Hydrologic Analyses Report

Roaring Fork River
Garfield County
Project # 32790109 - CWCB

Prepared for:

Colorado Water Conservation Board
1313 Sherman St, Denver, CO 80203

1/25/2019

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Garfield, Eagle, and Pitkin County
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List of Acronyms

CDOT	Colorado Department of Transportation
CWCB	Colorado Water Conservation Board
DEM	Digital Elevation Model
FEMA	Federal Emergency Management Agency
FFA	Flood Frequency Analysis
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
HEC-HMS	Hydrologic Engineering Center – Hydrologic Modeling Software
HEC-SSP	Hydrologic Engineering Center – Statistical Software Package
LOMA	Letter of Map Amendment
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
USDA	United States Department of Agriculture
USGS	United States Geological Survey

1.0 Introduction

Wood Environment & Infrastructure Solutions, Inc. (Wood) is working with the Colorado Water Conservation Board (CWCB) to perform a flood frequency analysis (FFA) to examine the flood risk potential for the entire Roaring Fork River Watershed for the Federal Emergency Management Agency (FEMA) that may or may not result in new or updated Flood Insurance Rate Maps (FIRM) and Flood Insurance Study (FIS) reports.

2.0 Scope

New detailed hydrology was developed the Roaring Fork River within Garfield, County. Detailed hydrology was developed using the Bulletin 17C stream gage analysis procedures. A summary of the studied reaches is shown in Table 1. The gage and extent of the Roaring Fork River are displayed in Figure 1.

Figure 1: Roaring Fork River Extents

2.1 Existing Hydrology

2.1.1 Flood Insurance Study

The current Garfield County, Colorado studies define the Roaring Fork River as both Zone A and Zone AE. Previous hydrology was developed from annual peak flow data for snowmelt and rainfall floods published by the USGS and using a composite flow-frequency curve. No flows for the Roaring Fork were listed in Table 1 - Summary of Discharges in the FIS.

2.1.2 Letters of Map Amendment

As of May 2018, five Letters of Map Amendment (LOMA) were previously completed in Garfield County. There were no LOMRs. The LOMAs all removed properties from the Special Flood Hazard Area (SFHA) along the Roaring Fork River.

2.2 Proposed Hydrology

2.2.1 Bulletin 17C Stream Gage Analysis using Log-Pearson Type III and EMA

The U.S. Geological Survey (USGS) gaging station: Roaring Fork River at Glenwood Springs, CO (09085000) was evaluated in the Hydrologic Engineering Center's Statistical Software Package) HEC-SSP Version 2.1.1) using Log-Pearson Type III (LPIII) and Expected Moments Algorithm (EMA) outlined in Bulletin 17C. The annual peak flow data was extracted directly from the USGS and the Colorado Department of Water Resources websites when performing the HEC-SSP Bulletin 17C analysis. Due to the 1968 construction of Ruedi Reservoir on the Frying Pan River Tributary upstream of the gage, flows prior 1968 were adjusted for the analysis as further discussed below. Flows prior to 1935 were similarly adjusted to reflect the 1935 construction of the Twin Lakes Tunnel at the headwaters of the Roaring Fork River. Figure 2 below shows the location of Ruedi Reservoir and Twin Lakes Tunnel.

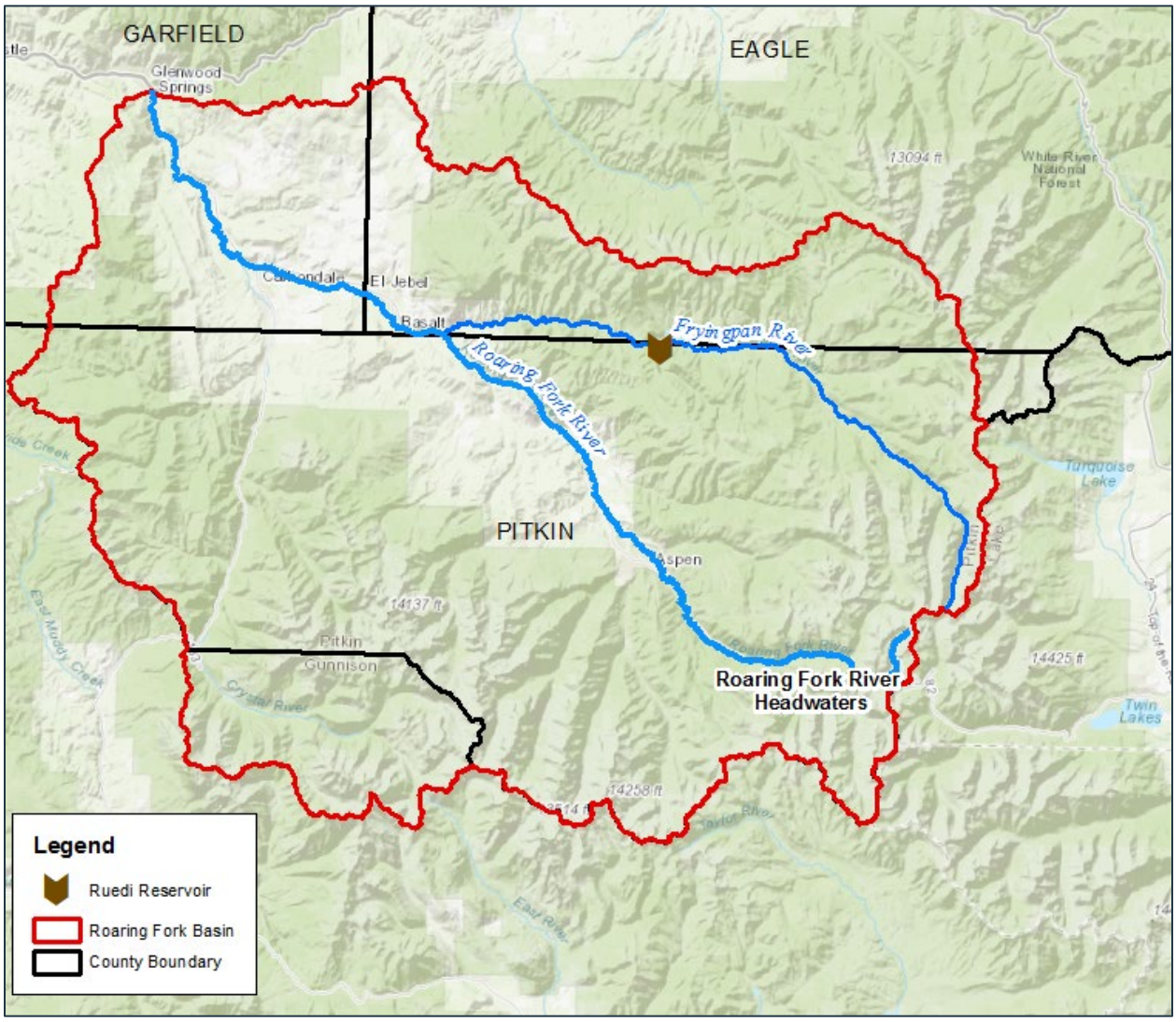

Figure 2: Ruedi Reservoir and Twin Lakes Tunnel Location

Both Ruedi Reservoir and the Twin Lakes Tunnel intercept basin flow that would contribute to the peak flow value recorded at the mouth of the Roaring Fork River. Therefore, the flows prior to the construction of these two structures at the mouth of the Roaring Fork River are higher than what would be expected to be observed under the influence of the two structures. Therefore, the peak flows prior to the construction of the two structures were reduced as described below to allow more data points to be used in the Bulletin 17C analysis.

To determine the reduction in flow from Fryingpan River due to the construction of Ruedi Reservoir, an analysis was performed on the stream gages upstream and downstream of the reservoir to determine the percentage of peak flow intercepted by the structure. The gage downstream of the reservoir is USGS 09080400, Fryingpan River near Ruedi, CO which contains 53 years of peak flow data from 1965-2017. The gage upstream of the reservoir is a combination of USGS 09080100 Fryingpan River at Meredith, CO and Colorado Division of Water Resources (DWR) gage Fryingpan River at Meredith (FRYMERCO) to create a dataset of 38 years of peak flow data from 1911-2017 with data missing from 1915-1966, 1981-1990, 1998-2003, and 2007. The two gages provided 30 years of overlapping peak flow events and were used to determine the influence of the reservoir on peak flow events. It was noted that many annual peak flow events did not occur on the same day; however, to simplify the analysis it was assumed that the peaks were from the same event. This assumption results in higher flow values in the Bulletin 17C analysis which produces more conservative results. Years where peak flow occurred on separate dates and the flow increased downstream compared to upstream were considered outliers and not included in the analysis. The results of this analysis gave an average decrease in peak flow from upstream to downstream of the reservoir of 43%, with a maximum decrease of 82% and a minimum decrease of 13%.

The decrease in peak flow due to Ruedi Reservoir was then compared to the flows at the mouth of the Roaring Fork River near Glenwood Springs to associate the reduction in flow From Ruedi Reservoir with the percentage of flow being intercepted from reaching the mouth of the Roaring Fork River. USGS Roaring Fork River at Glenwood Springs, CO gage 09085000 has 110 peak flow data points from years 1906-2017, with data missing from 1910-1911. All 30 years of overlapping peak flow events analyzed at the reservoir had peak flow data at the Glenwood Springs gage. The result of this analysis gave an average percent peak flow interception of 7.5% of the total peak flow at the mouth of the Roaring Fork River, with a maximum interception of 17%, a minimum decrease of 2.8%, and a sample standard deviation of 4%. As the analysis does not account for other losses within the basin (e.g. attenuation) from other contributing tributaries to the Roaring Fork River, it was determined to select an average decrease in peak flow due to interception of 12% (8% plus one standard deviation) to account for the influence of the reservoir prior to its construction as well as other losses within the basin. This was done over using the more conservative 8% to account for attenuation, inflow from other non-gaged tributaries into the reservoir, and other losses within the basin and downstream of the reservoir to best reflect how the basin responds to the influence of the reservoir.

To determine the reduction in flow from the Twin Lakes Tunnel, which used to divert water from the western slope of the continental divide to the agricultural communities on the eastern slope of the continental divide, the tunnel's max capacity of 625 cfs (Schaack and Anderson, 2001) was removed from flows prior to the tunnel's construction in 1935. Because no data for the Twin Lakes Tunnel could be found prior to 1991, it was assumed that for a given annual peak flow event, the tunnel would be diverting water at its max capacity of 625 cfs.

Given the variable nature of the losses, data used for the Bulletin 17C analysis prior to 1968 were converted to threshold data, with the low values reduced by 12% to represent the influence of the Ruedi Reservoir. The peak data and high flow limits were reduced by 625 cfs prior to the construction of the Twin Tunnels in 1935 from their recorded values with the assumption that the tunnel flows would have been at max capacity during an annual peak flow event. The low flow limits and peak flow values were adjusted as summarized below:

- Peak flow from 1906-1968 was reduced by 12% to account for the influence of Ruedi Reservoir and other in basin irrigation diversions
- 625 cfs was further subtracted from flows 1906-1935 to account for the flow through the Twin Lakes Tunnel.

A Bulletin 17C analysis was performed using the threshold pre-reservoir and tunnel data in addition to the unmodified post-reservoir data. The low outlier threshold was manually set to 4,200 cfs to censor out 11 low outliers which did not fit the general trend of the data. Missing data from 1910 and 1911 was given low perception threshold of 13,000 cfs which was the likely maximum flow value that would have occurred for the missing years based on data from surrounding years.

Skew is a measure of the asymmetry of the probability distribution of a real-valued random variable about its mean. Station Skew option is based solely on computing a skew from the data points contained in the dataset. Station skew is chosen due to the significant record length at the gage and the reaches in question being on major streams and not smaller tributaries.

2.2.2 USGS Quality Codes

USGS quality codes were available for all data used in the analysis. Table 1 shows the codes encountered in the gage data along with an approach of how they were incorporated into the FFA.

Table 1: USGS Quality Codes and Approach

Code #	Description	Approach
1	Discharge is a Maximum Daily Average	Values are investigated further and if one of the top three flows at the gage, possibly increased based on other peak vs. average daily discharge comparison points. If not one of the top three flows, value is treated as a systematic record.
6	Discharge affected by Regulation or Diversion	The Fryingpan River, a tributary to the Roaring Fork, is regulated by Ruedi Reservoir. This results in approximately 12% reduction in peak flow from the basin being regulated at the confluence between the Roaring Fork and the Colorado River. Flows prior to the construction of the reservoir in 1968 were reduced by 12%

2.2.3 Gage Projection

The methodology outlined in the Water Resources Investigations Report 99-4190 "Analysis of the Magnitude and Frequency of Floods in Colorado" was consulted to project gage results to locations on the same stream. This portion of the Roaring Fork within Garfield County is entirely located within the Northwest Region so an exponent (x) of 0.64 as used in Equation (3) from the Water Resources Investigations Report.

$$Q_{T(u)} = Q_{T(g)}(A_u/A_g)^x$$

Equation (3): Peak Discharge Projection

Where $Q_{T(u)}$ is the peak discharge, in cubic feet per second, at the ungaged site for T-year recurrence interval; $Q_{T(g)}$ is the weighted peak discharge, in cubic feet per second, at the gaged site for T-year recurrence interval; A_u is the drainage area, in square miles, at the ungaged site; A_g is the drainage area, in square miles, at the gaged site; and x is the average exponent for drainage area. The peak discharge projection was used to project flows from the Glenwood Springs gage to the locations listed in Table 1 below.

2.2.4 Flood Frequency Analysis Summary

The estimated flood frequency curve and the final flows from the FFA analysis are shown in Figure 3 and Table 2 below. Flow change locations were projected from the Roaring Fork River at Glenwood Springs gage using the methodology outlined in Section 2.2.3.

Table 2: Bulletin 17C Stream Gage Analysis

Gage/Location		Drainage Area (mi^2)	Peak Discharge (cfs)					
Number	Name		10%	4%	2%	1%	1% Plus	0.2%
-	Roaring Fork River at Glenwood Springs, CO	1,460	11,400	13,200	14,400	15,600	16,900	18,000
09085000	Roaring Fork River at Glenwood Springs, CO	1,453	11,400	13,100	14,400	15,500	16,900	17,900
-	Upstream of Cattle Creek	1,280	10,500	12,100	13,200	14,300	15,600	16,500
-	Upstream of Crystal River	904	8,390	9,700	10,600	11,400	12,500	13,200

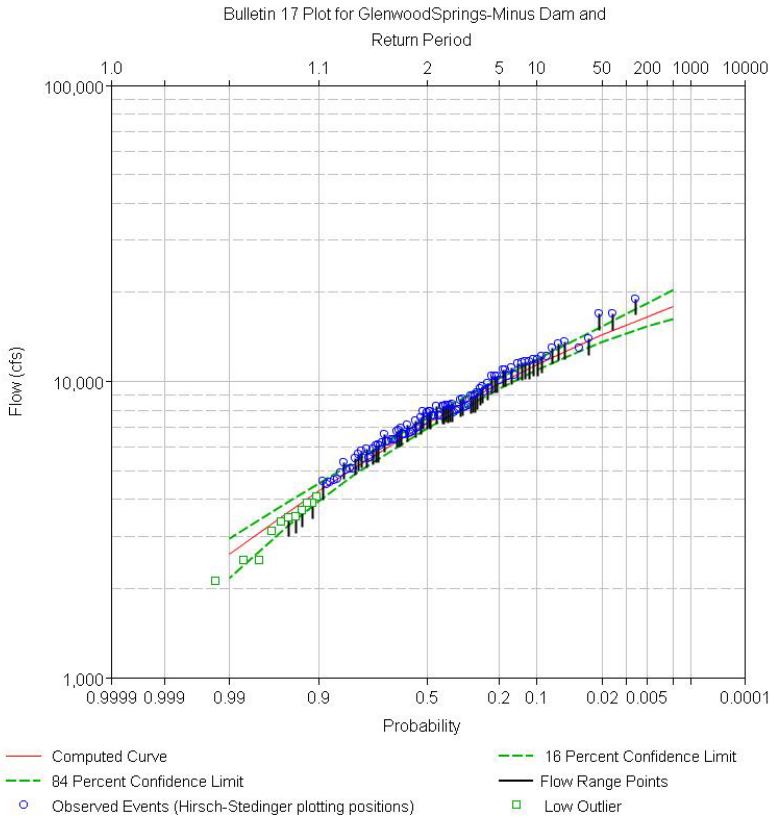

Figure 3: Bulletin 17C Calculated Frequency Curve for
USGS Roaring Fork River at Glenwood Springs, CO Gage 09085000

These flows are reasonable with regards to the developed flows on the Colorado River upstream and downstream of the Roaring Fork. Based on the newly developed flows for the Colorado River (AMEC Foster Wheeler, 2017), how the developed flows tie-in with those developed for the Colorado River for the 1%-annual-chance event are shown below in Table 3:

Table 3: Flow Coordination

Gage/Location	1% Peak Discharge (cfs)
Colorado River – Upstream of the Roaring Fork	23,400
Roaring Fork River – at Glenwood Springs, CO	15,600
Colorado River – Downstream of the Roaring Fork	32,900

3.0 MIP Submittal File Structure

All hydrologic data development TSDN files have been submitted digitally along with this TSDN. The contents have been structured according to the February 2018 Data Capture Standards (DCS) Technical Reference.

4.0 References

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