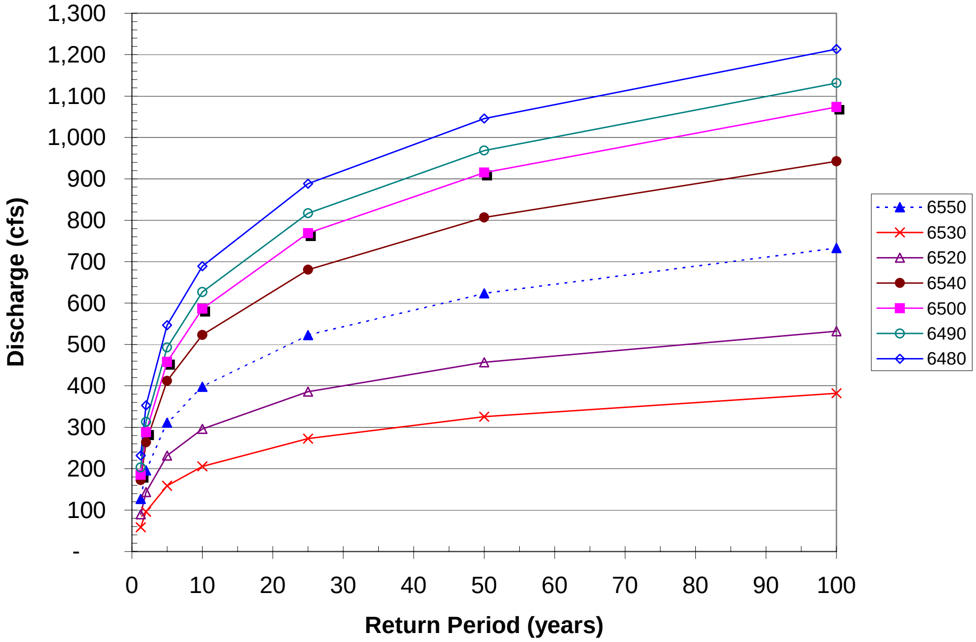

Figure 1: Discharge-Frequency plot for the Willow Creek catchments.

Analysis Method

A brief narrative of the past discharge-frequency studies performed for Willow Creek at Creede, a description of similar watersheds in the region, and a detailed discussion of the regional analysis are provided.

Summary of Past Studies

In 1986 the Flood Control and Floodplain Management Section of the Colorado Water Conservation Board, part of the Department of Natural Resources, issued a report that was intended to help local officials perform planning within floodplain areas. It was prepared by William Mullen, PE. This report discusses high streamflows that occurred at or near the USGS streamgage (08216500), which are provided in Table 2. These discharge estimates are from an older COE study. The supporting computations for these values have not been found. The CWCB hydrologic analysis that was performed on the gage data and these six previous events consisted of separate analyses for the rain (and rain on snow) and snow melt events. The frequency curves that resulted from these two analyses were then statistically combined, using an undisclosed procedure, to form the adopted results (Mullen, 1986). These discharge-frequency values are provided in Table 3.

Table 2: Flood events occurring before USGS gage installation (Mullen, 1986). Estimated peak flows are from a COE study. Supporting computations have not been found.

Year	Estimated Peak Flow (cfs)	Event Type
1911	1800	rain
1921	1400	snow
1927	1400	rain on snow
1941	1400	snow
1948	1200	snow
1949	1300	snow

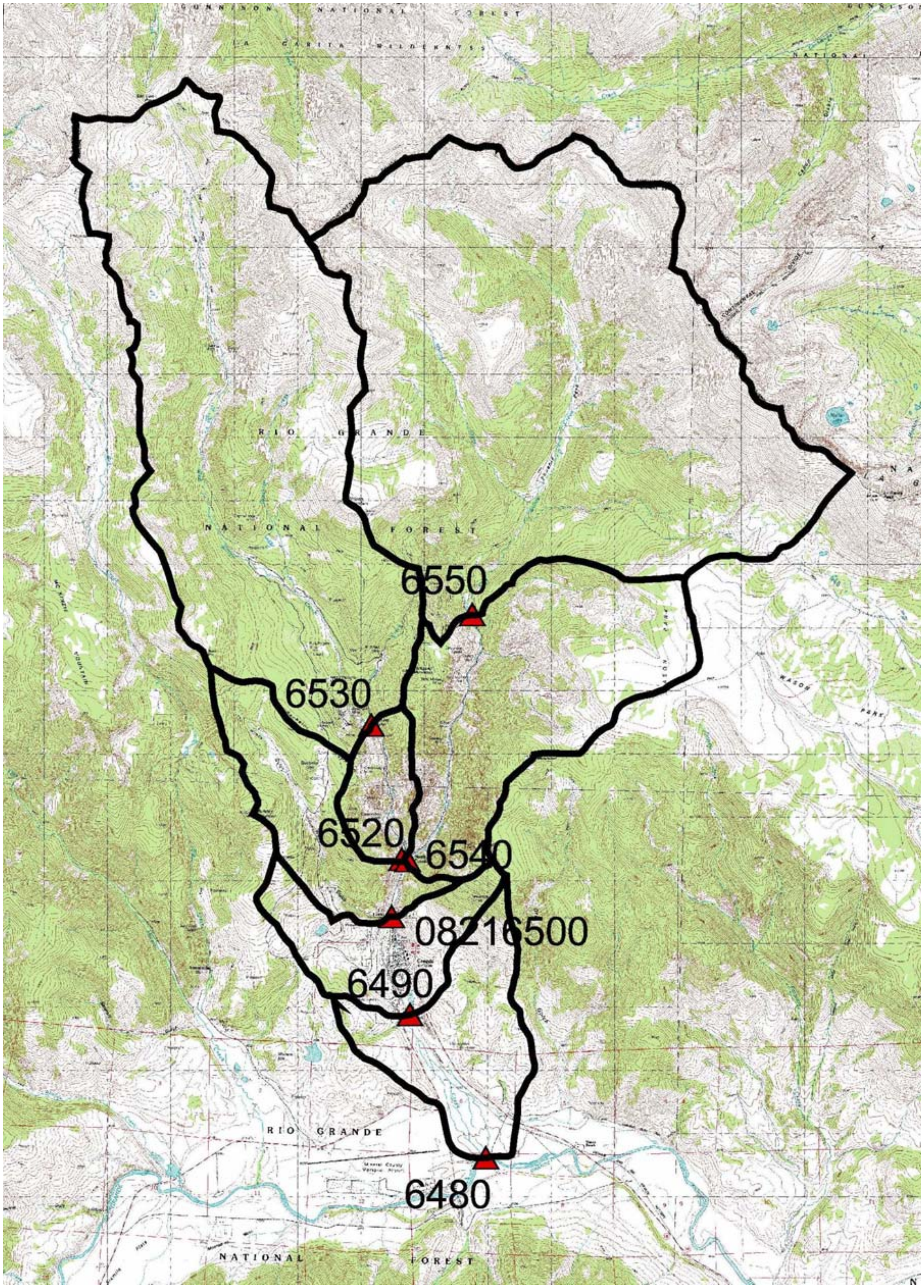

Figure 2: Willow Creek watershed, with catchments and points of discharge-frequency computation (which are indicated with triangles).

The estimated peak flows provided in Table 2 were probably computed using a normal depth procedure within the irregular wooden flume that conveyed Willow Creek though Creede prior to the construction of the masonry flume. Potential errors in these calculations could be from various sources including poorly identified high water marks, misleading high-water marks from the failure of temporary debris dams, inappropriate roughness coefficients, and violation of the normal depth assumption through cross-section and slope variability.

In 1989 the COE, the organization that installed the masonry channel through Creede, performed a "Detailed Project Report and Environmental Assessment" as part of a proposed reconstruction of this lined channel. A hydrologic analysis was performed and is detailed within the COE report. This analysis used the 32 years of gage record plus the four non-rain historic events, in the years 1921, 1941, 1948, and 1949. The rain and rain on snow events of 1911 and 1927 were not used. The method consisted of a Log-Pearson distribution with a regional skew coefficient of zero and the use of regional weighting procedures developed by the COE (COE, 1989). The results of this analysis are included in Table 3.

In 1999 an additional hydrologic analysis was performed by the COE. This analysis used the existing Log-Pearson analysis prepared by the COE in 1989 as a starting point. A mixed population analysis was performed using analytical and graphical techniques described in a separate COE document (EM-1110-2-1415). The results of this mixed population analysis were compared to the results from six sets of USGS regional regression equations. Estimates for the 100-yr event from these generic regional equations ranged from 4241 cfs to 342 cfs. (Both of these extreme values are from one method, specifically USGS 96-4112. The other five sets of discharge-frequency estimates ranged from 667 to 1097 cfs for the 100-year event.) The mixed population results were adopted, since the author found it unlikely that lower discharge-frequency estimates were appropriate with six extreme events (that were assumed to have accurate peak-discharge estimates) occurring in the first half of the 20th century. These results are also presented in Table 3.

Table 3: Previous discharge-frequency estimates at the Creede gaging station, by various agencies. CWCB = Colorado Water Conservation Board, COE = US Army Corp of Engineers. Weighed skew coefficient Log-Pearson analyses, using various combinations of the unsubstantiated historic discharge estimates, are also provided.

Discharge Frequency	Discharge-Frequency Estimates (cfs)						
	CWCB, 1986	COE, 1989	COE, 1999	Gage Data, no est.	Gage Data, + '49 est.	Gage Data, + '49, '48 est.	Gage Data, + all est.
500-yr	1680	2810	----	----	----	----	----
200-yr	----	2000	6,000	----	----	----	----
100-yr	1120	1530	2,300	674	982	1244	2591
50-yr	910	1160	1,500	583	803	988	1914
25-yr	----	867	1,000	494	643	769	1377
10-yr	510	568	600	382	460	527	843
5-yr	----	392	400	300	339	375	542
2-yr	----	203	210	187	193	202	244
1.25-yr	----	111	----	115	113	113	117

It is evident that using various combinations of the historic flow estimates and methodologies leads to substantially higher and more variable discharge-frequency estimates. Since the accuracy of these historic estimates has not been substantiated, and since the period of diligent record keeping (1951-1982) consistently recorded much smaller discharge estimates immediately after the last historic event (1949), the controversy only grows. A regional regression analysis has been performed in an attempt to reduce the uncertainty in discharge-frequency estimates within the Willow Creek watershed.

Regional Watersheds

Seventeen watersheds of appropriate size and within relatively close proximity to the Willow Creek watershed were selected to shed light on this problem. Only watersheds with drainage areas less than 125 square miles were analyzed. The smallest gaged watershed had a drainage area of 23.3 square miles. The period of records varied from 13 to 63 years. Six watersheds were East of the Continental Divide, in the Rio Grande watershed, while the remaining eleven were West of the Divide, in the Gunnison or San Juan River watershed. Gage-to-gage distances from the Willow Creek watershed range from 12.6 miles to 54.8 miles. Figure 3 illustrates these watersheds, Table 4 provides the range of characteristics, and Appendix A provides additional information.

Log-Pearson analyses were performed on all of these watersheds – these discharge-frequency values are shown in Table 5. The mixed population (rain or rain on snow) events that occur in the majority of the watersheds (11 of 17 watersheds have summer events) were not separated in the frequency analyses. The station skew coefficients in the Log-Pearson analyses were weighted by a generalized skew coefficient, as described in *Guidelines for Determining Flood Flow Frequency* (United States Water Resources Council, 1981). Generalized skew was estimated as being +0.11 by computing the arithmetic mean and variance of the skew coefficients for the 18 regional watersheds. The average skew coefficients provided in Plate 1 of *Guidelines for Determining Flood Flow Frequency* indicate that this generalized skew is reasonable.

Table 4: Regional watershed characteristics, range of magnitudes.

Characteristic	Smallest Magnitude	Largest Magnitude
Drainage Area (square miles)	23.3	120.5
Percent Forest	22.4	92.5
Maximum Elevation (feet)	12,449	13,895
Minimum Elevation (feet)	7330	9800
Length/Width Ratio	0.53	2.81
Average Precipitation, Centroid (inches)	21	43
Average Precipitation, Maximum (inches)	31	53
Average Precipitation, Minimum (inches)	11	31
Streamgage Record Length (years)	13	63

Table 5: Discharge-frequency for the regional watersheds.

Streamgage Number	Discharge-Frequency Values (cfs)						
	100-yr	50-yr	25-yr	10-yr	5-yr	2-yr	1.25-yr
8216500	982	803	643	460	339	193	113
8224500	426	354	289	212	160	94	57
8230500	1461	1105	811	504	323	140	61
8231000	806	669	542	390	285	155	83
8220500	890	742	605	441	327	184	103
8218000	1818	1521	1249	924	699	415	249
9347500	2566	2247	1944	1559	1273	876	612
9340000	2671	2352	2043	1644	1344	918	631
9359000	1926	1732	1543	1296	1108	831	636
9343500	771	653	542	407	312	186	112
9344000	1878	1680	1485	1227	1026	729	519
9343000	2304	2036	1779	1450	1202	852	614
8245500	1745	1622	1496	1320	1175	941	754
9145000	2629	2320	2024	1648	1367	971	704
9342000	1182	1013	855	660	520	333	217
9340500	1675	1514	1354	1143	978	732	554
9341500	3329	2977	2632	2177	1825	1309	944
9123500	1744	1601	1456	1259	1101	855	667

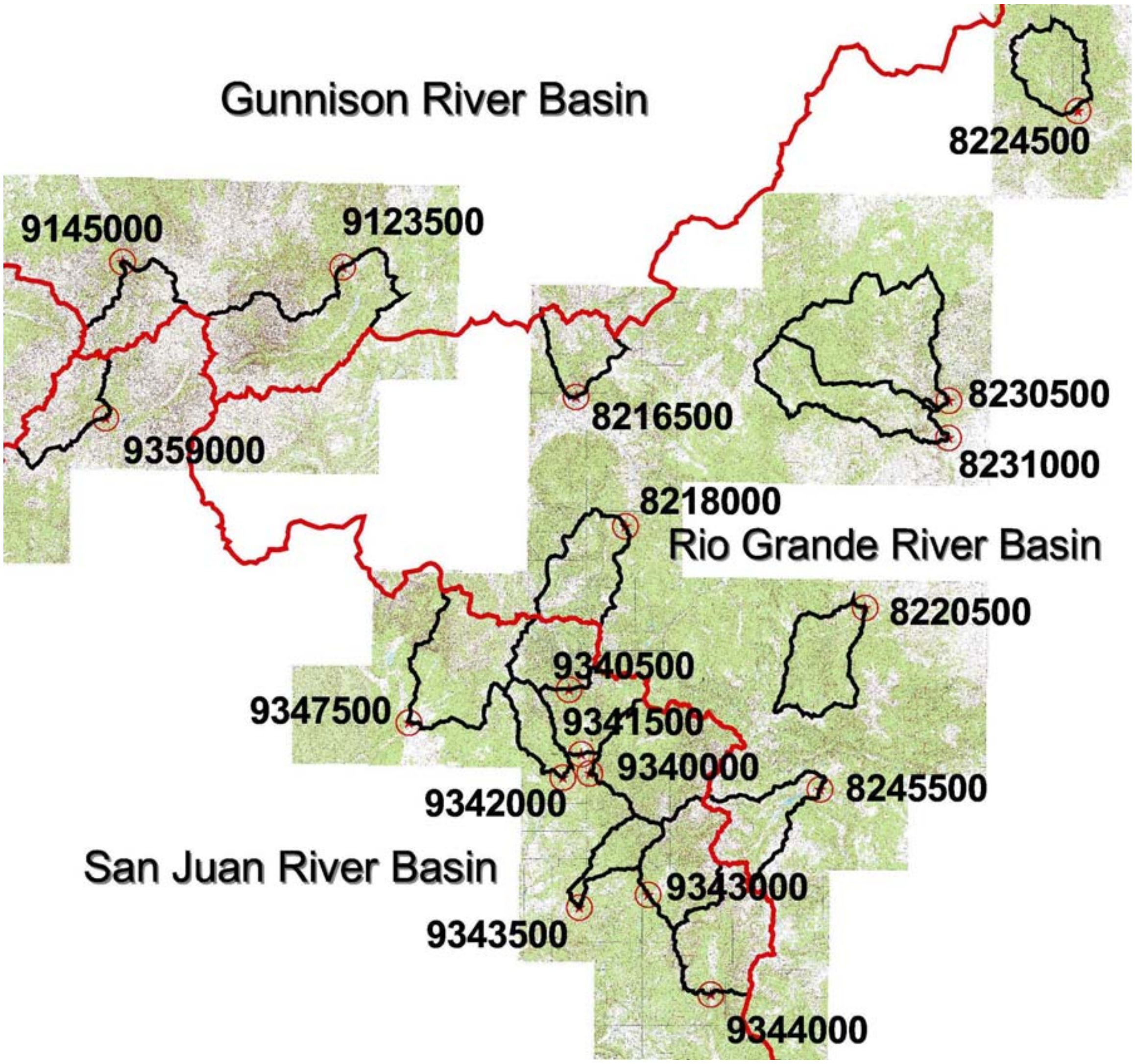

Figure 3: Watersheds used in regional regressions. The circled star symbol represents a USGS gaging station while the number indicates the gage number. The Willow Creek gage number is 8216500.

The four watersheds that have drainage areas closest to Willow Creek's drainage of 36.1 mi^2 (at the gaging station) are 09343500 (23.3 mi^2), 09342000 (24.4 mi^2), 08224500 (41.2mi^2), and 09340500 (41.9 mi^2). These watersheds, with 100-yr discharge estimates of 771, 1182, 426 and 1675 cfs, respectively, can help illuminate the range in reasonable discharge-frequency estimates for the Willow Creek at Creede gage.

Various parameters beyond drainage area are needed to understand what discharge-frequency estimates are reasonable. For example, average precipitation can be useful. For these four watersheds, the higher 100-yr discharge estimates correlate well with higher average precipitation estimates. The average precipitation for Willow Creek (at the watershed centroid) is 29 inches. This compares more with the lower-peaked watersheds (21 and 29 inches) than the higher peaked watersheds (33 and 41 inches).

Interestingly, two other watersheds (09145000, 09359000) analyzed in the San Juan Mountain region are of similar size (42.9 mi^2, 43.4 mi^2) to two of these four watersheds, but have considerably larger 100-year estimates, 2629 and 1926 cfs respectively. These watersheds do have fairly high average precipitation estimates (31 and 33 inches), but not remarkably so. However, these high estimates can be correlated to two other watershed characteristics: percent tree coverage and watershed shape. Lesser tree cover encourages faster and more runoff through lack of interception and storage, as well as less shade and rapid snowpack melting. Watershed shape (a length/width ratio was used in this analysis) relates to peak discharge attenuation and storage. The 09145000 watershed has the least forest cover (22.4 percent) in the region. The 09359000 watershed also has relatively little cover (27.6 percent) and the smallest length/width ratio (0.53) in the region. For comparison, the Willow Creek at Creede watershed has 50.1 percent forest cover and a 1.02 L/W ratio.

The review of these regional gaged watersheds provides insight on what discharge-frequency values are appropriate within the Willow Creek basin, but a more quantitative methodology is required.

Regional Regression Analysis

Initially, a number of watershed characteristics were computed for each of the 18 regional watersheds. Multiple linear regression analyses, with numerous combinations of these explanatory variables and with discharge in both normal and natural logarithm space, were performed using the statistical software S-Plus. Five of the watershed characteristics, with discharge in logarithm space, were found to heavily influence the discharge prediction and result in significant t-values ($\geq |+/-2.0|$) for at least some of the return periods. To insure consistent results, the same variables were used for all return periods. The number of variables were minimized to maximize the degrees of freedom and the predictive power of the models. The five variables are described below:

- Drainage area was measured using XTools after delineation of the watersheds in ArcView GIS. Delineation was accomplished by manually creating polygons over borderless digital raster graphic USGS 7.5-minute quadrangles within a UTM 13 projection.
- Percent forest was computed by measuring the area of forest cover represented on the USGS 7.5-minute quadrangles and dividing this forested area by total area. Recent aerial photography would have been a more accurate base map for computing this value, but the extra effort required to attain this resolution was not deemed necessary.
- The minimum elevation of the watershed was found to be a good explanatory variable. This value was also attained from the USGS 7.5-minute quadrangles, at a resolution of 10 feet.
- A watershed length/width (L/W) ratio was found to be an important explanatory variable in the statistical analyses, especially for less frequent discharge-frequency events. The length is defined by passing a line from or near the stream outlet through the centroid of the watershed and measuring the overall length. The width is measured by summing the maximum distances between the length axis and the sides of the watershed. Hence, a minimum-sized rectangle is essentially drawn around the watershed and the L/W ratio is simply a ratio of the lengths of the sides of this encompassing rectangle.
- Average precipitation was found to be an excellent explanatory variable. Average precipitation estimates were taken from a PRISM plot for Colorado. A description of PRISM, quoted from http://www.ftw.nrcs.usda.gov/prism/prism.html, is provided below. For additional information and to download maps, see this same web site.

PRISM (Parameter-elevation Regressions on Independent Slopes Model) was developed by Dr. Christopher Daly of Oregon State University, and is a hybrid statistical-geographic approach to mapping climate. PRISM uses point measurements of climate data and a digital elevation model (DEM, a digital, gridded version of a topographic map) to generate estimates of annual, monthly and event-based climatic elements. These estimates are derived for a horizontal grid, and are compatible for use on Geographic Information Systems (GIS). PRISM is not a static system of equations; rather, it is a coordinated set of rules, decisions and calculations designed to mimic the decision-making process an expert climatologist would invoke when creating a climate map. PRISM was originally developed in 1991 for precipitation estimation, but more recently has been generalized and successfully applied to other climate elements and derived variables, including temperature, snowfall, degree-days (heat units) and frost dates.

These five variables should not have strong relationships with each other, which should bypass the problems stemming from multi-collinearity. A possible exception are the minimum elevation and average precipitation parameters. But considering the importance of both of these variables to the models, the questionable existence of multi-collinearity, and the lesser impact that multi-collinearity has on a prediction model (Helsel and Hirsch, 1992), it was decided to leave both of these variables in the models.

Two sets of models were developed – one set excludes Willow Creek frequency estimates and another includes it. This was done to independently verify that the method was providing reasonable results within the Willow Creek watershed.

A set of models were first developed without Willow Creek discharge-frequency estimates (model set 1). These model runs indicated the five relevant explanatory parameters and provided equations that were then applied to the Willow Creek at Creede watershed. Results from this application estimated flows to be 1097, 948, 803, 625, 497, 323, and 212 cfs for the 100-yr through 1.25-yr return periods at the Creede gaging station. These estimates match relatively closely with the CWCB's estimates (see Table 3) but are substantially lower than the COE predictions.

This regional analysis indicates three possibilities: that some or all of the six historic discharge estimates are not accurate; that one or more of the methods using these estimates is not appropriate; or that the Willow Creek watershed is atypical in comparison to 17 other San Juan mountain watersheds. Given that the Willow Creek basin has characteristics that fall within the range of it's neighboring watersheds, and also given that it is spatially located within this group of similar watersheds, the first two scenarios are considered more likely.

As shown in Table 3, including a variety of combinations of the six unverified discharge estimates to a standard Log-Pearson analysis considerably changes the discharge frequency estimates for Willow Creek. The inclusion of only the 1949 event, which occurred during the construction of the masonry flume by the COE, is deemed the most justifiable since it is more likely that high water marks were correctly located and discharge estimates accurately calculated with the construction crew being on site and the design crew being currently (or recently) involved. With the inclusion of this single historic data point, a Log-Pearson analysis (with a weighted skew coefficient) provides discharge frequency values that were similar to the CWCB's estimates of 1986 and the regional estimates from model set 1.

The results from this Willow Creek Log-Pearson analysis were added to the data from the 17 regional watersheds and a multiple-linear regression analysis was performed to attain the predicting equations (model set 2) that were applied to the catchments of interest within the Willow Creek basin. The resulting predictions are provided in Table 1 in the summary section of this report. The characteristics provided in Table 6 were used in the computations.

Table 6: Catchment characteristics. L/W Ratio = length/width ratio of watershed. Ave. precip. = average precipitation at centroid of watershed.

ID	Description	Drainage Area (mi^2)	Percent Forested	Max. Elev. (ft)	Min. Elev. (ft)	L/W Ratio	Ave. Precip. (in)
6480	Willow Crk at confluence with Rio Grande	40.3	46.4	13,895	8570	1.47	29
6490	Willow Crk at Railroad Crossing	37.9	48.5	13,895	8750	1.18	29
6500	Willow Crk at Creede gaging station	36.1	49.9	13,895	8860	1.03	29
6520	W Willow Crk at confluence with E Willow Crk	13.2	56.8	13,285	8940	2.89	29
6530	W Willow Crk at Nelson Creek (inclusive)	12.3	56.9	13,285	9800	2.56	31
6540	E Willow Crk at confluence with W Willow Crk	20.7	42.9	13,895	8940	1.27	29
6550	E Willow Crk at road crossing near Phoenix Mine	15.7	39.5	13,895	9670	0.88	29

It is important to notice, when inspecting Table 6 and comparing these characteristics to the range in regional watershed characteristics provided in Table 4, which characteristics and Willow Creek catchments fall within the range of the analyzed watersheds and which do not. Characteristics falling outside of the analysis range are extrapolations from the data used in the statistical analysis and may provide estimates that are known with less confidence. Four of the catchments, and two of the parameters, involve extrapolation. The upper East and West Willow Creek catchments have drainage areas less than the minimum drainage area used in the regional analysis (23.3 mi^2). The greater the extrapolation (or lesser drainage), the larger the error that may exist in these estimates. Additionally, the lower West Willow Creek site has a L/W ratio (2.89) greater than the maximum used in the regional analysis (2.81). This will also contribute to the estimates for this catchment being known with less certainty, but since this catchment is only slightly out of range, it is expected that this contribution to estimate uncertainty will be minimal.

Table 7 provides a few regression diagnostics that are helpful in determining the importance of individual variables and the relative quality of each model.

The t-value statistic is useful in determining if an explanatory variable is significantly linearly related to a dependant variable. With an α of 0.05 (a 95% confidence interval), variables with t-values less than -2 or greater than +2 are considered statistically significant. The L/W ratio has the lowest (absolute) t-values in the models, ranging from 2.9 for the 100-year to 0.7 for the 1.25-year. These t-values indicate that the L/W ratio linearly explains the logarithm of discharge much better for less frequent events. This is not unexpected - the storage and attenuation that the L/W ratio is accounting for is less important for more frequent events.

The R^2 statistic, or the fraction of the variance described by the explanatory variables, is useful in understanding the relative quality of the individual models. The higher the R^2, the greater the explanatory power of the model. However, R^2 is not a good tool for deciding to include additional variables since any explanatory variable (even random numbers) will increase R^2. The loss of a degree of freedom is not worth a small increase in R^2 (Helsel and Hirsch, 1992). However, the relative R^2s do indicate that the five selected variables better explain the variance for the 100-year through 5-year models than the 2-year and 1.25-year models. In general, the typically high R^2 indicate that these five explanatory variables explain most of the variance in the logarithm of the discharge for these 18 watersheds.

S-Plus provides an overall F-statistic. This test indicates how good a complex model is in comparison to no model at all. Like the R^2 parameter, this value is not very useful in determining the value in adding individual explanatory variables, but it is useful in judging how well a model is performing overall. This value indicates that the 50-year and 25-year events are best fitted, that the 100-year and 10-year are reasonably well fitted, and that the 2-year and 1.25-year are predicted the least well. This pattern can also be seen in Table 8, which provides ("actual" – predicted) percent differences.

The five explanatory variables were not selected using a rigorous statistical method, such as a stepwise procedure, but were instead selected as follows. A watershed characteristic was considered a good explanatory variables if it, through hydrologic experience, had been found to be effective in regional analyses, if they had high t-ratios for at least some of the return periods, and if their inclusion provided a large increase in R^2 and provided a relatively large F-statistic. The number of variables were minimized to maximize the degrees of freedom of the models and increase their predictive powers.

Table 7: Model diagnostics for model set 2, which includes Willow Creek at Creede. The range in t-values are absolute values and exclude the intercept term.

Diagnostic	100-yr	50-yr	25-yr	10-yr	5-yr	2-yr	1.25-yr
Range in t-values	2.9 to 8.9	2.8 to 10.0	2.5 to 10.3	1.9 to 9.6	1.4 to 8.6	0.9 to 7.1	0.7 to 6.2
Multiple R^2	0.95	0.95	0.95	0.94	0.93	0.89	0.86
F-statistic	42.2	49.7	49.9	40.1	30.4	19.6	14.4

The percent differences between the Log-Pearson analyses for each regional watershed and the discharge frequency predicted by model set 2 are shown in Table 8. Inspection of this table indicates that the 100-year predicting equation underestimates more than overestimates discharges, but the differences are usually within the accuracy of stream gaging. Importantly, the largest differences are more commonly overestimates. Overall for the 18 watersheds, the 100-year average absolute difference is 10.6 percent.

This table also confirms the regression diagnostics indication that the discharge-frequency predictions for less frequent events are better predictions. The 100-year through 25-year models provide results that are, on average, within 11 percent of the Log-Pearson analyses. For more frequent events, the average difference rises from 12.8 percent for the 10-year events to a maximum of 27.7 percent for the 1.25-year events.

Table 8: Percent differences ("actual" - predicted) between Log-Pearson analyses for each of the regional watersheds and values predicted by model set 2, including Willow Creek at Creede. The statistics were performed upon absolute values of the percent differences.

Site Number	Percent Difference						
	100-yr (cfs)	50-yr (cfs)	25-yr (cfs)	10-yr (cfs)	5-yr (cfs)	2-yr (cfs)	1.25-yr (cfs)
8216500	-8.8	-12.9	-17.6	-23.8	-29.6	-39.2	-47.9
8224500	-9.5	-5.3	-0.6	7.8	15.7	31.9	48.0
8230500	10.8	2.6	-6.4	-19.4	-31.4	-53.0	-73.1
8231000	6.1	5.2	3.9	2.3	0.4	-3.5	-9.1
8220500	5.5	5.5	5.3	5.6	5.1	4.0	1.1
8218000	1.7	-6.0	-14.4	-26.3	-37.5	-56.7	-74.5
9347500	-8.5	-9.7	-10.9	-11.7	-12.4	-12.6	-12.2
9340000	8.6	10.0	11.5	14.7	17.5	23.5	29.1
9359000	16.3	18.1	20.1	23.4	26.3	31.7	36.6
9343500	-7.7	-6.6	-5.5	-2.9	-1.1	3.1	6.4
9344000	-15.4	-13.2	-10.9	-7.1	-4.0	1.5	5.7
9343000	13.7	14.2	14.9	16.8	18.4	22.9	27.6
8245500	7.9	8.7	9.6	11.2	12.4	14.7	16.3
9145000	1.1	-0.4	-1.9	-4.0	-6.1	-9.8	-13.5
9342000	10.5	9.5	8.5	8.0	7.4	8.3	9.8
9340500	-25.8	-24.9	-23.8	-21.7	-20.1	-16.6	-13.9
9341500	14.5	16.3	18.2	22.0	25.2	31.5	37.1
9123500	-17.6	-13.9	-9.6	-2.0	5.4	20.5	36.1
Absolute Ave:	10.6	10.2	10.8	12.8	15.3	21.4	27.7
Absolute Median:	9.1	9.6	10.3	11.5	14.1	18.5	21.9
Absolute Std. Dev.:	6.0	6.0	6.4	8.3	11.2	16.6	22.2

Conclusions

The US Geological Survey operated a streamgage on Willow Creek at Creede from 1951 through 1982. This streamgage recorded annual flood peaks ranging from 66 cfs to 430 cfs. Six large events reportedly occurred prior to the gage installation. Estimates of these historic peak discharges, believed to have been computed prior to 1950, ranged from 1200 to 1800 cfs. The reliability of these estimates can't be determined since the computations supporting these values have not been found.

Using the gage data as well as the additional historic data for flood events that occurred before the gage installation, discharge-frequency estimates have been computed by the Colorado Water Conservation Board and the US Army Corps of Engineers. These estimates have a wide range, resulting in uncertainty in what the "true" discharge-frequency relationship is.

A regional discharge-frequency analysis was performed. This regional method provided results that were consistent within the watershed and agreed at the gaging station with the results from the CWCB's study as well as an additional frequency analysis.

This method provides discharge-frequency values that are felt to be the most scientifically defensible. However, the risk to life and property from underestimation of discharge-frequency estimates within the town of Creede is significant. Due to the variable nature of the estimates (from numerous agencies), it may be prudent to use an additional factor of safety in the engineering design of projects that would impact or be susceptible to water surface elevations within Creede.

References

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Appendix A: Additional regional watershed characteristics.

Streamgage Number	Description	Drainage Area (mi^2)	100-yr Discharge (cfs)	100-yr Unit Discharge (cfs/mi^2)
8216500	WILLOW CREEK AT CREEDE, CO.	36.1	982	27.2
8224500	KERBER C AT ASHLEY RANCH, NR VILLA GROVE, CO.	41.2	426	10.3
8230500	CARNERO CREEK NEAR LA GARITA, CO.	106.1	1461	13.8
8231000	LA GARITA CREEK NEAR LA GARITA, CO.	62.4	806	12.9
8220500	PINOS CREEK NEAR DEL NORTE, CO.	52.7	890	16.9
8218000	GOOSE CREEK NEAR WAGONWHEEL GAP, CO.	53.8	1818	33.8
9347500	PIEDRA R AT BRIDGE RNGR STA, NR PAGOSA SPGS, CO.	81.0	2566	31.7
9340000	EAST FORK SAN JUAN RIVER NR PAGOSA SPRINGS, CO.	90.9	2671	29.4
9359000	MINERAL CREEK NEAR SILVERTON, CO.	43.4	1926	44.4
9343500	RITO BLANCO NEAR PAGOSA SPRINGS, CO.	23.3	771	33.1
9344000	NAVAJO R AT BANDED PEAK RANCH, NEAR CHROMO, CO.	69.0	1878	27.2
9343000	RIO BLANCO NEAR PAGOSA SPRINGS, CO.	57.9	2304	39.8
8245500	CONEJOS RIVER AT PLATORO, CO.	46.0	1745	37.9
9145000	UNCOMPAHGRE RIVER AT OURAY, CO.	42.9	2629	61.3
9342000	TURKEY CREEK NEAR PAGOSA SPRINGS, CO.	24.4	1182	48.5
9340500	WF SAN JUAN R AB BORNS LAKE,NR PAGOSA SPGS, CO.	41.9	1675	40.0
9341500	WEST FORK SAN JUAN RIVER NR PAGOSA SPRINGS, CO.	85.2	3329	39.1
9123500	LAKE FORK AT LAKE CITY, CO.	120.5	1744	14.5