



**US Army Corps  
of Engineers** ®  
Omaha District

**FINAL REPORT**

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## **GI Feasibility Study CACHE LA POUVRE RIVER AT GREELEY, COLORADO**



**Engineering Division  
Hydrologic Engineering Branch**

**February 2008**

## Cache la Poudre River at Greeley, Co GI Feasibility Study

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## **INTRODUCTION**

### ***Study Purpose***

The purpose of this study is to develop the hydrologic data necessary to evaluate the water related problems on the Cache la Poudre River in and around Greeley, Co. The results of the hydrologic analysis will serve as the foundational basis for understanding the Cache la Poudre River system through Greeley and for making decision on flood reduction and environmental restoration alternatives. This study was initiated as part of the General Investigation Report/Environmental Impact Statement (GR/EIS) for the Cache la Poudre River through Greeley.

### ***Study Scope***

A scope of work was developed for the hydrologic analysis of the Cache la Poudre River at Greeley and consists of three phases of study of which this is Phase I. Numerous objectives were established for Phase I which examined and addressed, 1) updating the flow probability relationships for the Cache la Poudre River through Greeley, 2) identifying historical trends between surface flow and precipitation, and 3) develop low flow volume probability relationships.

### ***Study Area***

The study area is located in Weld County, Colorado in the north central portion of the state and encompasses the area in and around the city of Greeley. The study area extends along a 17 mile reach of the Cache la Poudre River, from its confluence with the South Platte River near Greeley upstream into rural Weld County. A map of the area is shown on Figure 1.

### ***Basin Description***

The Cache la Poudre River is a left bank tributary of the South Platte River with its headwaters located in the Rocky Mountains near Rocky Mountain National Park approximately 45 miles upstream from Greeley. The Cache la Poudre basin originates along the eastern slope of the Continental Divide and flows in a generally northerly direction and then east towards it confluence with the North Fork of the Cache la Poudre River. From here, the river travels about 4 miles to the bluff line and then in a southeasterly direction to its confluence with the South Platte River near Greeley, Co. The flow of the Cache la Poudre is affected by trans-mountain (which import water to the basin from the western slopes of the Rocky Mountains) and trans-basin diversions, storage reservoirs, power developments, diversions for irrigation and municipal use, and return flow from irrigated areas.

The drainage area of the Cache la Poudre encompasses an area of 1,890 square miles. The topography of the basin varies greatly; ranging from mountainous terrain with peak elevations around 13,600 feet above mean sea level (ft msl) on the

Continental Divide to rolling foothills and high plains with elevations near 4,600 ft msl at the mouth.

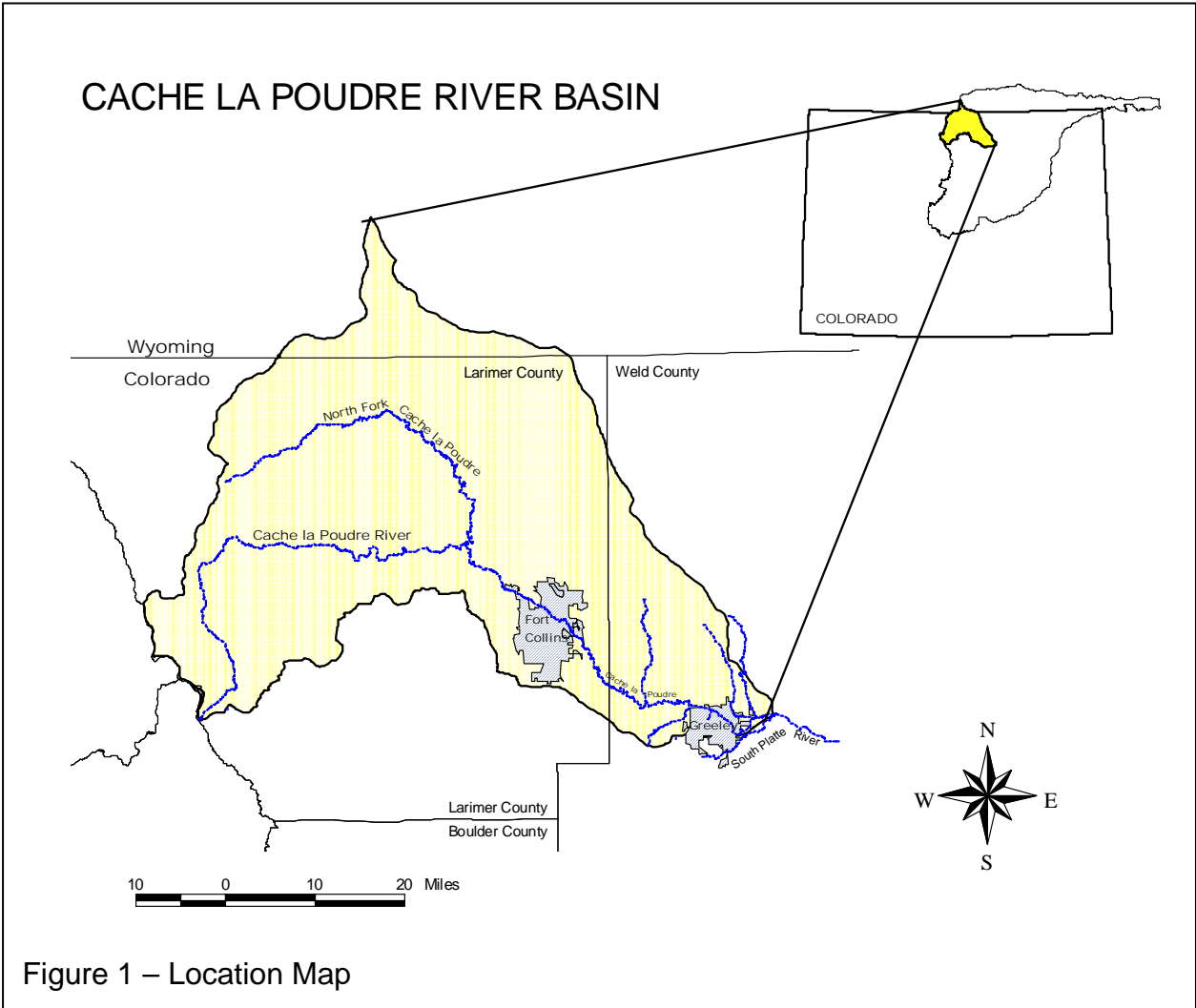


Figure 1 – Location Map

**DATA ACQUISITION**

For this study, considerable historical and geospatial data were required to conduct the analyses. Before the analyses began, all relevant sources of data were explored. The types of data that needed to be collected for this study included streamflow data, meteorological data, and topographic data.

***Hydrologic Data***

Discharge information was required for hydrologic model development, calibration, and verification, and for performing statistical analyses. The hydrologic data were obtained from the USGS Water Resources computer database. Data on

the USGS streamflow gages, their locations, gage identification numbers, periods of record, and other pertinent information are shown in Table 1.

**Table 1**  
**Cache la Poudre Basin Gaging Station Data**

<b>Stream and Location</b>	<b>Station ID</b>	<b>Gage Type</b>	<b>Contributing Drainage Area (sq mi)</b>	<b>Period of Record</b>
Cache la Poudre at Mouth of Canyon, nr Fort Collins, CO	06752000	Flow	1,056	1883-2004
Cache la Poudre nr Greeley, CO	06713500	Flow	1,877	1914-1919 1924-2005

### ***Meteorological Data***

Meteorological records were needed for modeling and trends analysis. Precipitation data were obtained from the National Oceanic and Atmospheric Administration (NOAA) Climatological Data for nearby gages and are listed in Table 2.

**Table 2**  
**Climatological Data Station Data**

<b>Gage and Location</b>	<b>NOAA Index Number</b>	<b>County</b>	<b>Gage Type</b>	<b>Period of Record</b>
Greeley	3546			1915-67
Greeley UNC	3553	Weld	Precipitation	1968-04
Fort Collins	8932	Larimer	Precipitation	1948-02

### ***Other Data.***

Other sources of relevant data were also used for this study. Corps of Engineers reports included, Hydrologic Analysis of the Cache la Poudre River Basin, Engineering Technical Report, (COE, 1988).

## **HYDROLOGICAL ANALYSIS**

The hydrologic analysis will be used to evaluate the water related problems on the Cache la Poudre River in and around Greeley, Co. The results of the hydrologic analysis will serve as the foundational basis for understanding the Cache la Poudre River system through Greeley and for making decision on flood reduction and environmental restoration alternatives. Major tasks involved for the hydrologic analysis include: 1) updating the flow probability relationships for the Cache la

Poudre River through Greeley, 2) identifying historical trends between surface flow and precipitation, and 3) develop low flow volume probability relationships.

### ***Discharge Probabilities***

The computed discharge probability relationships developed for the 1988 study were reviewed and updated for use in the HEC-RAS model that will be developed by the Hydraulics Section. The methodology used in the original study was used for this analysis and included the additional annual peak discharges from 1986 through 2005.

In the original analysis, discharge probabilities were developed for the USGS gage sites located on the Cache la Poudre at the bluff line and 3 miles upstream from the mouth near Greeley utilizing the methodology based on Bulletin 17B (WRC,1981) and the log Pearson Type III distribution. The procedure used to estimate the discharge frequency relationships at intermediate locations along the main stem of the Cache la Poudre was based on the routing of the hypothetical 100-year flood from the bluff line to the Greeley gage using a calibrated HEC-1 rainfall/runoff model. The standard deviation at intermediate locations was interpolated from the statistics at the two gages based on river miles along the main stem. A skew coefficient of the 1.0 was used with the interpolated standard deviation and the routed 100-year discharge to calculate the mean flood logarithm at each location.

For the update, discharge probabilities were updated for the bluff line and Greeley gage with additional annual peak discharges from 1986 through 2005 and compared to the earlier studies results. A discussion of each USGS gage is given in the following paragraphs.

### ***Cache la Poudre River at Mouth of Canyon, nr Fort Collins***

For the Cache la Poudre at the mouth of the canyon, an additional 19 years of record were added (1986-2004) for a total period of record from 1882 through 2004. The methodology used was based on Bulletin 17B (WRC,1981) utilizing the log-Pearson type III distribution. A generalized skew coefficient of 1.0 was based on a Corps regional study of similar streams. The final curve is shown in Figure2 and listed in Table 3 along with a comparison to the 1988 study results. Since the 100-year peak discharge for the 1988 and 2006 update showed no appreciable change (0.0 percent), the flow probability curve from the 1988 study was used for this study.

### ***Cache la Poudre River near Greeley.***

The USGS gage referred to as the near Greeley gage is located approximately 3.0 miles upstream from its confluence with the South Platte River. The drainage area upstream of the near Greeley gage is 1,877 square miles. For the 1988 hydrologic analysis study, the original frequency analysis was initially derived based on the methodology presented in Bulletin 17B. However, the computed frequency curve did not fit the recorded flows and so the final curve was based on a graphical

analysis with an adopted skew of 1.0. For this study, an additional 20 years of record (1986 thru 2005) were available. A computed curve was derived based on methodology presented in Bulletin 17B. Again, the log-Pearson type III distribution did not adequately fit the observed data and so a graphical analysis with an adopted skew of 1.4 was used. While the 100-year discharge for the update did not change from the 1988 study, the more frequent events did increase. The adopted frequency curve is shown in Figure 3 and listed in Table 3 along with a comparison to the 1988 study results.

**Table 3**  
**Comparison of 1988 and 2006 Update Peak Discharge (cfs)**

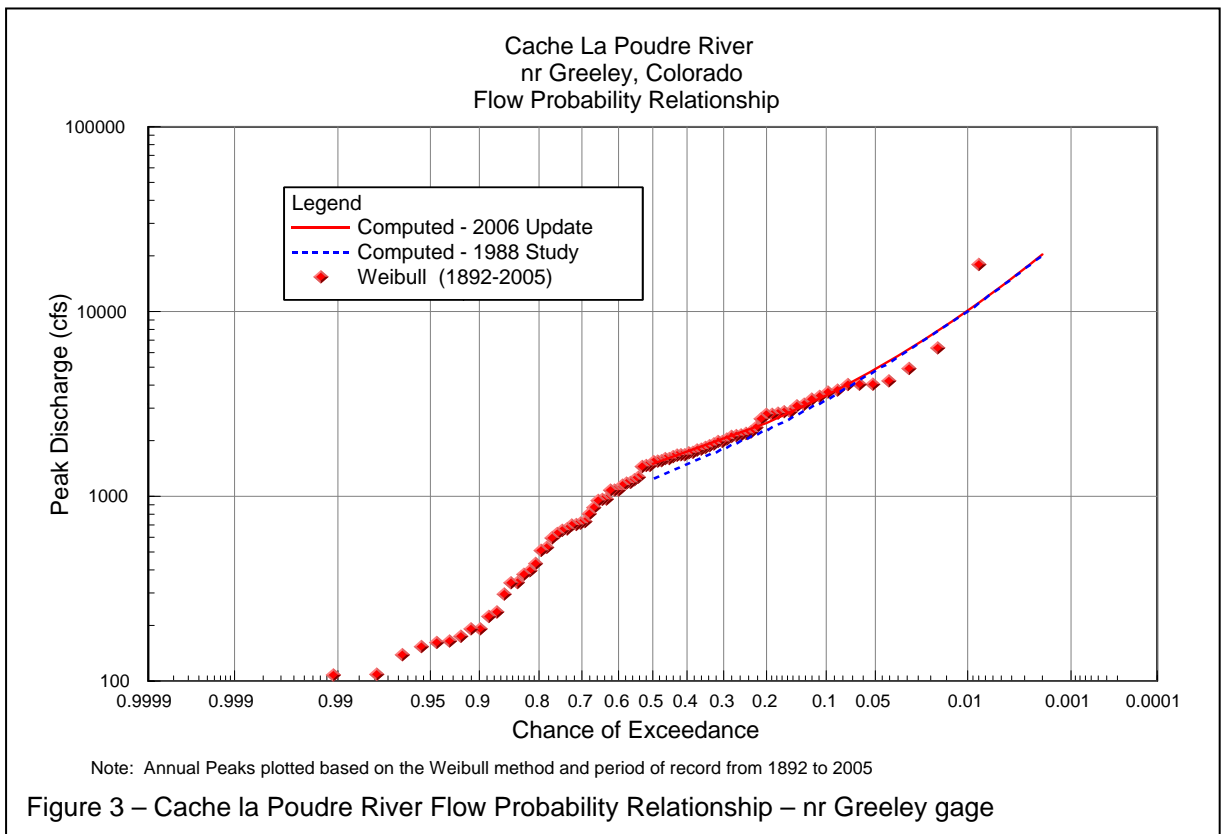
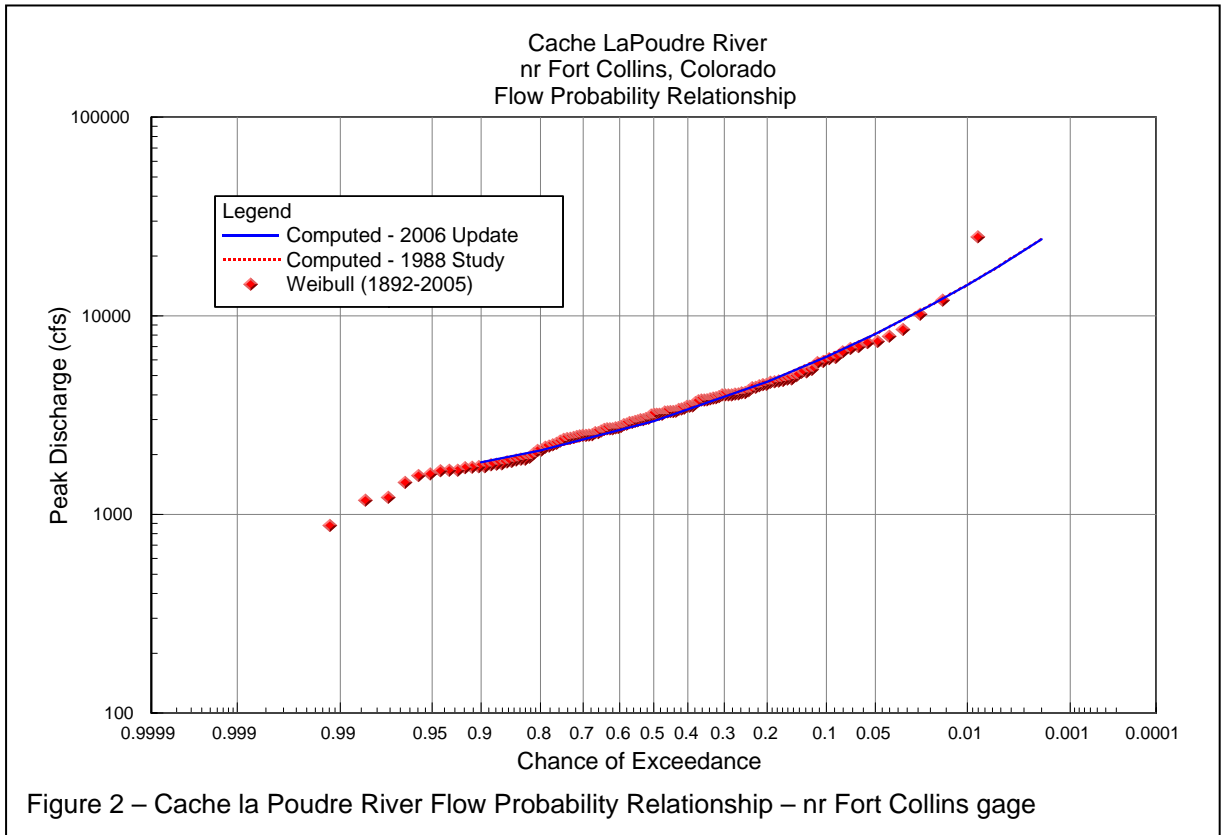
Location	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
<b>Cache la Poudre River at Bluff Line gage</b>							
<b>1988 Study</b>	3,110	4,850	6,430	9,020	11,500	14,500	24,200
<b>2006 Update</b>	3,110	4,850	6,430	9,030	11,500	14,500	24,300
	0.0	0.0	0.0	+0.1	0.0	0.0	+0.4
<b>Cache la Poudre at Greeley</b>							
<b>1988 Study</b>	1,250	2,290	3,350	5,320	7,380	10,100	20,300
<b>2006 Update</b>	1,500	2,490	3,520	5,410	7,420	10,100	20,300
	+16.7	+8.0	+4.8	+1.7	+0.5	0.0	0.0

**Note: Bottom value is the percent change from the 1988 study.**

***Adopted Flows.***

The procedure used to estimate the discharge frequency relationships at intermediate locations along the main stem of the Cache la Poudre is based on the frequency curves at the bluff line and Greeley gages and the 100-year discharge profile between the two gages. Since the updated 100-year flows did not change for the two gaged sites, the 100-year discharge profile from the 1988 study was used in this analysis. The standard deviation and skew for the bluff line gage were the same as those used for the 1988 study. The updated standard deviation and skew for the Greeley gage were used.

Using the adopted results for the two gaging stations, the standard deviation and the skew at intermediate locations were interpolated from the statistics at the two gages based on river miles along the main stem. The interpolated skew coefficient, standard deviation, and the routed 100-year discharge were used to calculate the mean flood logarithm at each location and are listed in Table 4. Peak discharges for the various return periods at each location are listed in Table 5.



**Table 4**  
**Cache la Poudre River Streamflow Statistics**

Location	Drainage Area (sq mi)	River Mile (miles)	100-Year Discharge (cfs)	Standard Deviation	Skew	Mean Flood Logarithm
Bluff Line gage	1055	56	14,500	0.2098	1.0	3.5272
Abv Dry Creek	1102	45	12,700	0.2154	1.1	3.4389
Blw Dry Creek	1195	45	15,900	0.2154	1.1	3.5365
Abv Boxelder	1245	38	14,300	0.2190	1.1	3.4794
Blw Boxelder	1537	38	16,600	0.2190	1.1	3.5441
Abv Law Ditch	1662	20	12,400	0.2282	1.3	3.3606
Blw Law Ditch	1707	20	12,500	0.2282	1.3	3.3641
Abv Coalbank	1747	10	11,100	0.2333	1.3	3.2961
Blw Coalbank	1810	10	11,200	0.2333	1.3	3.3000
Abv Eaton Draw	1825	3	10,100	0.2369	1.4	3.2293
Blw Eaton Draw	1875	3	10,100	0.2369	1.4	3.2293
Mouth	1890	0	10,000	0.2384	1.4	3.2200

Note: Greeley gage located at Blw Eaton Draw

**Table 5**  
**Cache la Poudre River**  
**2006 Updated Computed Peak Discharge (cfs)**

Location	2-Year	5-Year	10-Year	20-Year	25-Year	50-Year	100-Year	500-Year
Bluff Line gage	3,110	4,850	6,430	8,340	9,030	11,500	14,500	24,300
Abv Dry Creek	2,510	3,980	5,340	7,030	7,650	9,900	12,700	22,100
Blw Dry Creek	3,150	4,980	6,690	8,800	9,580	12,400	15,900	27,700
Abv Boxelder	2,750	4,390	5,930	7,840	8,550	11,100	14,300	25,100
Blw Boxelder	3,200	5,100	6,880	9,100	9,920	12,900	16,600	29,200
Abv Law Ditch	2,050	3,350	4,640	6,310	6,950	9,310	12,400	23,600
Blw Law Ditch	2,070	3,370	4,670	6,360	7,000	9,390	12,500	23,800
Abv Coalbank	1,770	2,910	4,060	5,560	6,140	8,280	11,100	21,500
Blw Coalbank	1,780	2,940	4,100	5,610	6,190	8,360	11,200	21,700
Abv Eaton Draw	1,500	2,490	3,520	4,880	5,410	7,420	10,100	20,300
Blw Eaton Draw	1,500	2,490	3,520	4,880	5,410	7,420	10,100	20,300
Mouth	1,470	2,440	3,460	4,810	5,340	7,330	10,000	20,200

Note: Greeley gage located at Blw Eaton Draw

***Equivalent Period of Record.***

For the risk and uncertainty analysis, the historic period of record was considered to be 124 years. This is based on the discharge records available for the bluff line gage for the period from 1882 through 2005.

***Trends Analysis.***

A trend analysis was performed to help identify if peak flows and/or low flows have changed over the historic streamflow period or record. For this analysis, the historical precipitation and streamflow data were plotted several different ways to try to identify possible climatic cycles and their impact on the Hydrology of the Cache la Poudre River. Data developed for the Cache la Poudre River near Greeley gage for the seasonal flow duration analysis and volume probability relationships will be used in this analysis. Available daily precipitation data were taken from the NCDC gage in Greeley. A discussion for each of the different plotting methods used for this analysis is given below followed by a discussion of the trends evaluated.

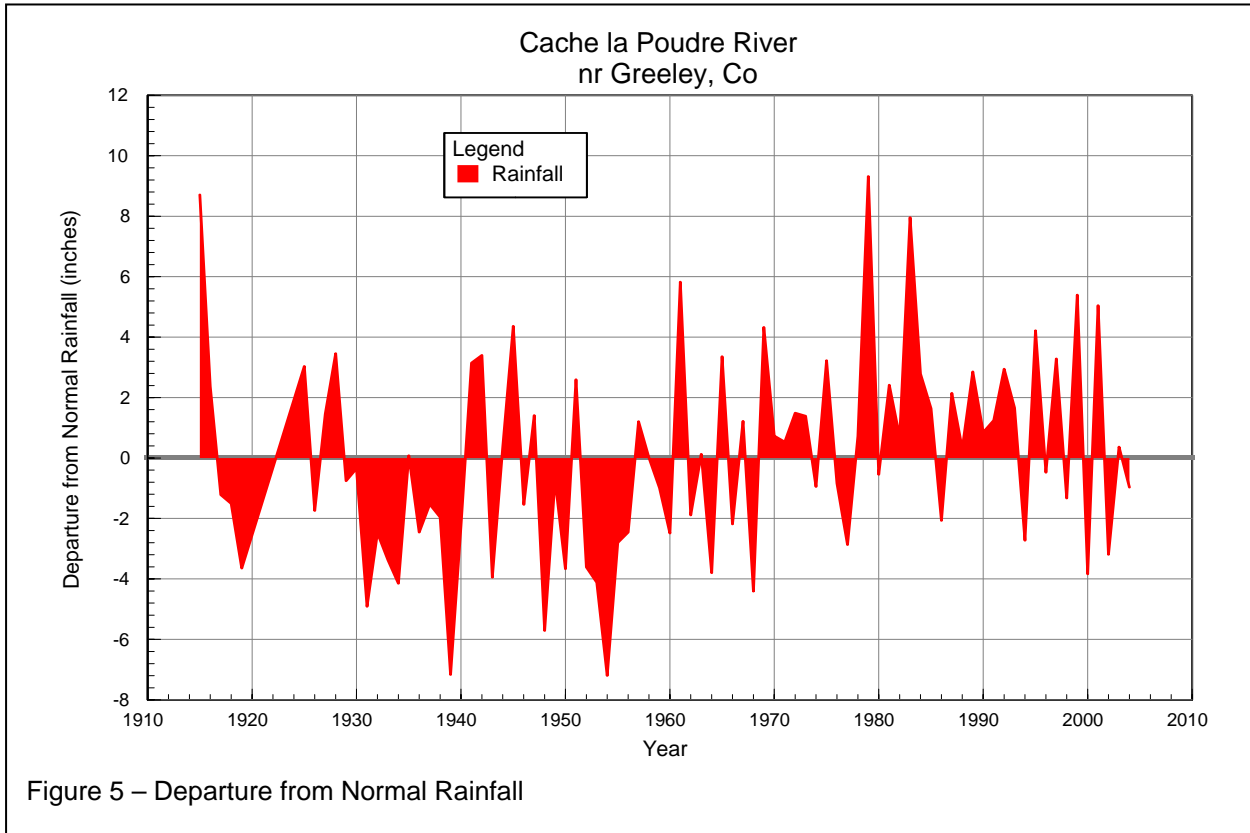
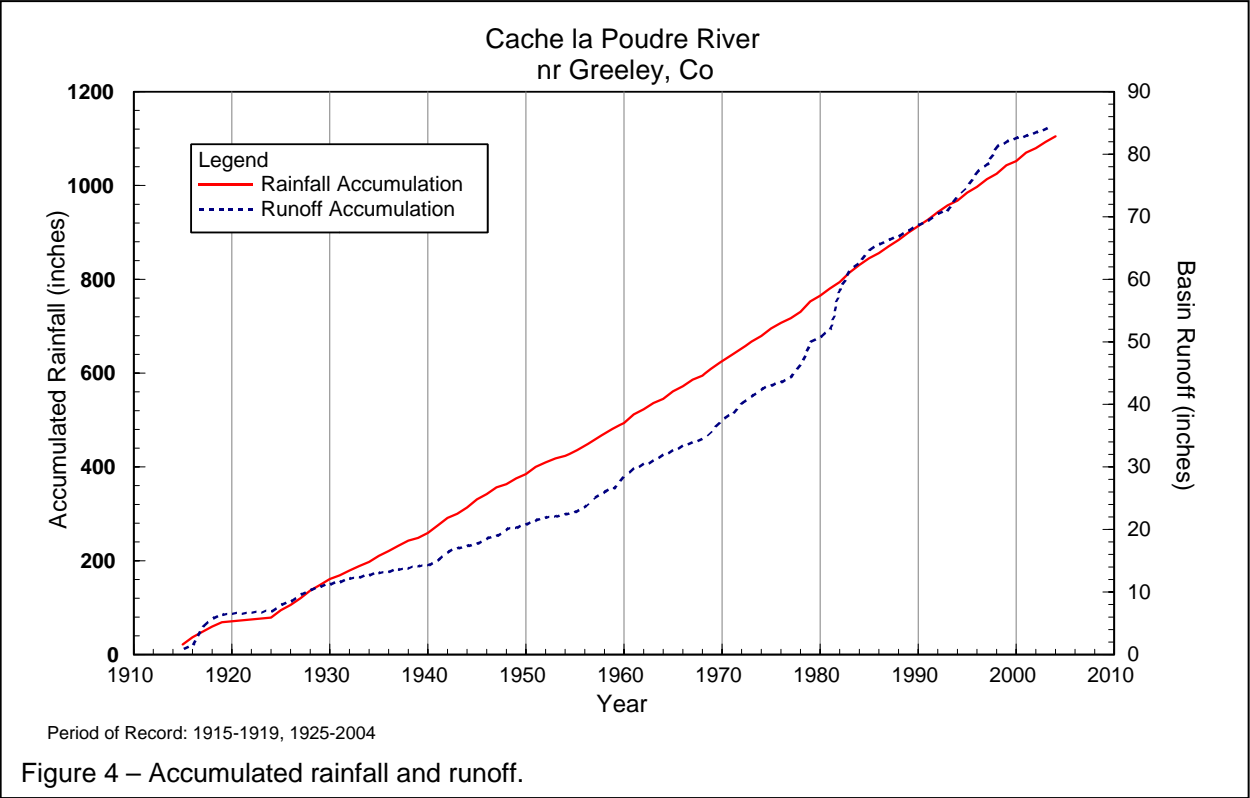
1) The first method was to compare the annual basin rainfall and the annual basin runoff to observe any trends that would show the relationship between the precipitation and runoff for corresponding wet and dry periods.

2) The next method was to plot the annual departure from the average annual precipitation and runoff for each year. This will help define wet or dry cycles that may not be evident in the plotting of annual values. The average annual precipitation and runoff were derived for the period of record corresponding to the streamflow gage period of record.

3) This method takes the previously developed annual departure from the average annual precipitation and runoff for each year and accumulates it for the period of record

4) Another way to analyze the historical inflow data is to plot the consecutive 1-, 7-, 30-, and 90-day maximum and minimum inflows for each year of available record to observe if, over time, there has been an increase or decrease in runoff. The consecutive 1-, 7-, 30-, and 90-day maximum and minimum flows were derived using HEC's statistical program STATS (HEC,1987).

The period of record used for this analysis was 1915 through 1919 and 1925 through 2005 utilizing daily records. Runoff data were not available for 1920 through 1924. Precipitation data for Greeley were used for the analysis. Runoff was taken from the Cache la Poudre River near Greeley gage and converted to inches based on the drainage area of the basin upstream of the gage. The resulting plots for the four methods discussed are shown in Figures 4 through 11.



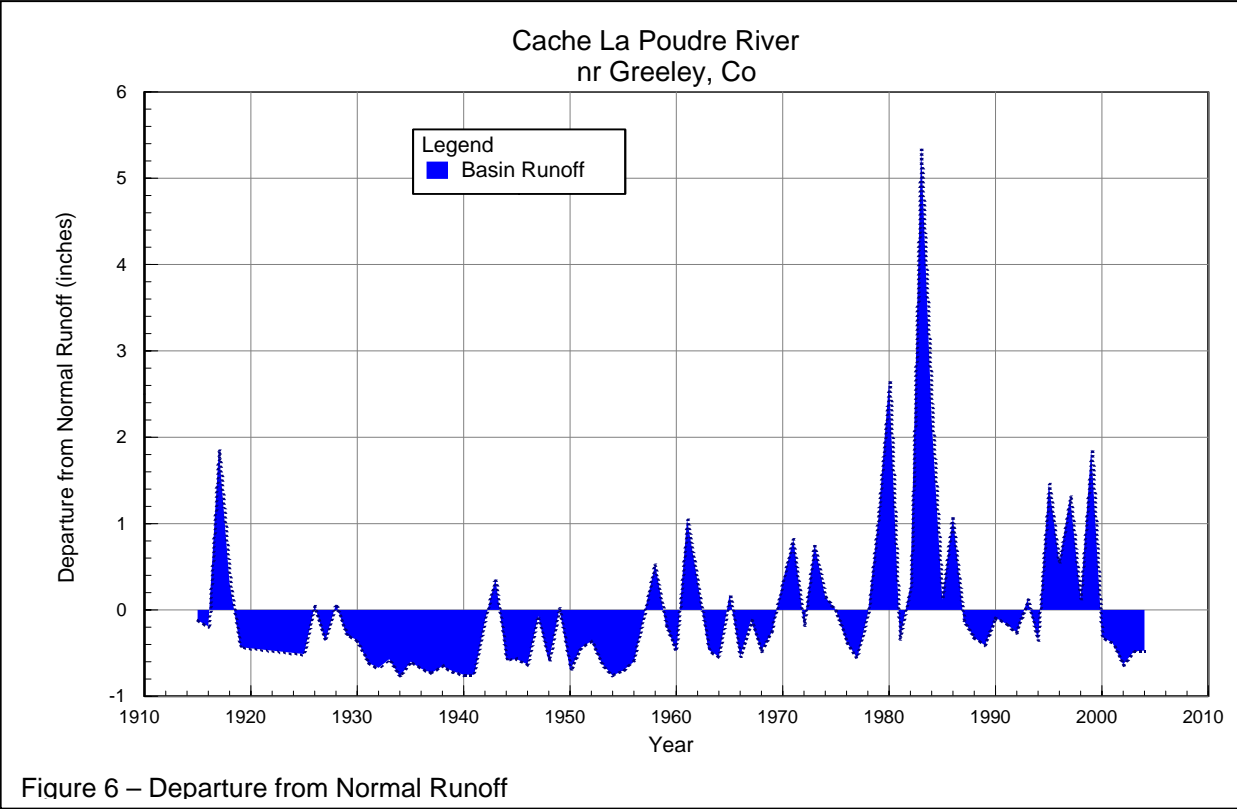


Figure 6 – Departure from Normal Runoff

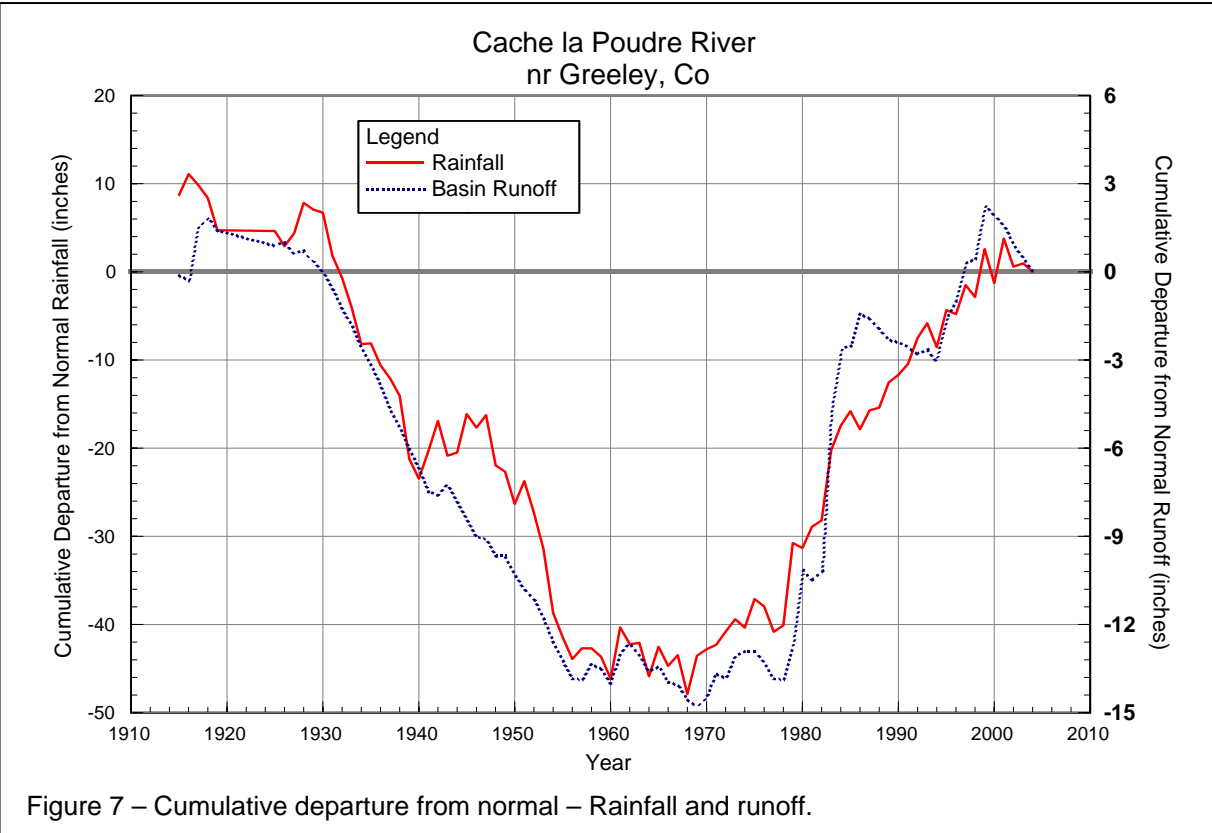


Figure 7 – Cumulative departure from normal – Rainfall and runoff.

The plot on Figure 4 for the accumulated rainfall and runoff for the Cache la Poudre at Greeley shows for the runoff, there are four distinct changes of slope in the curve over the period of record. The slope of the curve stays relatively constant from about 1915 through 1955. The slope of the curve then shows an increase in steepness from 1955 through about 1978 indicating an increase in runoff. In 1978 the slope of the curve increases in steepness which shows an even more pronounced increase in runoff through about 1984 before the slope flattens out again and is similar to the slope experienced between 1950 and 1978. For the precipitation curve, the breaks in the curve are consistent with those found in the runoff curve. However, they are not as pronounced.

The second method discussed on analyzing the historical data is to plot the annual departure from normal annual precipitation and runoff for each year. When plotted, this will show extended periods of either below normal or above normal conditions. The average annual rainfall and runoff for Greeley for the period of record were 12.85 inches and 0.99 inches, respectively.

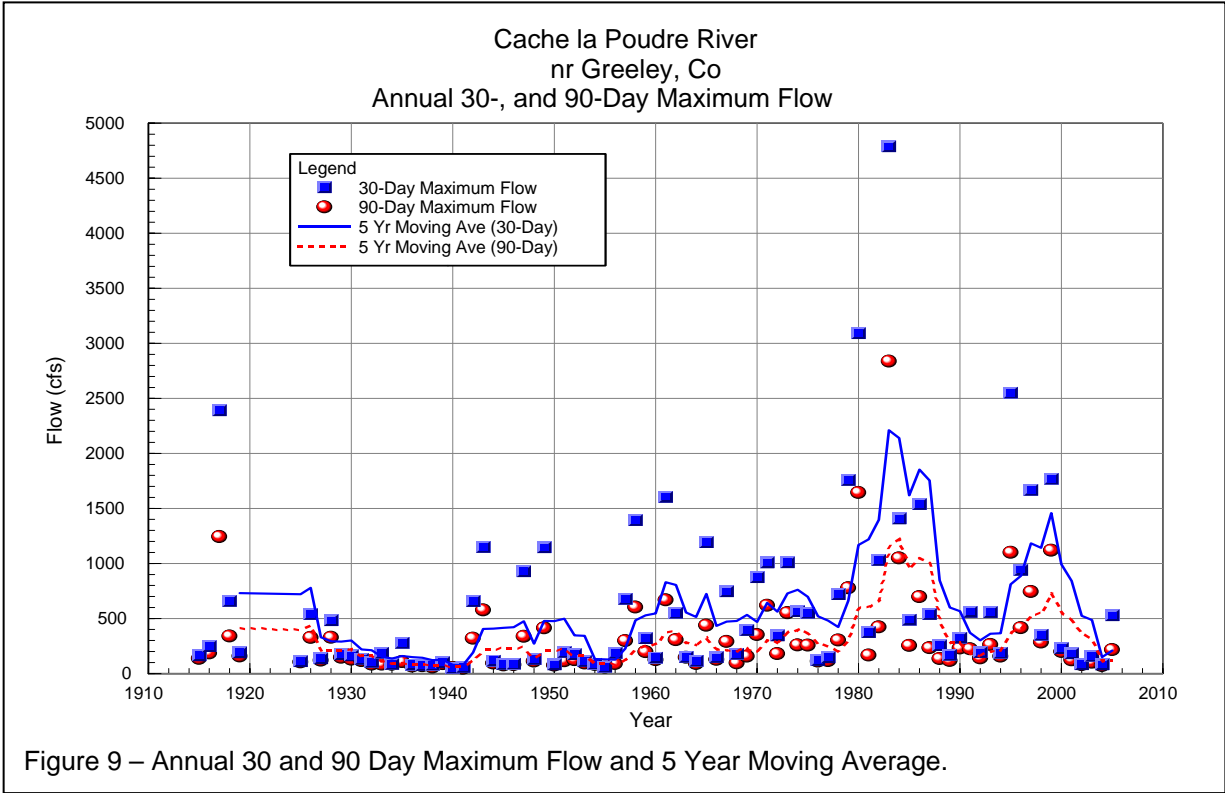
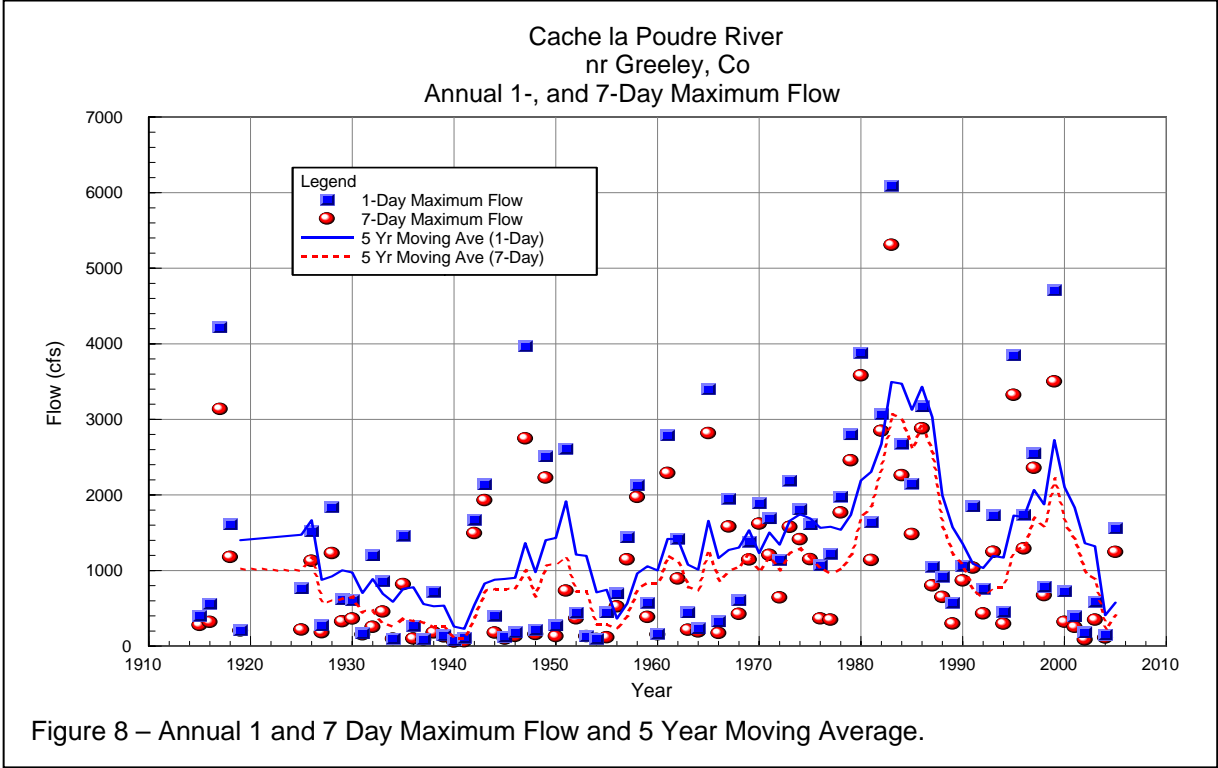
The graph in Figure 5 shows that the basin experienced below normal precipitation from 1928 through 1941 and again from 1952 through 1956. While the 1952 through 1956 drought period was shorter, it appears to be more severe than the earlier and much longer drought of the 1930's. The below normal conditions are even more pronounced in the runoff shown in Figure 6. This makes sense since it may take several years after precipitation has turned to normal before the basin runoff returns to normal. Conversely, there appears to be a wetter cycle starting in about 1978 and continuing through the 1990's where the wet years were well above normal while the dry years fell just below the normal.

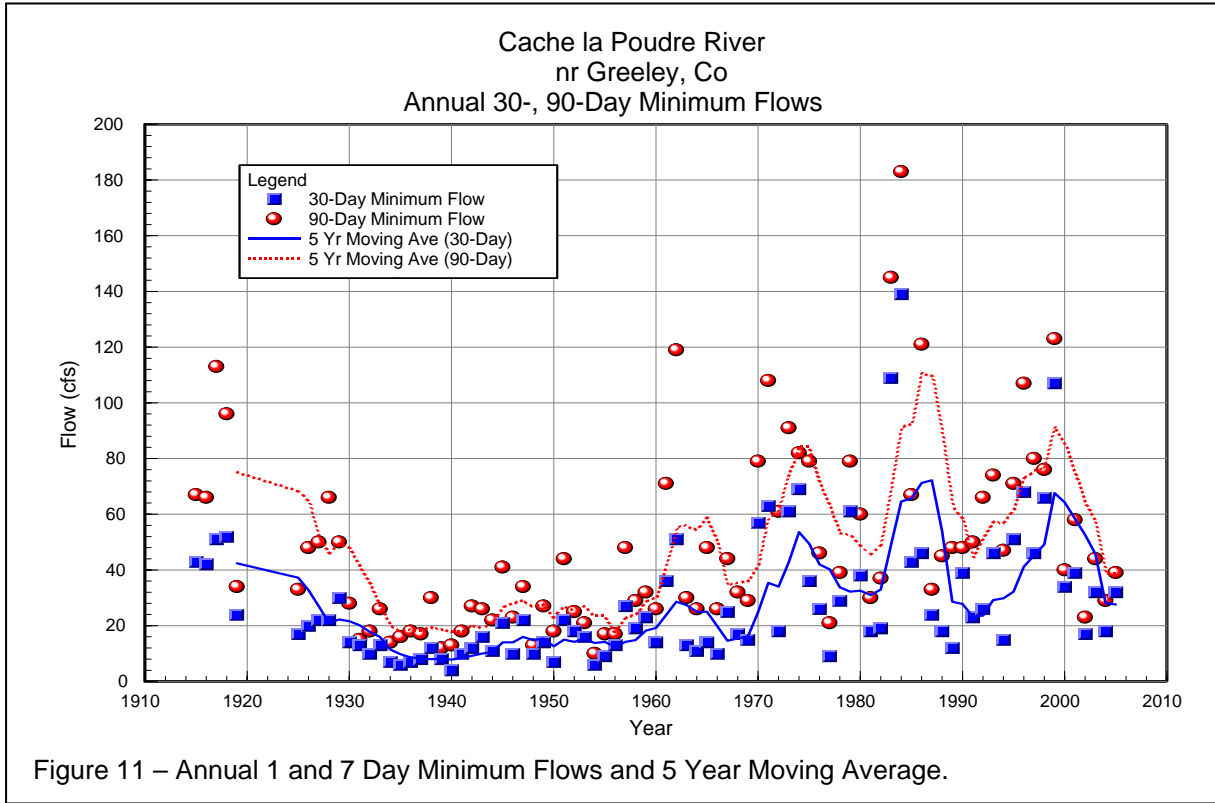
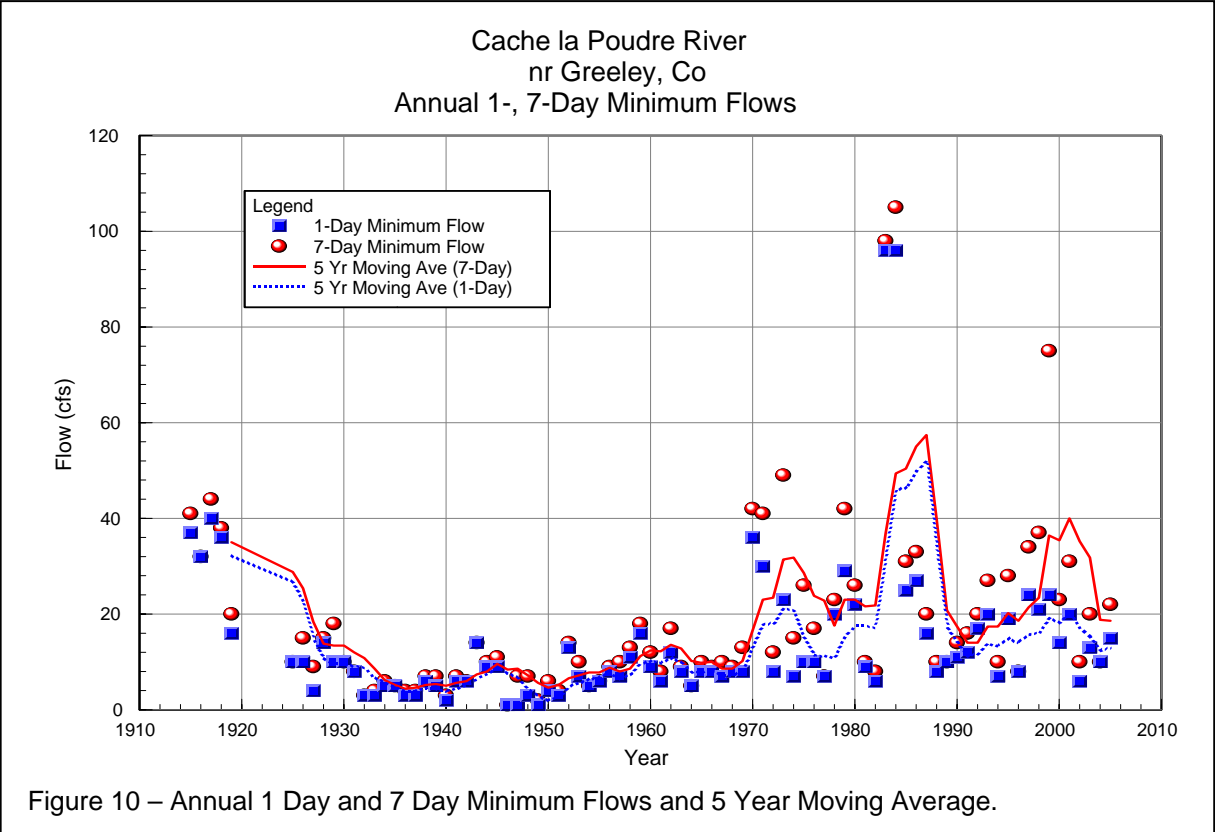
Another way to present the annual departure from normal precipitation and runoff data is to accumulate it over the period of record. This would help to better define any wet or dry cycles that may not show up in a mass curve analysis or just the annual departures. The annual departure of precipitation and runoff from the normal was determined for each year and accumulated and are shown in Figure 7.

Starting in about 1930, both the rainfall and runoff show a growing deficit over time with below normal values from year to year. While the precipitation showed a brief respite with near normal values from 1941 to 1947 there is no equivalent reaction from the runoff which continues to show an accumulated decline. The accumulated decline stops in about 1956 and the basin experiences near normal precipitation and runoff until about 1978 when there is a marked increase in above normal precipitation and runoff.

The final method that was used to analyze the historical flow data was to plot the consecutive 1-, 7-, 30-, and 90-day maximum and minimum flows for each year of available record to observe if, over time, there has been a change in runoff for both, low flow and high flow conditions. Graphs were developed showing the 1-, 7-, 30-, and 90-day maximum and minimum flows for each year over the period of record and

are shown in Figures 8 through 11. In addition, the 5-year moving average was included to potentially show any trends in the data.





For the maximum flow periods, the 1- and 7-day flow vary over the period of record with a drought period showing up between about 1927 and lasting until 1942. The 5-year moving average shows the drought of the 1930's but then starts a slow climb over the period of record before dropping off in the early 2000's. Even discounting the impact of the large 1983 event, there does appear to be a period of increased runoff. For the 30- and 90-day maximum flows, there is distinct drought period from the late 1920's through 1942. This is evident in the 5-day moving average for both conditions. And while there are higher flow years between the early 1940's to about the mid 1950's, there is a definite increase that starts to occur in about 1958. It appears to be more pronounced in the 30-day maximum flow and the 5-year moving average. Also, though the 1983 runoff was considerably above normal and had a major impact on the 5-year moving values, there still appears to be an increase in the year to year variability in flows for both the 30 and 90-day values.

For the minimum flow periods, there is a distinct change that occurs that from the late 1920's to the late 1960's, there was fairly constant 1-day and 7-day low flow periods. The 5-year moving average hovers around 10 cfs for both conditions. Following this period, the low flows become much more variable and the 5-year moving average starts to climb and continues to hovers around 20 cfs for the 7-day minimum flows and around 17 cfs for the 1-day minimum flows. The 30-day minimum flows also showed a similar pattern that started at the end of the 1920's through the late 1960's before increasing in its variability. The 90-day minimum flows show a similar pattern starting in the late 1920's but the flows are more variable during that period and it appears to start increasing at the beginning of the 1960's rather than at the end of the decade. This pattern can clearly be seen in the 5-day moving average for the 90-day minimum flows.

While flows in the Cache la Poudre River are certainly affected by many factors including upstream reservoirs, trans-mountain and trans-basin diversions, municipal water supply and irrigation diversions, and return flow from irrigated lands there appears to be a pattern of sustained below normal precipitation and runoff from the beginning of the 1930's through the mid 1950's. This was followed by a period of near normal conditions before turning into a period of above normal precipitation and a corresponding increase in runoff from the late 1970's through the 1990's. The basin is certainly subject to climatic cycles of above or below normal conditions that can last longer than 20 years.

### ***Volume Probabilities.***

In addition to the annual peak discharges, volume probability relationships were developed for different durations of floods to analyze the potential of using gravel pits located along the Cache la Poudre to store flood flows. The statistical analysis for developing the volume probabilities consisted of using the maximum flow over several durations for each year of available flow records to derive the inflow volumes for the 2-, 10-, 25-, 50-, 100-, and 500-year events. The different durations consisted of the maximum 1-day high flow for each year, the consecutive 3-day high flow for each year, the consecutive 7-day high flow, and so on through the

consecutive 183-day high flow for each year. To convert the annual maximum flow for each duration to a hypothetical flow for the 2-, through 500-year events, the log-Pearson Type III distribution was used. As was discussed earlier, the log-Pearson Type III distribution is the standard statistical method used for determining hypothetical flood events.

HEC's statistical program STATS (HEC,1987) was used to develop the 1-, 3-, 7-, 15-, 30-, 60-, 90, 120-, and 183-day volume probabilities for the 2-through 500-year return periods for both, the Bluff Line gage and Greeley gage on the Cache la Poudre. From these initial results, the standard deviations and generalized skew coefficients were plotted versus the mean logarithms for both,

the annual peaks and the 1-day through 183-day durations. The curves were smoothed and are shown in Figures 12 through 15. The adjusted standard deviation and skew coefficient were then used to derive new frequency curves. Skew coefficients were again adjusted as necessary to better fit the observed historical peaks. Final curves are shown in Figures 16 and 17. While the results for the Bluff Line gage were satisfactory, the preliminary results for the Greeley gage showed that the derived curves did not fit the plotted observed historical peaks. Since the daily streamflows at the Greeley gage are highly regulated, an effort was made to correlate the flows to the Bluff Line gage which are less so.

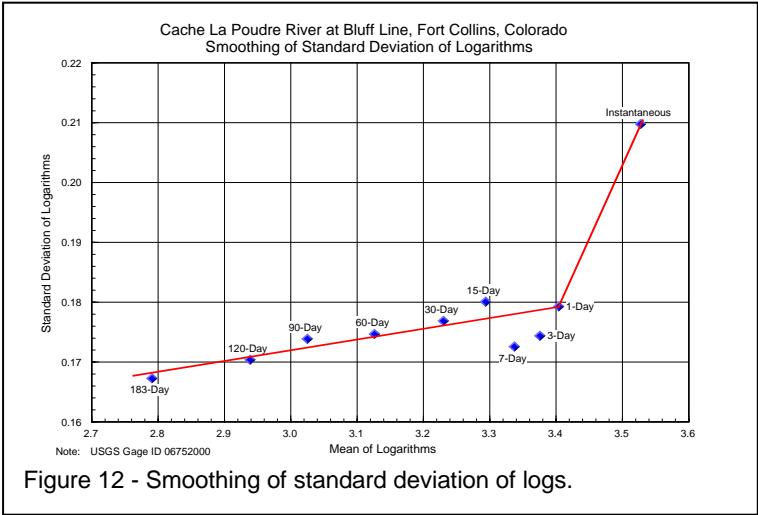


Figure 12 - Smoothing of standard deviation of logs.

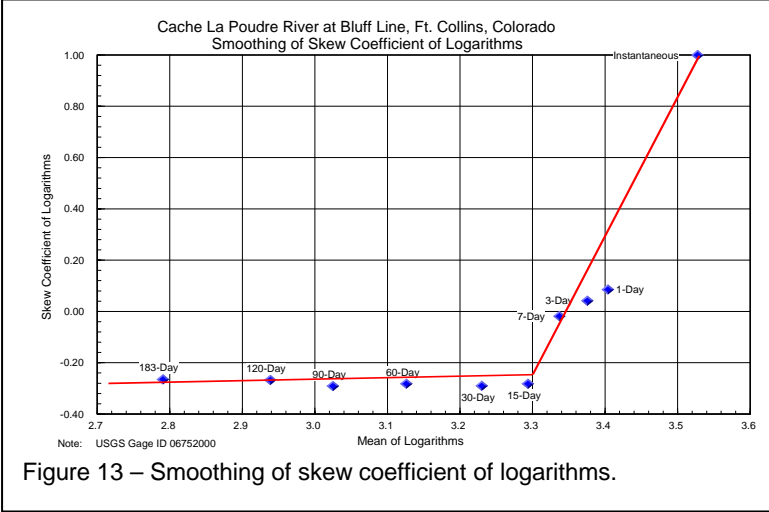


Figure 13 – Smoothing of skew coefficient of logarithms.

In lieu of a basin wide study to address the regulated streamflows on the Cache la Poudre, the maximum 1-, 3-, 7-, 15-, 30-, and 60-day consecutive high flows for the Bluff Line gage were plotted against the same durations for the Greeley gage. A linear regression equation was developed for five different time periods, 1) 1915-19, 25-40 2) 1941-60, 3) 1961-80 4) 1975-04 and 5)1915-19, 25-04 (the entire period

of record). The resulting curves for the 1-day duration are shown in Figure 18. The results show that over time, the flows for all the different durations have increased at the Greeley gage for a given flow at the Bluff Line gage. Since it appears that the trend of increased flows at the Greeley gage is continuing, the curve based on the time

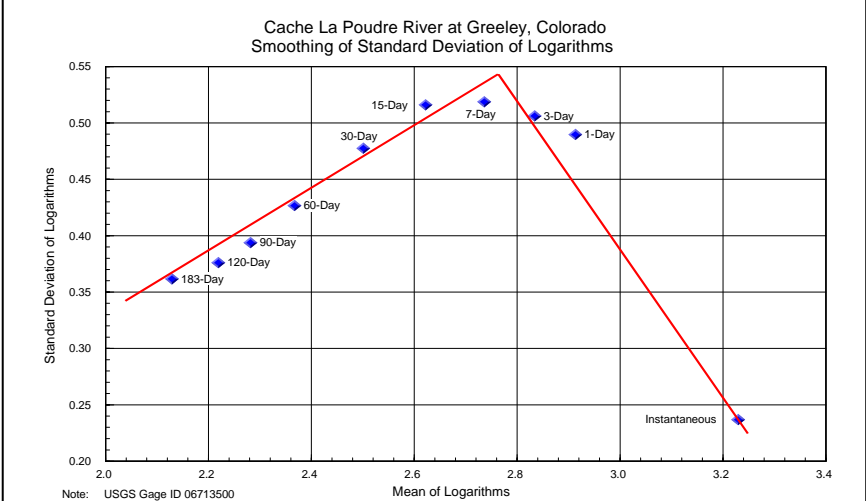
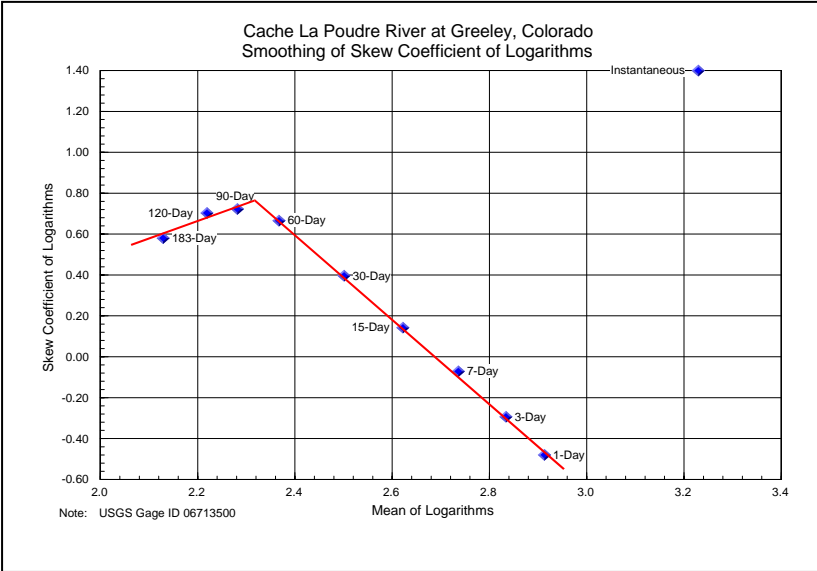


Figure 14 - Smoothing of standard deviation of logs.

period of 1975-2004 was used for deriving the final flows. A sensitivity analysis of the trends using the 20-year time frame, showed that, for the period 1981-2000 and 1985-2004, the resulting regression curves fell to either side of the 1975-2004

regression curve. Based on this, the regression curve using the 30-year time frame was considered reasonable. The formula used is listed below and the final regression equations used in the analysis are listed in Table 6 for the various durations.



$Y_{Greeley} = mx + b$  where,

- $Y_{Greeley}$  = Flow at Greeley for a given duration and return period.
- $m$  = Flow at Bluff Line gage for a given duration and return period.
- $b$  = Constant
- $x$  = Factor

**Table 6**  
**Factors to Convert Flows at Bluff Line Gage**  
**to Greeley Gage**  
**Based on 1975-2004 Period**

<b>Duration</b>	<b>Factor (x)</b>	<b>Constant (b)</b>
1-Day	1.1191	-957
3-Day	1.2051	-1143
7-Day	1.1964	-1101
15-Day	1.2373	-1158
30-Day	1.1391	-978
60-Day	1.0569	-751

Volume probabilities for the Greeley gage were then developed by taking the peak flows for the different return periods at the Bluff Line gage and applying the regression equations for each of the durations. Final values for the Greeley gage are shown in Figure 19 plotted against the historical peak flows at Greeley and listed in Table 7.

Results show that the upper half of the frequency curve fit the data better than the initial probability curves based just on the flows at Greeley with no adjustments. This would be the case since during years with lower snowmelt runoff, a larger proportion of the flows are more likely to be captured or diverted into storage after they go past the Bluff Line gage. During high snowmelt runoff events, storage is more likely to be filled near the start of the event and would also need a smaller proportion of the runoff to fill their storage. Since the adopted volume probability relationships are for present day development in the basin, they would not be expected to fit the lower historic Greeley flows very well since these were not adjusted to today's development.

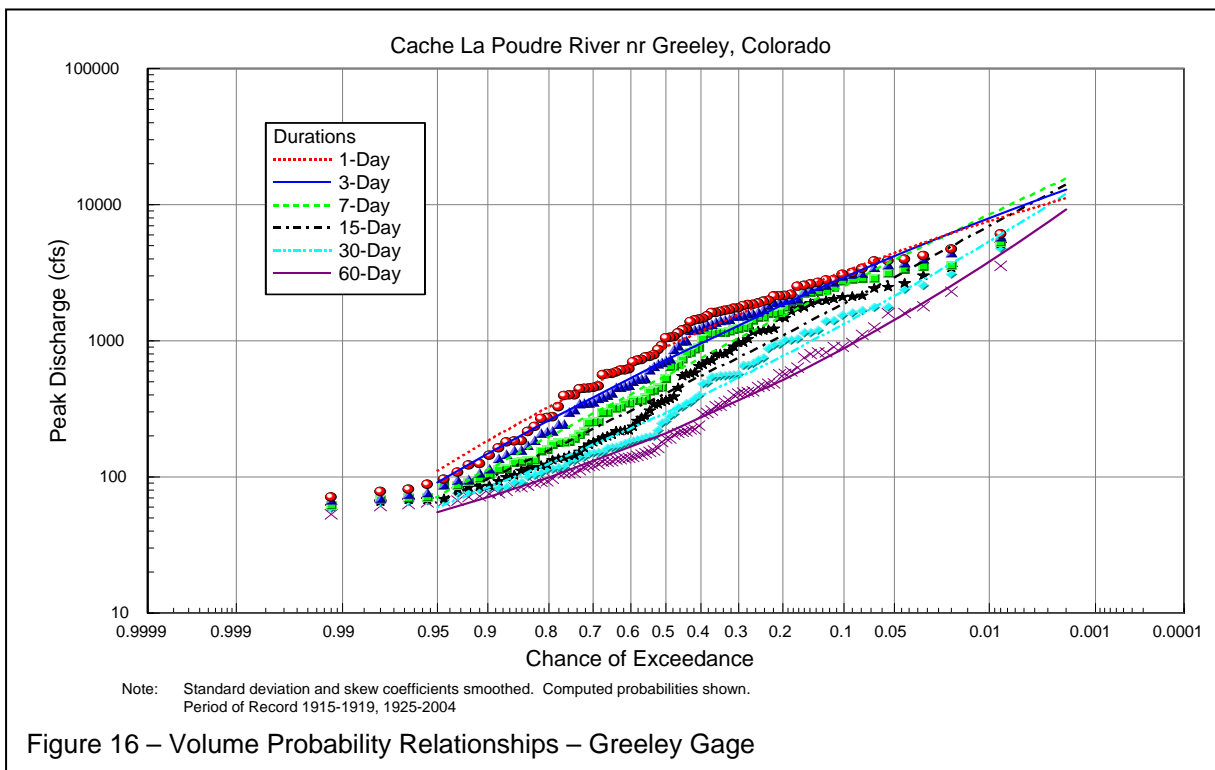
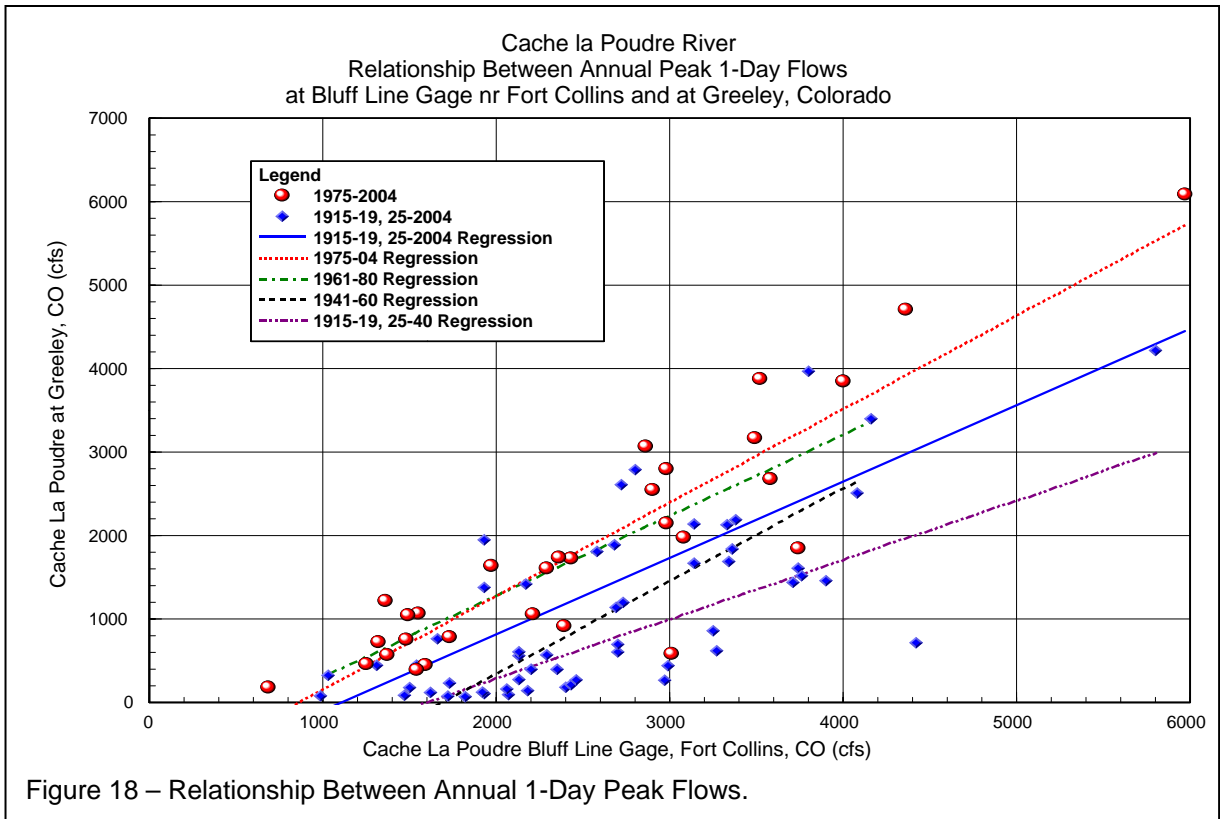
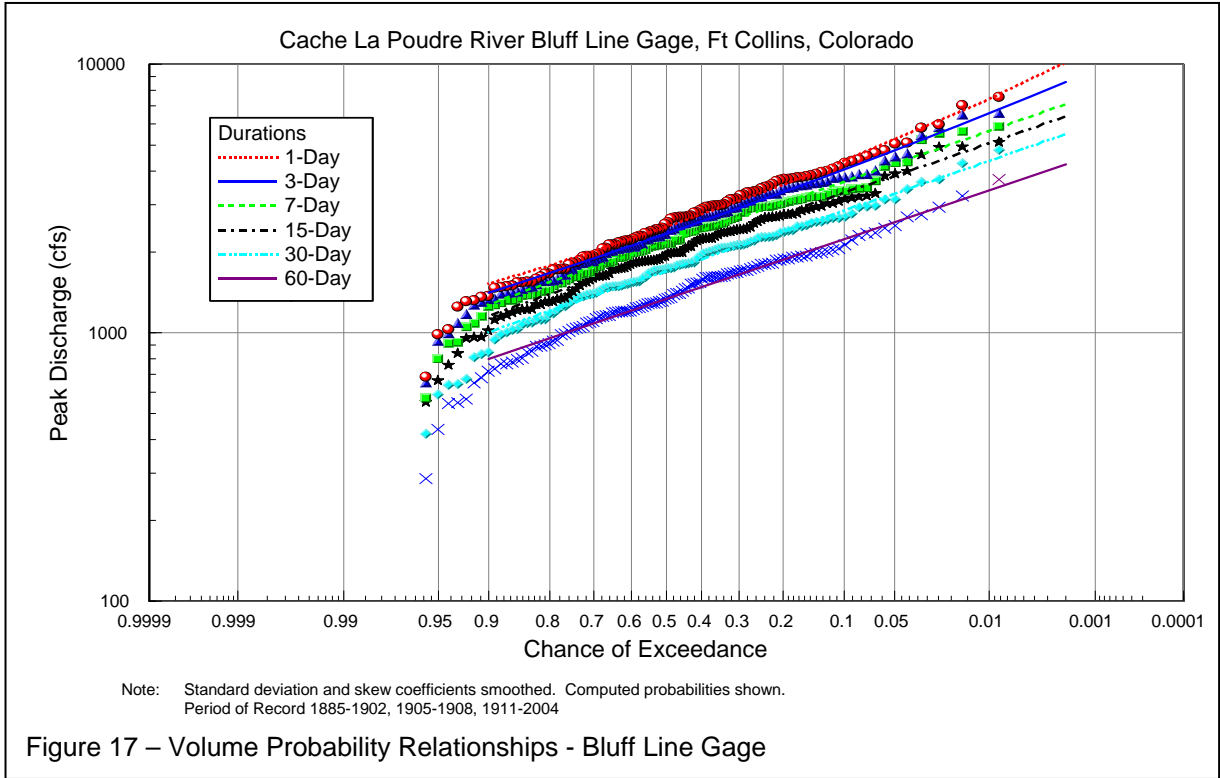
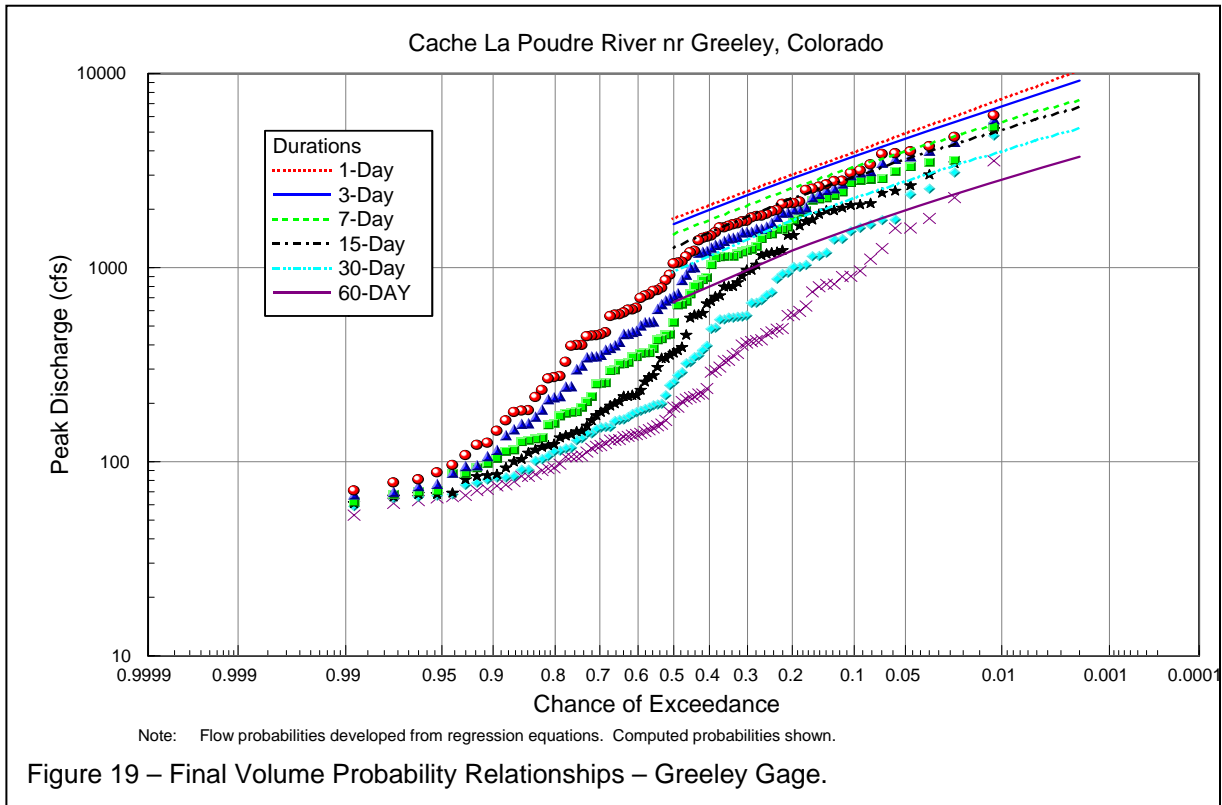


Figure 16 – Volume Probability Relationships – Greeley Gage



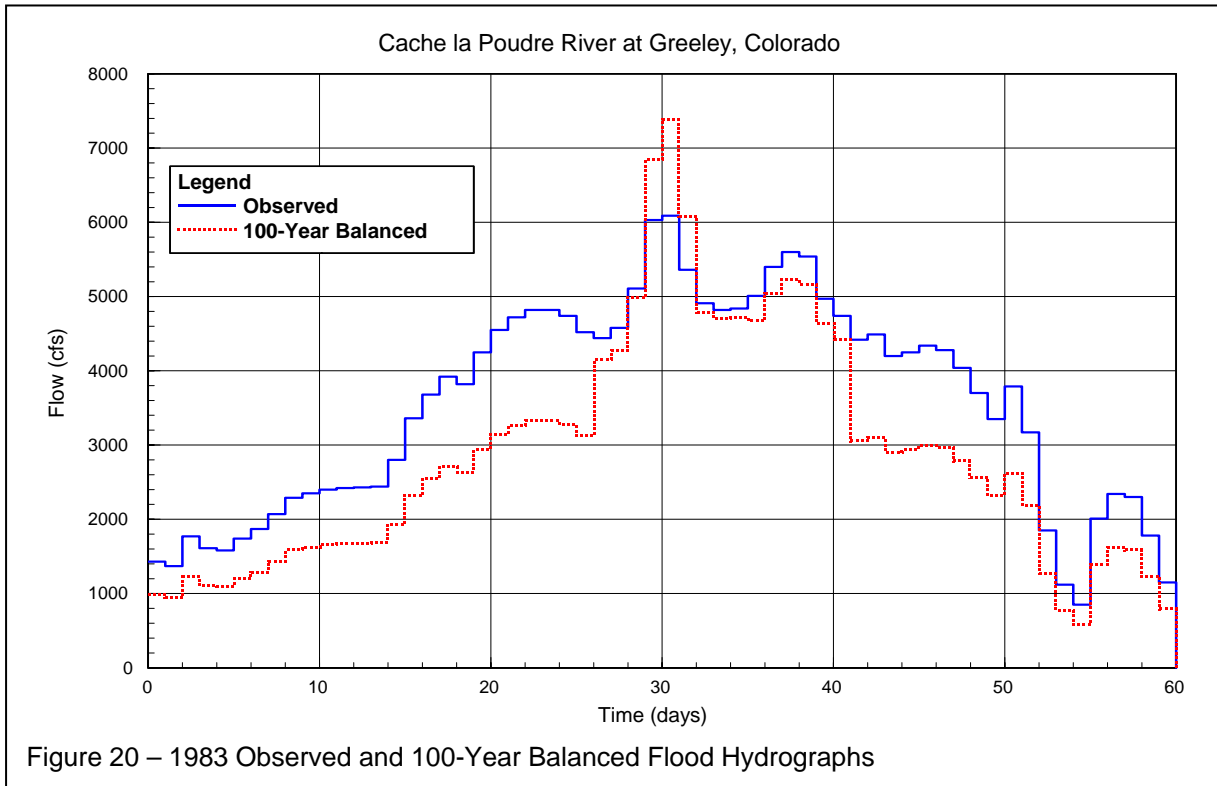


**Table 7**  
**Volume Probability – Bluff Line Gage nr Ft. Collins and at Greeley**

Gage	Volume Probabilities (cfs)						
	2-Year	5-Year	10-Year	20-Year	50-Year	100-Year	500-Year
<b>Bluff Line Gage nr Fort Collins</b>							
1-Day	2470	3550	4360	5220	6440	7450	10200
3-Day	2340	3340	4060	4780	5780	6570	8590
7-Day	2170	3070	3670	4260	5040	5640	7070
15-Day	1970	2770	3320	3850	4550	5090	6370
30-Day	1700	2390	2860	3310	3910	4370	5470
60-Day	1340	1870	2230	2580	3040	3400	4240
<b>At Greeley Gage</b>							
1-Day	1810	3020	3920	4880	6250	7380	10500
3-Day	1680	2880	3750	4620	5820	6770	9210
7-Day	1500	2570	3290	4000	4930	5650	7360
15-Day	1280	2270	2950	3610	4470	5140	6720
30-Day	960	1740	2280	2790	3480	4000	5250
60-Day	660	1230	1610	1980	2460	2840	3730

## Balanced Hydrographs

HEC-1 (HEC,1991) was used to convert the volume probabilities to balanced hydrographs. The shape of the hydrograph is based on using an actual historic event over the same duration but keeping the volume equal to the defined probability and not the event itself. For this study, the 1983 event was used for defining the shape of the hydrograph through the 60-day duration. The 1-day through 60-day balanced hydrograph for the 100-year event is shown in Figure 20 along with the observed hydrograph from the 1983 event.



## Gravel Pit Alternative.

To manage the risk of flooding in Greeley, the available gravel pits could be utilized by diverting the peak of the flood hydrograph from the Cache la Poudre River channel and storing it. This would allow a lower flow to continue downstream, reducing potential damages.

The initial concept to utilize the gravel pits was to build a concrete weir between the river and the gravel pit long enough to divert the top of the flood hydrograph of a given flood event and lowering the flow going downstream. For instance, to reduce the 50-year peak discharge of 7,400 cfs to the 20-year peak discharge of 4,880 cfs through Greeley, 5,700 acre-feet of water would need to be stored. Table 8 list the volumes needed to reduce peak discharges to a lower return period for several conditions.

With the gravel pit option, a pump would be required to remove the water from the gravel pit after the flood flows on the Cache la Poudre River have receded since the gravel pits will be 20 to 40 feet deep and well below the invert of the channel. In some cases, it may be possible to use a combination of gravity flow through a culvert and a pump. For this analysis, it was assumed that only a pump was used and that after the flood event has passed, it will take 30 days to remove the water from the gravel pit.

A map was provided by the City of Greeley showing potential gravel pit locations and is included as Plates 1 and 2 in this report. Table 9 lists the surface area and potential storage available for different depths. Based on the available information, the most viable option would be the 35th Avenue Reservoir which has a surface of 339 acres and 14,000 acre-feet of possible storage. To store the 5,700 acre-feet that would be needed to lower the 50-year peak discharge to a 20-year discharge in the 35th Avenue Reservoir would require the water surface to be about 15 feet below the crest of the weir. If the water is assumed to flow 3.0 feet over the top of the concrete weir, it would have to be about 190 feet in length to capture all the flows above 4,880 cfs. After the flood event has passed, it would take a pump size of approximately 100 cfs to remove the water from the gravel pit within 30 days.

If the potential maximum storage of 14,000 acre-feet for the 35<sup>th</sup> Avenue Reservoir were available, it would be able to reduce the 100-year peak discharge of 10,100 cfs to a 20-year peak discharge of 4,800 cfs provided a long enough weir could be built to allow flow to pass into the gravel pit. If water is assumed to flow 3.0 feet over the top of the weir, it would have to be about 400 feet in length. To remove the 13,000 acre-feet of stored water from the gravel pit in 30 days would require a pump size of about 220 cfs.

To utilize any of the other gravel pits would require using multiple combinations since they are much smaller. For instance, if the four gravel pits owned by the City of Greeley (based on the gravel pit map) were utilized, they would have a combined surface area of 149 acres and potential storage of 5,960 acre-feet (assuming a depth of 40 feet) This would be large enough to store the 5,700 acre-feet necessary to reduce the 50-year peak discharge to a 20-year peak. However, it would require at least three concrete weirs since the 4 sites are not located next to each other. It would also require the gravel pits to be kept dry to a depth of 40 feet and several of them are currently not lined and would need to be to prevent groundwater flow into them. A geotechnical analysis would also be required to determine what, if any, stability measures that would be needed due to the differential between the river and the 40 foot deep dry gravel pit.

Based on the number of gravel pits, there are many different alternatives that could be configured for lowering the flows downstream. However, the preferred alternative would be to use a single gravel pit that has a large surface area. This would allow for the need to have only one weir to let flow in, a single pump station,

and potentially would not have to have additional stability measures due to the differential in depth between the level of the river and the invert of the dry gravel pit.

**Table 8**  
**Volumes Needed to Reduce Peak Flows to a lower Return Period**

Return Period / Flow	Volume Needed to Store to Lower to Corresponding Return Period (acre-feet)			
	20-Year (4,880 cfs)	10-Year (3,920 cfs)	5-Year (3,020 cfs)	2-Year (1,810 cfs)
100-Year (10,100 cfs)	13,000	48,100	-----	-----
50-Year (7,420 cfs)	5,660	28,900	-----	-----
20-Year (4,880 cfs)	-----	7,520	30,300	-----
10-Year (3,920 cfs)	-----	-----	14,180	47,600

**Table 9**  
**Potential Gravel Pit Storage Sites**

Gravel Pit name	Owner	Surface Area (acres)	Assumed Depth and Corresponding Volume (acre-feet)			
			5-feet	10-feet	20-feet	40-feet
F-Street Reservoir	City of Greeley	55	275	550	1100	2200
35th Ave Reservoir	LaFarge West	339	1695	3390	6780	13560
Flatiron Reservoir #1	City of Greeley	28	140	280	560	1120
Flatiron Reservoir #2	City of Greeley	48	240	480	960	1920
Flatiron Reservoir #3	Cottonwood L&F	45	225	450	900	1800
Flatiron Reservoir #4	Cottonwood L&F	36	180	360	720	1440
Flatiron Reservoir #5	Cottonwood L&F	20	100	200	400	800
East 8th St Reservoir	Greeley Urban Renewal	17	85	170	340	680
WW Farms Reservoir #1	Camas Colorado	68	340	680	1360	2720
WW Farms Reservoir #2	Camas Colorado	17	85	170	340	680
WW Farms Reservoir #3	Camas Colorado	19	95	190	380	760
WW Farms Reservoir #4	Camas Colorado	31	155	310	620	1240
WW Farms Reservoir #5	Camas Colorado	77	385	770	1540	3080
Geiser Pit	Weld County	14	70	140	280	560
Island Grove Park	City of Greeley	14	70	140	280	560
Bucklen Equipment	Bucklen Equipment	102	510	1020	2040	4080
Hiner Pit	Hiner Construction	118	590	1180	2360	4720
83 Joint Venture	83 Joint Venture	26	130	260	520	1040
Small Pit	Iverson	55	275	550	1100	2200

**Interior Drainage.**

In the development of levee alternatives to manage the flood risk at Greeley, their construction may prevent the removal of interior runoff that would normally drain into the Cache la Poudre. To prevent flooding of the interior area by local runoff, a drainage structure alone may be used or in conjunction with a ponding area and/or pump. To develop the drainage structures, a concept called minimum facilities will be utilized. The basis for minimum facilities is to design a drainage facility so not to significantly increase interior expected annual damages over without project conditions. This requires that the interior runoff be removed to the extent possible to minimize or prevent damage to the urban area.

In general, for existing structures affected by the project, new pipes are sized to match those already in place, with a minimum of 24 inches to allow for ease of maintenance. When necessary, where levees are not involved, structures are sized to an event that keeps with the general design criteria for storm drains for cities which is usually a 10-year event. For new structures in areas where levees are proposed and will prevent the removal of interior runoff, the concept of minimum facilities is used.

For Greeley, a detailed analysis was not performed for Phase I for the proposed levee alignment. Instead, a cursory analysis was made looking at potential locations to be used to account for costs in the cost analysis. Several assumptions were made to account for potential interior drainage structures needed including estimating pipe sizes and lengths. It was assumed all pipes through the levee will need to be flap gated. The potential drainage structures for Alternative 1a, their location and size are listed in Table 10 and shown on Plates 3 and 4.

**Table 10  
Alternative 1A  
Interior Drainage Structures**

<b>Pipe ID</b>	<b>Estimated Stationing</b>	<b>Pipe Size</b>	<b>Length (feet)</b>	<b>Flapgate Required</b>
<b>Right Bank Levee</b>				
1	7+30	48-Inch RCP	65	Yes
2	7+70	48-Inch RCP	70	Yes
3	30+50	48-Inch RCP	160	Yes
4	54+00	48-Inch RCP	65	Yes
5	56+00	48-Inch RCP	65	Yes
6	90+30	48-Inch RCP	65	Yes
<b>Left Bank Levee</b>				
7	1+50	8-ft x 6-ft Box	65	Yes
8	8+50	8-ft x 6-ft Box	65	Yes
9	21+50	48-Inch RCP	65	Yes
10	52+50	48-Inch RCP	65	Yes

For Phase II, detailed modeling will be required if a specific levee alignment is chosen as the preferred alternative. This will also include a site visit which will consist of documenting existing structures along the alignment and observing existing overland drainage patterns that will be impeded by the construction of the levee. Available GIS data the City of Greeley may have will also be used to help locate storm drains affected by the proposed levee.

## REFERENCES

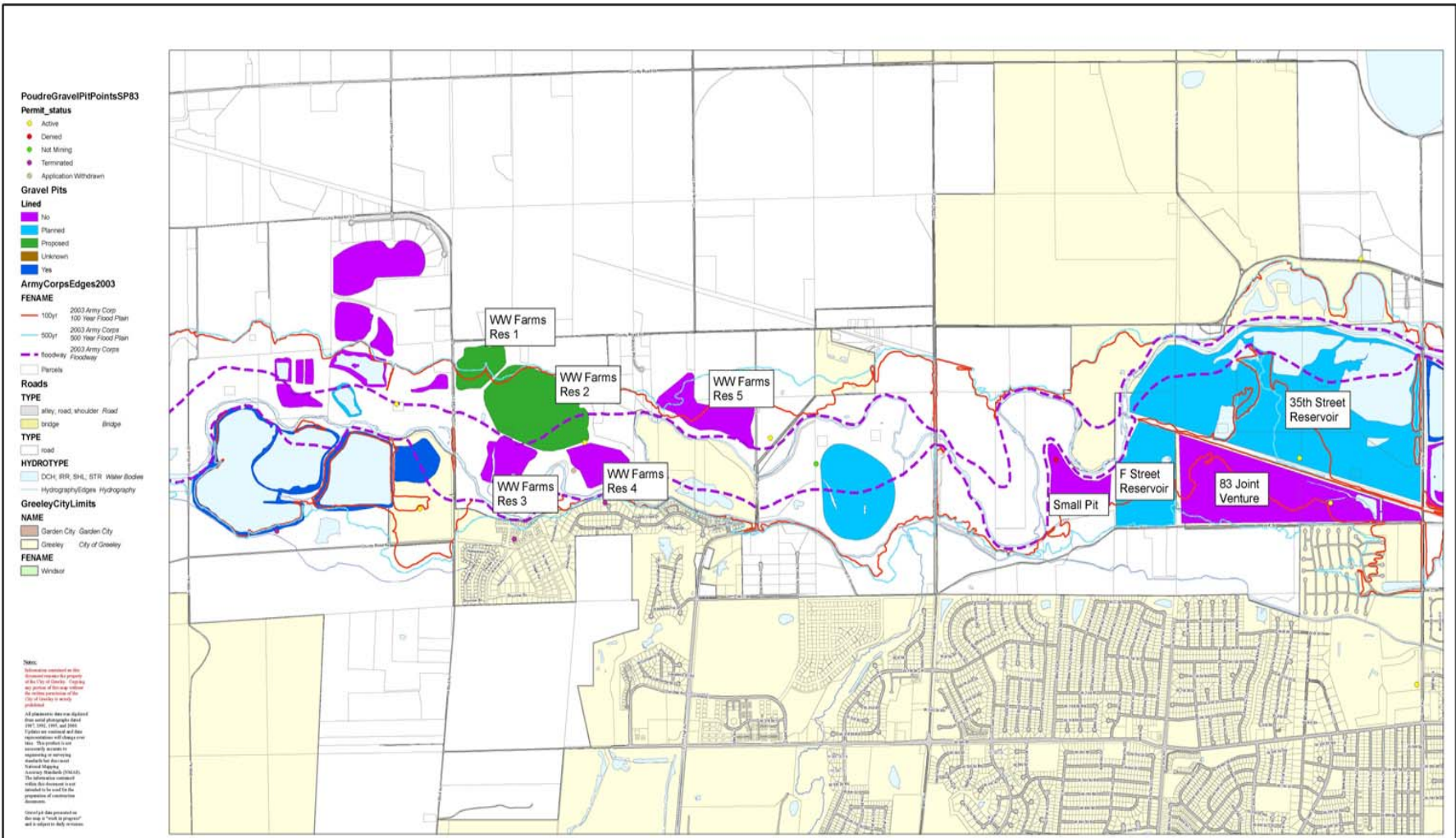
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**GRAVEL PITS**  
**35th Avenue to 95th Avenue**  
**POUDRE GI STUDY**



*City of Greeley, Colorado*  
**DIVISION OF ENGINEERING**

1001 NINTH AVENUE GREELEY, COLORADO 80631

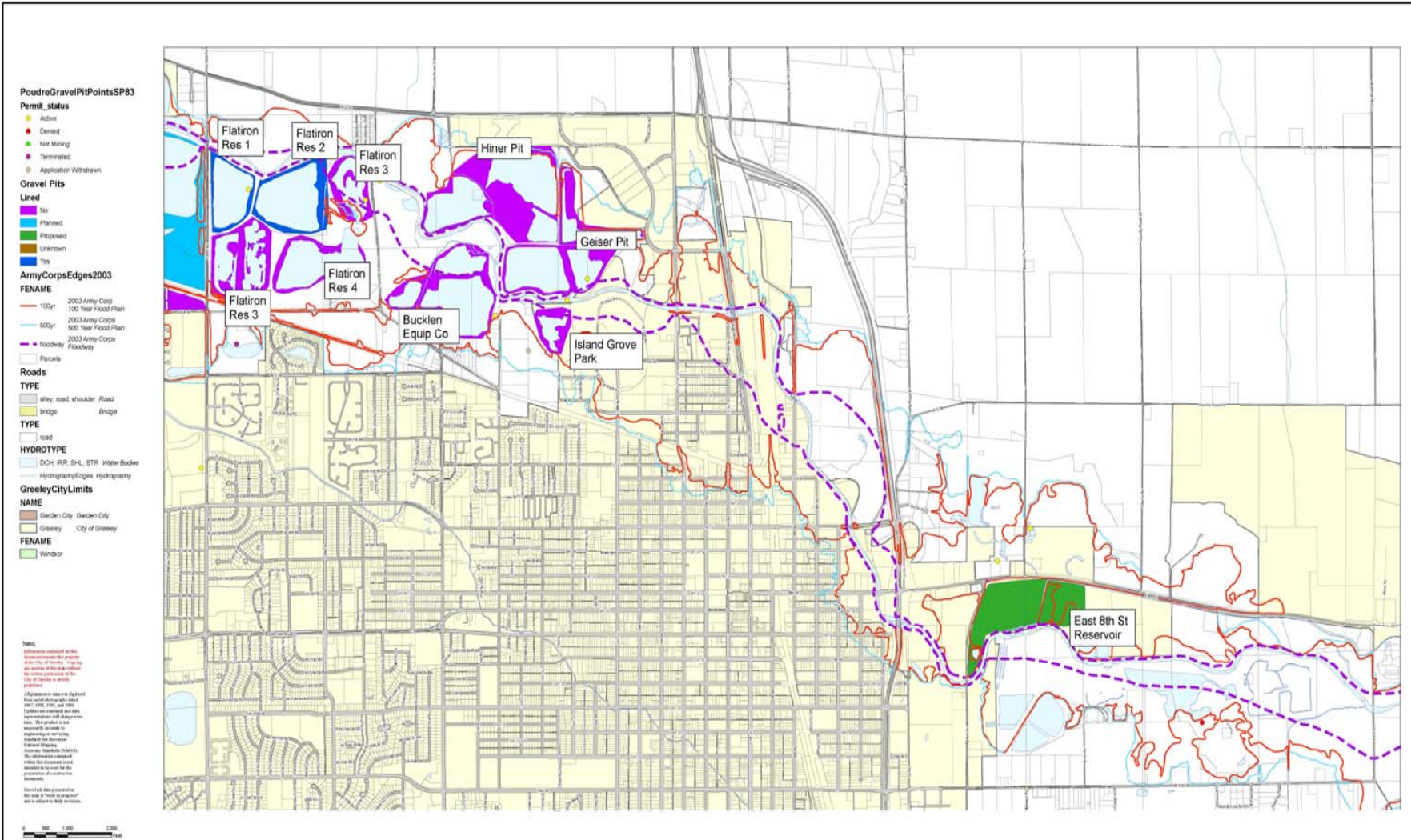
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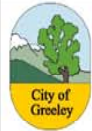
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Plate 1 – Potential Gravel Pit Storage Location (1/2)



**GRAVEL PITS**  
**Fern Avenue to 35th Avenue**  
**POUDRE GI STUDY**



*City of Greeley, Colorado*  
**DIVISION OF ENGINEERING**  
 1001 NINTH AVENUE GREELEY, COLORADO 80631

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Plate 2 – Potential Gravel Pit Storage Location (2/2)



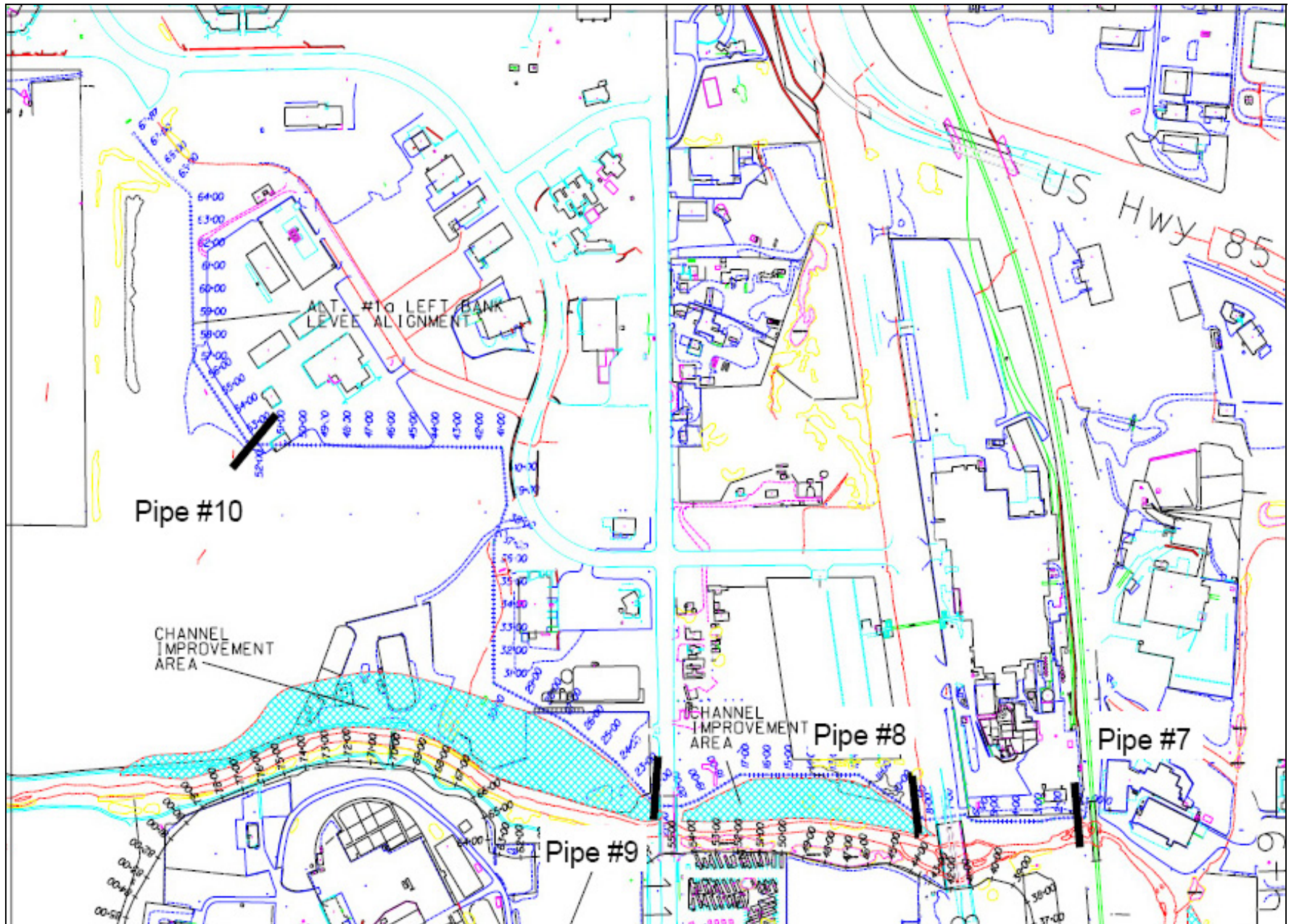


Plate 4 – Interior Drainage Structure Location. Alternative 1a.