Hydraulic Analysis and Floodplain Mapping Report

Rock Creek and Tributaries Floodplain Study
Missoula and Granite Counties, MT

July 26, 2021

Contract Number: WO-MM-200
Mapping Activity Statement No. 2019-02

Rock Creek and Tributaries Floodplain Study

Hydraulic Analysis and Floodplain Mapping Report

Missoula County, Montana

Granite County, Montana

PREPARED FOR:

Montana Department of Natural Resources and Conservation

Federal Emergency Management Agency

July 26, 2021

PREPARD BY:

I hereby certify that all work products (maps, reports, etc.) prepared for this project were done so under my direct supervision and that I am a duly Licensed Professional Engineer under the laws of the State of Montana.

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1.0 Introduction and Background

Morrison-Maierle completed the hydraulic analysis for Rock Creek and Tributaries within Missoula and Granite Counties, Montana, as part of the Mapping Activity Statement (MAS) 2019-02, Missoula-Granite Physical Map Revision (PMR) RiskMAP Project (FEMA 2019). This Flood Risk Project was initiated by the Montana Department of Natural Resources and Conservation (DNRC) in partnership with the Federal Emergency Management Agency (FEMA), Missoula County, Granite County, and other stakeholders. The purpose of this report is to document the hydraulic analysis and preliminary floodplain mapping and to provide results for incorporation into revised Flood Insurance Rate Map (FIRM) panels and a new Flood Insurance Study (FIS).

The study limits, per the MAS scope of work, consists of Rock Creek and six Tributary segments within Missoula-Granite Counties with a total length of approximately 73.5 miles. The analysis approach is divided into 5 reaches for Rock Creek: Rock Creek Reach 1 is Enhanced with Floodway, Rock Creek Reach 2 is Enhanced without Floodway, Rock Creek Reach 3 is Enhanced with Floodway, Rock Creek Reach 4 is an Enhanced without Floodway flood study. Rock Creek Reach 5 is Enhanced without Floodway and includes four short tributaries to Rock Creek: Maukey Gulch, Middle Fork Rock Creek, Ross Fork, and West Fork Rock Creek. Two additional tributaries, Ranch Creek and Upper Willow Creek were modeled as stand-alone reaches. Both Ranch Creek and Willow Creek are Enhanced without Floodway. The reaches and analysis approach developed for this project are summarized in Table 1 and Figure 1. Rock Creek is modeled from the north termination point at the at the confluence with the Clark Fork River to the termination of terrain data at the upstream scope of work boundary. Each tributary segment was modeled from its confluence with Rock Creek to the termination of terrain data at the upstream boundary established in the scope of work.

This Hydraulic Analysis and Floodplain Mapping Report presents the information and methods used to develop the one-percent-annual-chance (100-year) and 0.2-percent-annual-chance (500-year) floodplains. This study is based on the highest quality currently available information including LiDAR topography, structure surveys, and a new hydrologic analysis developed specifically for this mapping update. The LiDAR was provided by Quantum Spatial Inc. in 2019 (QSI 2019). The hydrologic analysis for Missoula-Granite Counties Map Modernization Project was completed by Pioneer Technical Services, Inc. in July 2020 (Pioneer 2020a) and was approved by FEMA in 2020. The hydraulic structure survey and hydraulic structure assessment was completed by Pioneer in the May of 2020 (Pioneer 2020c and Pioneer 2020b) and was approved by FEMA in 2020. The bathymetric survey was completed by DOWL in October of 2019 and was approved by FEMA in 2019 (DOWL 2019a).

Table 1. Rock Creek and Tributaries Model Segments

Reach	Stream	Analysis Approach	Length (miles)
1	Rock Creek	Enhanced Level Option E, with Floodway	12.7
2	Rock Creek	Enhanced Level Option E, without Floodway	7.9
3	Rock Creek	Enhanced Level Option E, with Floodway	1.0
4	Rock Creek	Enhanced Level Option E, without Floodway	21.3
5	Rock Creek	Enhanced Level Option E, without Floodway	10.0
	Middle Fork Rock Creek		1.6
	Middle Fork Side Channel		0.3
	Maukey Gulch		0.2
	Ross Fork		1.5
	West Fork Rock Creek		0.8
6	Ranch Creek	Enhanced Level Option E, without Floodway	3.1
7	Upper Willow Creek	Enhanced Level Option E, without Floodway	13.1
		Total	**73.5**

The hydraulic analysis for the seven reaches includes the 10%, 4%, 2%, 1%, 0.2%, and 1%+ annual-chance (AC) flood events. The 1% plus event is defined as a flood event using flood flow rates that include the average predictive error for the discharge calculation for the floodplain study. This flow rate is calculated to provide a confidence range within which the actual 1% AC discharge is likely to fall, given the uncertainty that often exists with estimating discharges (FEMA 2016e). The DNRC and the professional service contractor Morrison-Maierle have completed this study using guidelines and standards published in the FEMA Resource and Document Library to ensure the study complies with the requirements of the National Flood Insurance Program.

1.1 Basin Description

1.1.1 Rock Creek Mainstem

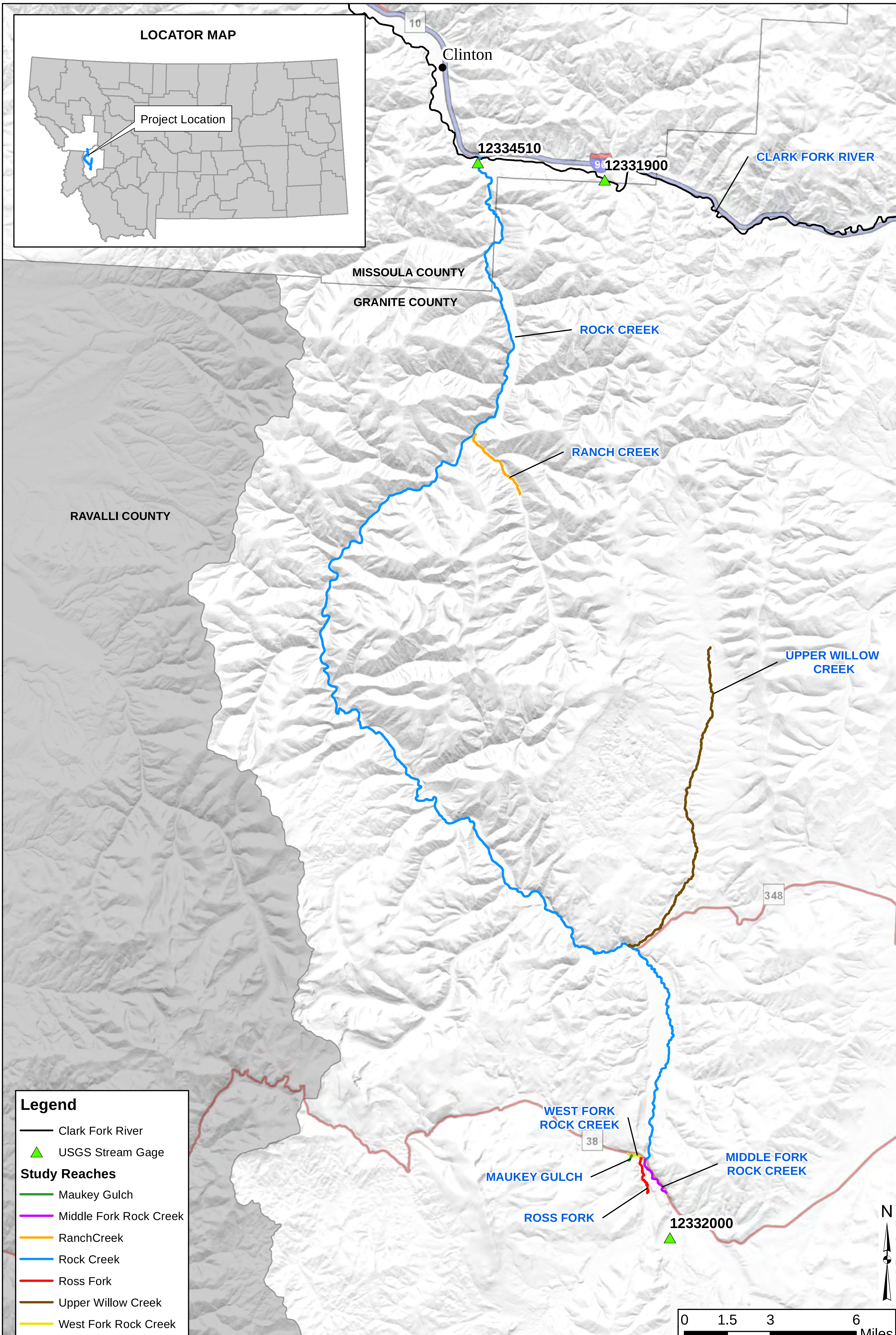
The Rock Creek mainstem is formed by the confluence of West Fork and Middle Fork Rock Creek which originate in the Lolo and Beaverhead-Deerlodge National Forests and the Anaconda-Pintler Wilderness (Pioneer 2020a). Rock Creek is a major tributary to the Clark Fork River and is part of the headwaters of the Columbia River basin in western Montana. The Rock Creek mainstem watershed area encompasses approximately 889 square miles. The terrain varies from a high alpine environment in its headwaters to narrow inter-mountain valleys. The East Fork Rock Creek Dam is a high-hazard dam located on the East Fork Rock Creek, a tributary to the Middle Fork Rock Creek above floodplain study extents. The dam has no flood storage capacity and cannot be utilized for flood routing purposes. The hydrology of the basin is primarily snowmelt driven.

Land use in the study reach is primarily recreational (guest ranches and lodges), with some small farming and ranching operations. The only community within the project bounds is Quigley, Montana. Figure 1 shows the Rock Creek mainstem study reach.

1.1.2 Rock Creek Tributaries

All six Rock Creek Tributary study reaches report to Rock Creek, which is a major tributary to the Clark Fork River and discharges into the Columbia River basin. The study watershed for the Rock Creek tributaries encompasses approximately 522 square miles (Pioneer 2020a). The tributaries and watershed are formed by the Sapphire Mountains, the Anaconda Range, and the John Long Mountains. The terrain varies from a high alpine environment in its headwaters to narrow inter-mountain valleys. The hydrology of the tributary basins is principally snowmelt driven.

The land use in the study reach is primarily rural with isolated residential developments and small irrigated farming and ranching operations along the Rock Creek tributaries. Figure 1 shows the Rock Creek Tributary study reaches.



Morrison Maierle — engineers · surveyors · planners · scientists	1 Engineering Place Helena, MT 59602 Phone: (406) 442-3050 Fax: (406) 442-7862	DRAWN BY: BNC CHK'D BY: LDC APPR. BY: LDC DATE: 6/25/2021	Rock Creek & Tribs Study Area	PROJECT NO. 1447.054
			Missoula-Granite PMR Rock Creek & Tribs Floodplain Study	Figure 1

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2.0 Previous Mapping

Flood Insurance Rate Maps (FIRM's) were completed for Rock Creek in Granite County, Montana in 1982. FIRM panels were issued for Rock Creek in Missoula County in 1983 with Zone A mapping and revised in 1985 to floodplain delineation and elevations in agreement with the Granite County FIRM panels. Both Granite and Missoula County floodplain mapping was updated under the FEMA program to transition older studies to digital mapping. A datum conversion to NAVD88 for the Rock Creek floodplain mapping was included in the FIRM map updates. The effective FIRM panels for Rock Creek in Granite County are dated April 2016 and the effective FIRM panels for Missoula County are dated July 2015.

The flood hazard currently mapped for Rock Creek is Zone AE with floodway for approximately 12.4 creek-miles above the confluence with the Clark Fork River within Granite County, Montana and within Missoula County to the Missoula-Granite county boundary. A second small portion of model backed Zone AE with floodway beginning approximately 20.8 miles above the confluence with the Clark Fork River is also included in the effective mapping. The second portion of Zone AE with floodway extends along Rock Creek for approximately 0.8 miles. The stream reach between the Zone AE with floodway reaches of Rock Creek is mapped as Zone A in the effective FIRM panels. The Zone A mapping of Rock Creek extends upstream to the beginning of Rock Creek at the confluence of Middle Fork and West Fork Rock Creek, approximately 53 miles above the confluence with the Clark Fork River. Effective floodplain mapping for the Rock Creek stream system in Granite County also includes Zone A mapping of Maukey Gulch (≈0.2 miles), Middle Fork Rock Creek (≈1.4 miles), Ranch Creek (≈2.7 miles), Ross Fork Rock Creek (≈1.2 miles), Upper Willow Creek (≈11.6 miles), and West Fork Rock Creek (≈0.6 miles). The reported mapped lengths reflect valley centerline length estimates.

Computer modeling was not completed to determine the Zone A delineations and the Zone AE with floodway delineations were prepared from HEC-2 computer modeling. A Flood Insurance Study (FIS) report was published with the original FIRM panels for Granite County. FIS report publishing lagged behind FIRM panel publishing in Missoula County, with the first FIS report available on the FEMA Map Service Center dated August 1988. The Rock Creek and tributaries Zone A flood maps were developed using approximate study methodologies, do not include Base Flood Elevations (BFEs), and have flood hazard zone boundary without hydraulic modeling support. This level of flood mapping is often used in rural areas with low populations. Zone A flood maps can be difficult for local communities to manage or administer since they do not include BFE information. This floodplain study will change the flood zones on the maps of the Rock Creek and the six tributaries to Zone AE and will include BFE's for these streams.

3.0 Hydrology

The study included a comprehensive hydrologic peak flow analysis for Rock Creek and selected Tributaries as shown on Figure 1. The area encompassed, a 53-mile reach of Rock Creek mainstem and 19.8 miles of the 6 Rock Creek tributaries. In total, the Rock Creek watershed is approximately 889 square miles within Missoula and Granite Counties. As part of the Missoula-Granite PMR project, the Montana Department of Natural Resources and Conservation (DNRC) contracted Pioneer Technical Services to complete a comprehensive hydrologic analysis of peak flows including flood flow frequency calculations for all ungaged flow node locations (Pioneer 2020a).

3.1 Rock Creek Mainstem

Rock Creek Mainstem encompasses the watershed from the Sapphire Mountains, the Anaconda Range, and the John Long Mountains which is approximately 889 square miles of watershed. Within the Rock Creek Mainstem study reach, 12 locations were identified as having significant changes in streamflow or being at a critical location (flow nodes). Of the 12 flow nodes, one is located at an active USGS stream gage site, one is at an inactive USGS stream gage site, and 10 are ungaged sites that are located upstream of the stream gage site.

3.1.1 Rock Creek Mainstem USGS Stream Gage Analysis

At the gaged sites all peak flood discharges were derived from gage data using Bulletin 17C methodologies. Peak flood discharge estimates at the Middle Fork Rock Creek gage and the Rock Creek mainstem gage were developed by the USGS using a peak flow flood frequency analysis based on the systematic gage data. To address non-congruent periods of records between the gages, the USGS performed a MOVE.3 analysis 3 (Maintenance of Variance Extension, Type 3), which extended the period of record of each gage. Higher confidence is associated with longer periods of record; therefore, the extended record values were used in this analysis. Information on the two USGS gages is shown in Table 2 and the locations are displayed in Figure 1.

Table 2. Rock Creek Mainstem USGS Gaging Station

USGS Gage Station Number	Station Name	Regulation Status as of 2018	Total Number of Years of Peak-Flow Records	Total Period of Record, in Water Years	2018 Status
12334510	Rock Creek near Clinton, MT	U	47	1972-2018	Active
12332000	Middle Fork Rock Creek near Phillipsburg, MT	U	81	1938-2018	Active

U: Unregulated stream.

3.1.2 Rock Creek Mainstem Gage Flood Frequency Estimates

The USGS performed an at-site gage analysis and a MOVE.3 analysis for the Rock Creek Mainstem Stations (USGS 2019). These gage analyses were used to develop estimates for 11 flood change (node) locations using the 2-site logarithmic interpolation method. Results of Annual Equivalent Peak (AEP) discharges for systematic and weighted flood frequency estimates with regional regression equations for the USGS gages located along Rock Creek mainstem and on Middle Fork Rock Creek are provided in Table 3.

Table 3. Rock Creek Mainstem USGS Gage Flood Frequency Estimates

USGS Gage Station Number	Station Name	Peak Flood Frequency Method	AEP Peak Discharge (cfs) for indicated exceedance probability (%)					
			50	10	4	2	1	0.2
			Peak Discharge (cfs), for indicated return interval (years)					
			2	10	25	50	100	500
12334510	Rock Creek near Clinton, MT	At-Site	3,130	5,520	6,580	7,320	8,010	9,460
		MOVE.3	3,340	5,780	6,900	7,690	8,440	10,100
12332000	Middle Fork Rock Creek near Phillipsburg, MT	At Site	901	1,440	1,650	1,800	1,930	2,190
		MOVE.3	902	1,500	1,750	1,920	2,070	2,390

MOVE.3: Maintenance of Variance Extension, Type III

3.1.3 USGS Gage 1%+ Peak Flow Analysis

The 1%+ AEP event was calculated by USGS in accordance with FEMA guidance (FEMA 2019) to provide a confidence range that the 1% flood frequency peak flow estimates are likely to fall within (Pioneer 2020a). The upper 84% confidence limit calculated in the gage analysis was used by USGS to determine the 1%+ flood frequency peak flow estimates (FEMA 2016b). The Rock Creek Mainstem 1%+ flood frequency peak flow estimates for the gages located on the Rock Creek Mainstem and Middle Fork Rock Creek are listed in Table 4.

Table 4. Rock Creek Mainstem USGS Gage 1%+ Peak Flow Analysis

USGS Gage Station Number	Station Name	Drainage Area (sq. mi)	1% + AEP Peak discharge, At-Site (cfs)	1% + AEP Peak discharge, MOVE.3 (cfs)
12334510	Rock Creek near Clinton, MT	885	10,100	10,000
12332000	Middle Fork Rock Creek near Phillipsburg, MT	123	2,210	2,370

3.1.4 Rock Creek Mainstem Flow Change Node Locations

Pioneer completed a detailed review of the study area to identify all potential flow change locations (flow nodes) within the Rock Creek Mainstem study (Pioneer 2020a). Using ArcGIS, the flow nodes were generally located based on the USGS HUC-12 delineated watershed boundaries. A drainage basin area was delineated at each flow node and streamflow values were calculated for the various recurrence interval floods using the 2-site logarithmic interpolation method.

Flow nodes were assigned for two gage locations and ten ungaged locations to account for additional flow resulting from tributary confluence and to accurately reflect flows in the reach downstream of the confluence. Each flow node was located directly upstream of a significant confluence. The ungaged flow nodes were generally assigned the nearest GNIS hydrographic feature name and the gaged flow nodes were assigned the USGS gage number.

FEMA guidance requirements were referenced to address the issue of coincident peaks between the Clark Fork River and Rock Creek Mainstem. For the assumption of coincident peaks to be appropriate, FEMA guidance documents (FEMA 2016b) require the following criteria be met:

1. The ratio of the drainage areas lies between 0.6 and 1.4.
2. The arrival times of flood peaks are similar for the two combining watersheds.
3. The likelihood of both watersheds being covered by the storm being modeled is high.

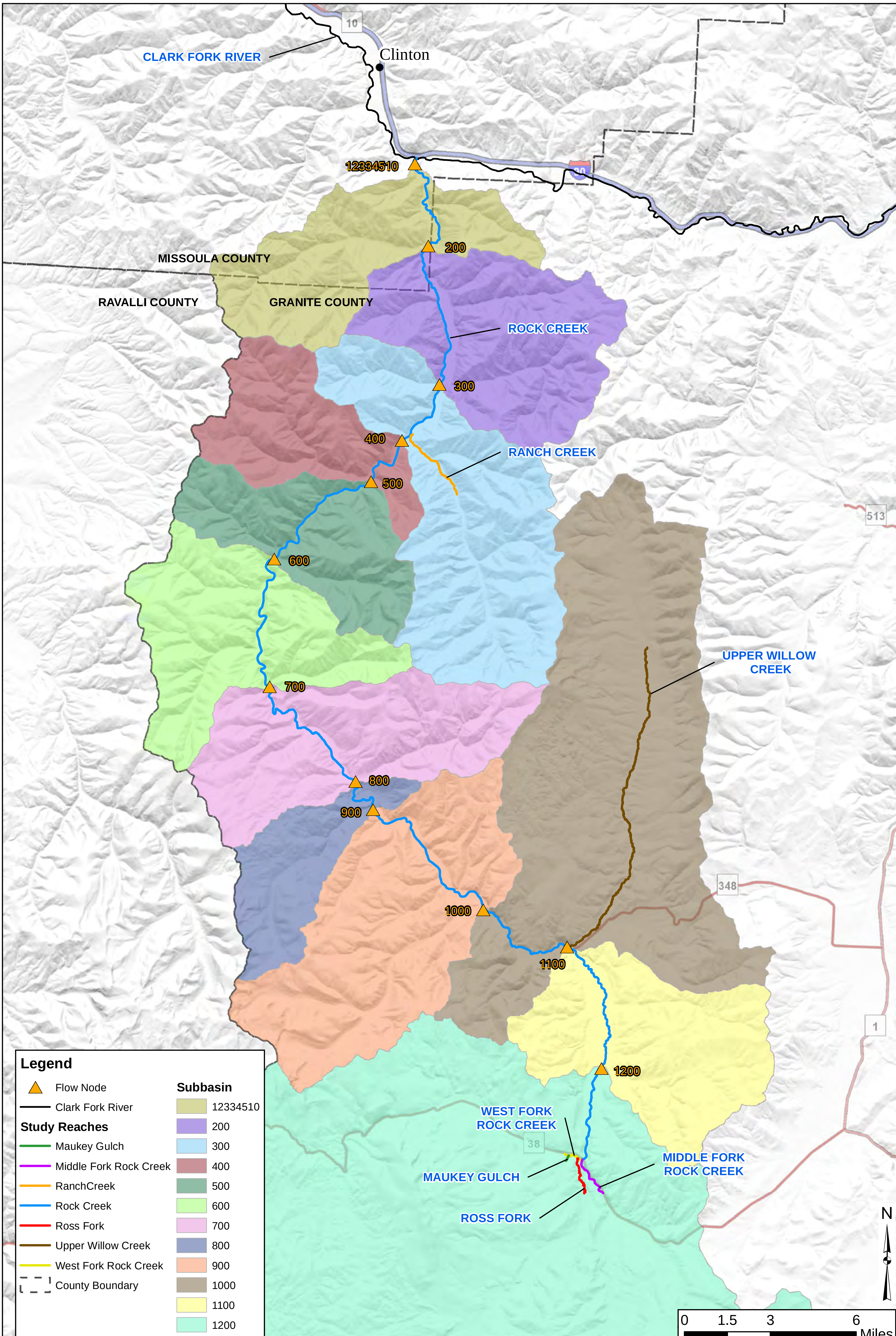
The Rock Creek Mainstem drainage area at the confluence with the Clark Fork River is not within the drainage ratio of 0.6 to 1.4. Pioneer noted that the drainage area ratio criteria was not met and, therefore, coincident peaks were not further considered (Pioneer 2020a). Rock Creek Mainstem flow nodes used in this study are summarized in Table 5 and the Rock Creek Mainstem flow nodes and sub-basin locations are shown on Figure 2.

FEMA floodplain studies are generally prepared using hydraulic models which simulate steady-state conditions. The steady-state option is used for 1D model development. In steady-state models, the peak flow rate calculated for each flow node is projected to the next upstream flow node.

Table 5. Rock Creek Mainstem Flow Nodes

Node/USGS Station ID	Location Description	River Mile Where Accumulated Flow Computed	Calculated Basin Area[2] (sq. mi)	Tributary
12334510	Rock Creek near Clinton, MT	0.3	888	Rock Creek
200	Gilbert Creek	4.3	854	Rock Creek
300	Brewster Creek	9.8	811	Rock Creek
12333500	Rock Creek above Quigley, MT	12.4	756	Rock Creek
500	Welcome Creek	14.7	731	Rock Creek
600	Rock Creek-Wahlquist Creek	19.7	702	Rock Creek
700	Rock Creek-Hutsinpilar Creek	25.5	662	Rock Creek
800	Hogback Creek	31.3	619	Rock Creek
900	Wyman Gulch	33.3	601	Rock Creek
1000	Rock Creek-Flat Gulch	39.7	543	Rock Creek
1100	Lower Upper Willow Creek	43.8	431	Rock Creek
1200	Mallard Creek	49.3	390	Rock Creek
12332000*	Middle Fork Rock Creek near Phillipsburg, MT	NA	121	Rock Creek

1. River miles start at the downstream extent of each study reach (mi: miles).
2. Basin Area in square miles (sq. mi).



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Rock Creek Mainstem
Flow Node Locations

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Figure 2

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3.1.5 Rock Creek Mainstem Discharges

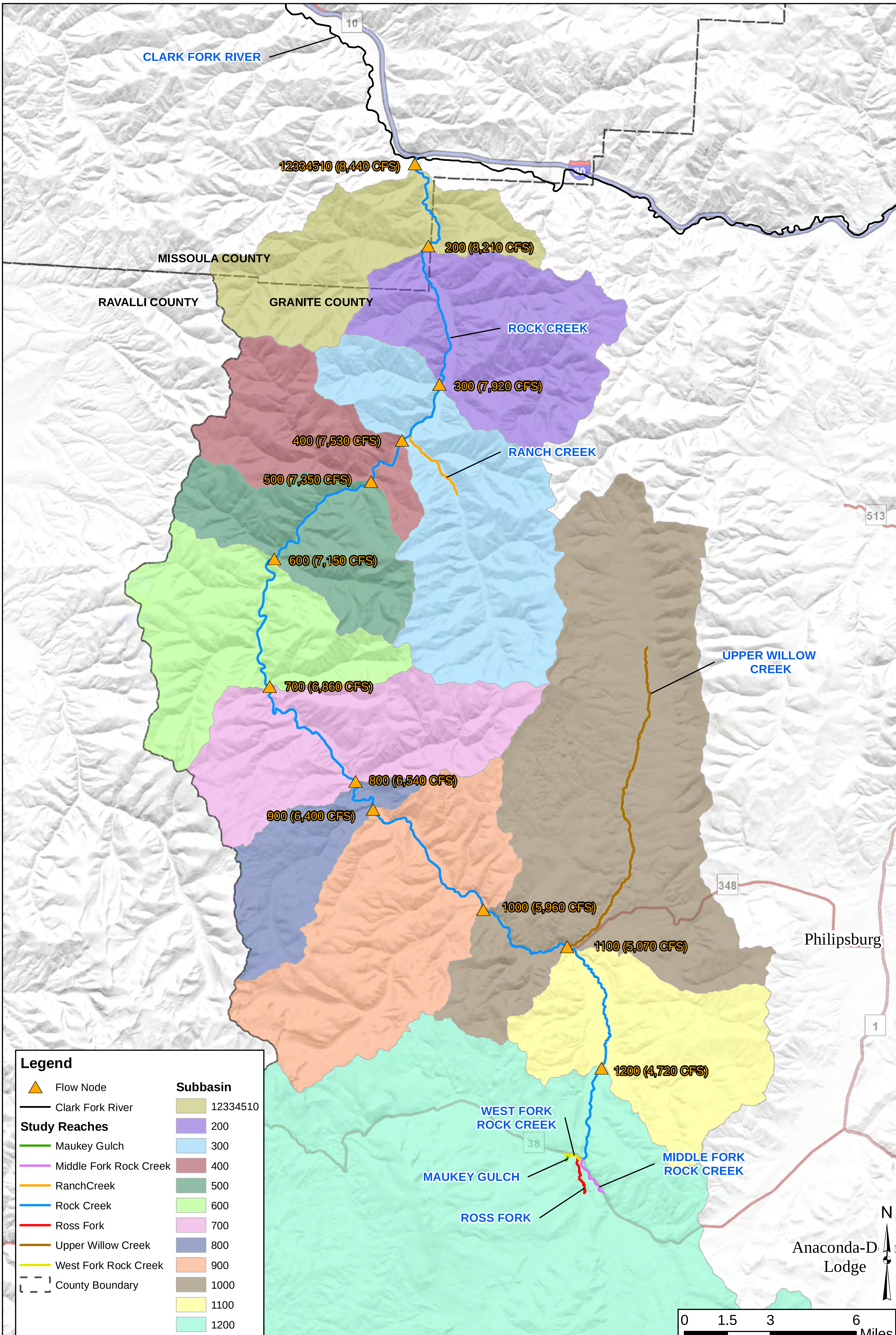
Peak flood discharges for Rock Creek Mainstem were estimated at the ungaged flow nodes using Bulletin 17C methodologies translating gaged data to ungaged locations (drainage-area ratio adjustment or logarithmic interpolation between two gaged sites) from the MOVE.3 methods at the gaged locations. Peak flow discharges were computed for all flow nodes for the 50, 10, 4, 2, 1, 0.2% and 1%+ AEP events. Peak flow discharges for gage station 12332000 were not included since it is outside the study of reach.

Flood frequency discharge rates recommended in the Pioneer Hydrology Report for the Rock Creek Mainstem study reaches are summarized in Table 6. The 1% AEP discharge for each flow node location is shown on Figure 3. This hydrologic analysis conforms to FEMA standards for enhanced level studies and was approved by FEMA in 2020.

Table 6. Rock Creek Mainstem Summary of Discharges

Node/USGS Station ID	Location Description	Estimated Discharge (cfs) 50% Annual Chance 2-year	10% Annual Chance 10-year	4% Annual Chance 25-year	2% Annual Chance 50-year	1% Annual Chance 100-year	0.2% Annual Chance 500-year	1% + Annual Chance 100-year-plus
1200	Mallard Creek	1,940	3,310	3,920	4,340	4,720	5,570	5,520
1100	Lower Upper Willow Creek	2,080	3,540	4,190	4,650	5,070	5,990	5,930
1000	Rock Creek-Flat Gulch	2,420	4,140	4,920	5,460	5,960	7,070	7,010
900	Wyman Gulch	2,580	4,430	5,270	5,860	6,400	7,610	7,540
800	Hogback Creek	2,640	4,530	5,380	5,980	6,540	7,780	7,710
700	Rock Creek-Hutsinpilar Creek	2,750	4,740	5,640	6,270	6,860	8,170	8,090
600	Rock Creek-Wahlquist Creek	2,860	4,930	5,870	6,530	7,150	8,520	8,440
500	Welcome Creek	2,940	5,060	6,030	6,710	7,350	8,770	8,680
400	Ranch Creek	3,000	5,180	6,170	6,870	7,530	8,990	8,900
300	Brewster Creek	3,150	5,440	6,480	7,220	7,920	9,460	9,370
200	Gilbert Creek	3,250	5,630	6,710	7,480	8,210	9,810	9,720
12334510	**Rock Creek near Clinton MT**	**3,340**	**5,780**	**6,900**	**7,690**	**8,440**	**10,100**	**10,000**

cfs: cubic feet per second.



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Rock Creek Mainstem
1% AEP Discharges

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Figure 3

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3.2 Rock Creek Tributaries

Rock Creek Tributaries encompass a total of six tributaries and 607 square miles. The tributaries are formed by the watershed from the Sapphire Mountains, the Anaconda Range, and the John Long Mountains. Within the Rock Creek Tributaries study reaches, nine locations were identified as having significant changes in streamflow or being at a critical location (flow nodes). All nine flow nodes are ungaged locations that have significant changes in streamflow.

3.2.1 Rock Creek Tributaries USGS Stream Gage Analysis

At the gaged sites all peak flood discharges were derived from gage data using Bulletin 17C methodologies. Bulletin 17C methods were used to estimate the 50, 10, 4, 2, 1, and 0.2% AEPs and the 1%+ AEP for gages with more than 10 years of record. Peak flood discharges for the Rock Creek Tributaries were conducted by the USGS using the peak flow flood frequency analysis and the systematic gage data. The USGS gage 12332000 has the oldest recorded data beginning in 1938 and remains active. The FEMA guidance document (FEMA, 2019) indicates that gage station records equal or exceeding 10 years in length are applicable to all types of studies. To address the non-congruent periods of record, USGS employed the MOVE.3 method to extend the historical gage record used in this analysis (Pioneer 2020a). The gages used in this study meet this criterion. The two USGS gages are shown below in Table 7 and the locations are displayed in Figure 1.

Table 7. Rock Creek Tributaries USGS Gaging Station

USGS Gage Station Number	Station Name	Regulation Status as of 2018	Total Number of Years of Peak-Flow Records	Total Period of Record, in Water Years	2017 Status
12334510	Rock Creek near Clinton, MT	U	47	1972-2018	Active
12332000	Middle Fork Rock Creek near Phillipsburg, MT	U	81	1938-2018	Active

3.2.2 USGS Gage 1%+ Peak Flow Analysis

The USGS calculated the 1%+ AEP event to provide a confidence interval for the 1% flood frequency peak flow estimates. FEMA guidance defines the 1%+ as "…a flood elevation derived by using discharges that are at the upper 84-percent confidence limit as calculated in the gage analysis for the 1-percent-annual-chance event for the Flood Risk Project. Methods for estimating synthetic statistics outlined in Bulletin 17C Appendix 7 are used to estimate the upper 84 percent confidence limit of the Log Pearson III frequency Curve at the 1-percent-annual-chance event" (FEMA 2019). The USGS analysis resulted in the Rock Creek Tributaries' peak flow estimates that are displayed in Table 8.

Table 8. Rock Creek Tributaries USGS Gage Flood Frequency Estimates

USGS Gage Station Number	Station Name	Drainage Area (sq. mi)	1% + AEP Peak discharge, At-Site (cfs)	1% + AEP Peak discharge, MOVE.3 (cfs)
12334510	Rock Creek near Clinton, MT	885	10,100	10,000
12332000	Middle Fork Rock Creek near Phillipsburg, MT	123	2,210	2,370

cfs: cubic feet per second.
sq. mi: square miles

For the ungaged locations where USGS regional regression methods were used for peak discharge estimates, the 1%+ discharge was computed from the predictive error for the regression equation discharge calculation (Pioneer 2020a).

3.2.3 Rock Creek Tributaries Flow Change Node Locations

Pioneer completed a detailed review of the study area to identify all potential flow change locations (flow nodes) within the Rock Creek Tributaries study (Pioneer 2020a). At each flow node, a drainage basin area was delineated, and streamflow values were calculated for the various recurrence interval floods using the USGS StreamStats website.

Flow nodes were assigned the nine ungaged locations to account for additional flow resulting from tributary confluence and to accurately reflect the reach downstream of the confluence. Drainage basin areas were generally measured using ESRI ArcGIS software. Low-gradient topographic conditions related to drainage basins for nodes 700 and 900 required checking and revision of drainage basin areas using USGS's StreamStats. Using ArcGIS, Rock Creek Tributaries' flow nodes were located just upstream of each tributary confluence with Rock Creek or HUC 12 watershed boundaries where multiple flow nodes were assigned for a tributary (i.e. Upper Willow Creek nodes 300 and 400 and West Fork Rock Creek node 700). In the study, the nearest GNIS hydrographic feature and location description was used to name the ungaged flow nodes.

All other unregulated flow nodes were estimated using the USGS Regional Regression equations. Variables used in the regression equation for Rock Creek Tributaries included the drainage area size, the percent of the basin with forest land cover, and the mean annual precipitation. The drainage area was calculated using ESRI ArcGIS mapping software and the forest land cover and the mean annual precipitation were calculated using USGS's StreamStats online application. With this analysis, Pioneer noted that the results indicate increasing flow magnitude with increasing drainage area. Flow nodes for the Rock Creek tributaries are summarized in Table 9 and the flow nodes and related sub-basin locations are shown on Figure 4.

Table 9. Rock Creek Tributaries Flow Nodes

Node/USGS Station ID	Location Description	River Mile Where Accumulated Flow Computed	Calculated Basin Area[2] (sq. mi)	Tributary
1234510	Rock Creek near Clinton, MT	NA	888	Middle Fork Rock Creek
100	Ranch Creek at junction with Rock Creek	0.4	43	Ranch Creek
200	Upper Willow Creek at junction with Rock Creek	0	95	Upper Willow Creek
300	Middle Upper Willow Creek	5.6	76	Upper Willow Creek
400	Upper Upper Willow Creek	11.8	46	Upper Willow Creek
500	Middle Fork Rock Creek at junction with Rock Creek	0.1	203	Middle Fork Rock Creek
12332000*	Middle Fork Rock Creek near Phillipsburg, MT	NA	121	Middle Fork Rock Creek
600	West Fork Rock Creek at junction with Rock Creek	0	178	West Fork Rock Creek
700[3]	Lower West Fork Rock Creek	0	93	West Fork Rock Creek
800	Ross Fork at junction with West Fork Rock Creek	0	85	Ross Fork
900[3]	Maukey Gulch at junction with West Fork Rock Creek	0.1	3	Maukey Gulch
1234510	Rock Creek near Clinton, MT	NA	888	Middle Fork Rock Creek
100	Ranch Creek at junction with Rock Creek	0.4	43	Ranch Creek

1. River miles start at the downstream extent of each study reach (mi: miles).
2. Basin Area in square miles (sq. mi).

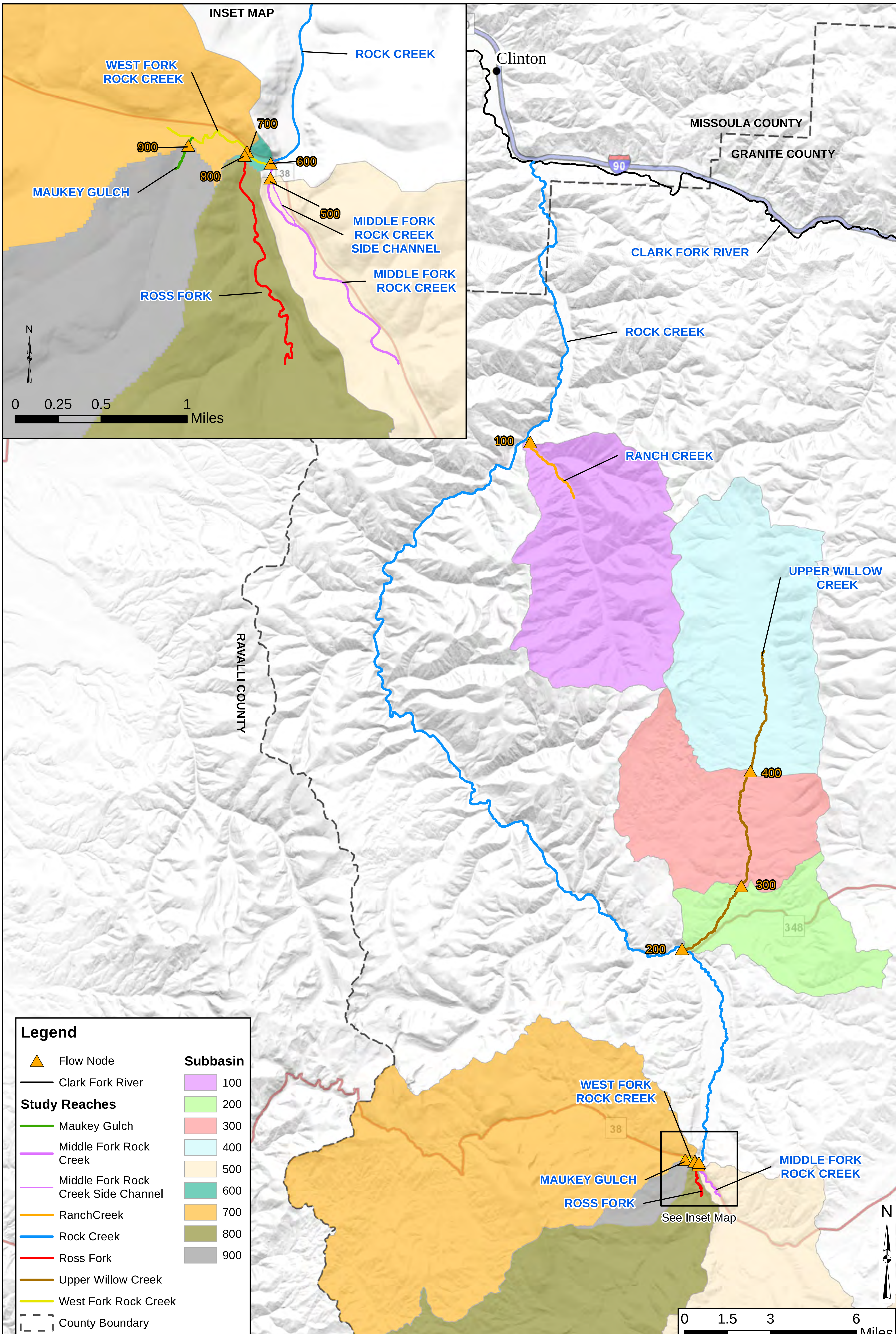

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Figure 4

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3.2.4 Rock Creek Tributaries' Discharges

To calculate peak flood discharge estimates at the ungaged flow nodes, Pioneer considered multiple methods for estimating flood frequency. These methods included regional flood-frequency (regression analysis) and estimating flood frequency on gaged streams using both gaged data translation to ungaged locations by drainage area ratio adjustment from a single stream gage station and logarithmic interpolation between two gaged sites. The two-site logarithmic interpolation method was selected for the Middle Fork Rock Creek (node 500) since it is located between two USGS gaged sites on Rock Creek and Middle Fork Rock Creek.

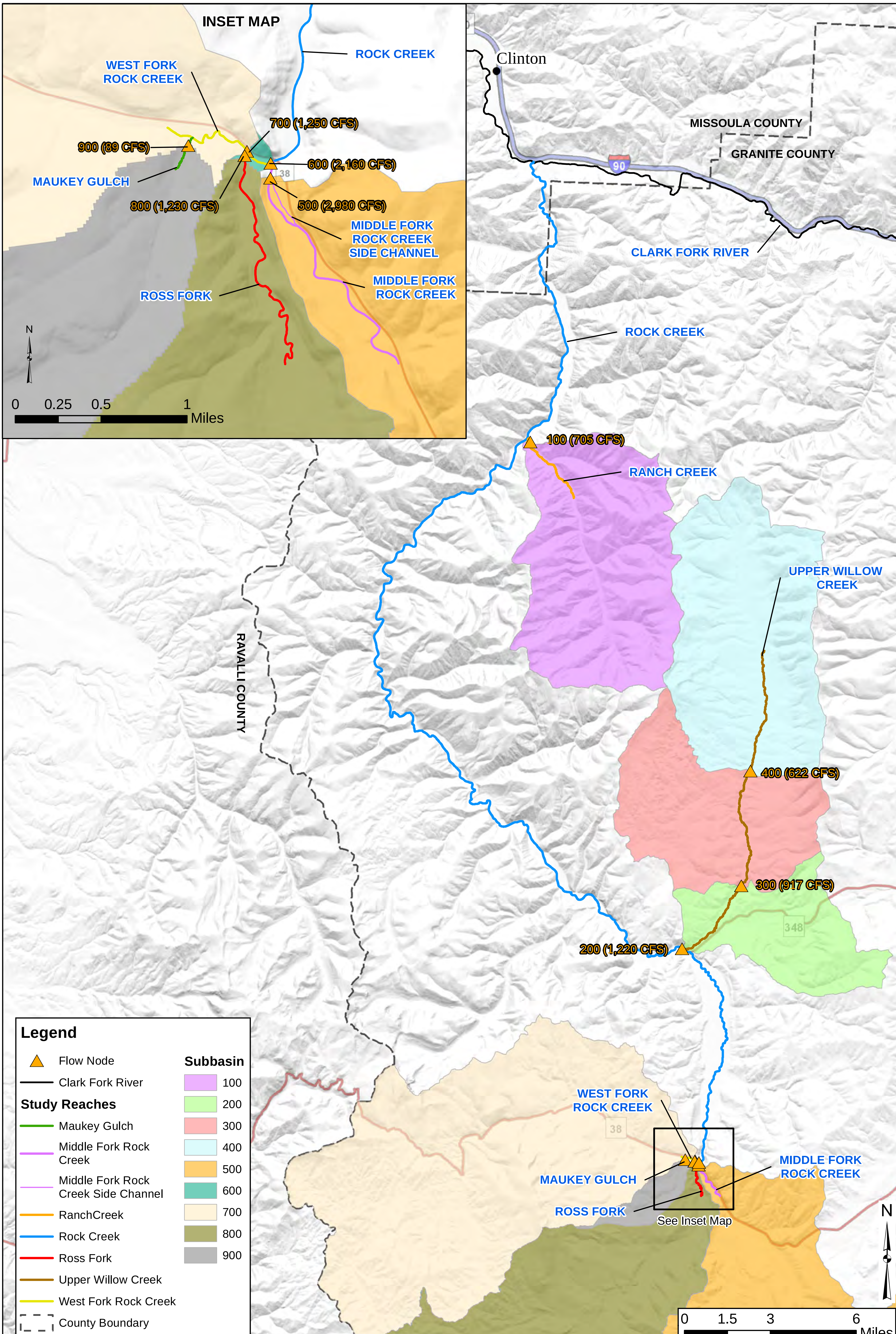
Pioneer used the regional regression method for the other eight Rock Creek Tributaries flow node locations (Pioneer 2020a). The flow nodes are not regulated by upstream dams and the flow nodes are located within the Montana West Region (USGS, 2015a). The regression equations use drainage area (A), percentage of drainage basin with forest land cover (F), and the mean annual precipitation of the watershed (P). Peak flow estimates for the 50-, 10-, 4-, 2, 1-, 0.2% and 1%+ AEP events were recommended for the flood study.

The flood frequency discharge rates recommended in the Pioneer Hydrology Report for the Rock Creek Tributaries study reaches are summarized in Table 10. The 1% AEP discharge for each flow node location is shown on Figure 5. This hydrologic analysis conforms to FEMA standards for enhanced level studies and was approved by FEMA in 2020. Note that the statistically derived flow for the 1%+ AC flow profile is higher than the 0.2% AC flow profile at Rock Creek Tributaries node 600 and less than the 0.2% flow profile for the downstream of the confluence with Middle Fork Rock Creek. The shift in relationship between these flows creates a crossing profile just upstream of the location where the flow change occurs.

Table 10. Rock Creek Tributaries Summary of Discharges

Node/USGS Station ID	Location Description	Estimated Discharge (cfs)						
		50% Annual Chance	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance	1% + Annual Chance
		2-year	10-year	25-year	50-year	100-year	500-year	100-year-plus
900	Maukey Gulch at junction with West Fork Rock Creek	13	39	56	72	89	134	139
800	Ross Fork at junction with West Fork Rock Creek	355	723	908	1,060	1,230	1,590	1,920
700	Lower West Fork Ross Creek	374	749	935	1,090	1,250	1,620	1,950
600	West Fork Rock Creek at junction with Rock Creek	688	1,330	1,640	1,900	2,160	2,750	3,370
500	Middle Fork Rock Creek at junction with Rock Creek	1,270	2,130	2,500	2,750	2,980	3,480	3,450
400	Upper Upper Willow Creek	159	348	448	533	622	828	970
300	Middle Upper Willow Creek	229	509	657	784	917	1,230	1,430
200	Willow Creek at junction with Rock Creek	297	668	868	1,040	1,220	1,640	1,900
100	Ranch Creek at junction with Rock Creek	206	418	524	613	705	911	1,100

cfs: cubic feet per second.



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Rock Creek Tributaries
1% AEP Discharges

Missoula-Granite PMR
Rock Creek & Tribs Floodplain Study

PROJECT NO.
1447.054

Figure 5

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4.0 Hydraulics

The methods and techniques used to complete the hydraulic analysis for Rock Creek and Tributaries within Missoula and Granite Counties, Montana are presented in the following sections. The analysis utilized LiDAR mapping and field hydraulic structure assessments to develop the Enhanced Level Option E, 1% AC Zone AE and 0.2% AC Zone X. The Rock Creek analysis included a floodway on two reaches and the rest of Rock Creek and Tributaries were developed without a floodway.

4.1 Hydraulic Analysis

This flood study covers Rock Creek and selected tributaries within Missoula and Granite Counties, Montana. The study area, as shown on Figure 1, consists of reaches of the following five streams: Rock Creek, Ranch Creek, Upper Willow Creek, Middle Fork Rock Creek, Ross Fork, Maukey Gulch and West Fork Rock Creek. The studied length of each reach is summarized in Table 1.

Standard engineering practice, HEC-RAS modeling guidance, and FEMA Guidance were followed for the hydraulic model development. FEMA Guidance documents specifically pertinent to hydraulic modeling development include *General Hydraulic Considerations* (FEMA 2016), *Hydraulics: One-Dimensional Analysis* (FEMA 2016e) and *Hydraulics: Two-Dimensional Analysis (FEMA 2016)*. The water surface elevations (WSEL's) were calculated with HEC-RAS, Version 5.0.7 hydraulic modeling software (USACE 2019a). HEC-RAS provides the steady-flow analysis using the standard step energy balance calculation between cross sections starting at the most downstream cross section and moving upstream for subcritical analysis.

Cross sections were placed with the GeoHECRAS hydraulic computer modeling software (CivilGEO 2020) at flow distances or reach lengths generally ranging from 15 to 500 feet and at structures located within the floodplain study reach. The Rock Creek Reach 4 hydraulic model has one channel flow length (River Station (RS) 169,276) exceeding 500 feet. The Rock Creek Reach 5 model has two flow lengths exceeding 500 feet one on the Rock Creek mainstem (RS 248,813) and on Ross Fork (RS 7,890). At these locations, the profile baseline is meandering, and the down valley reach lengths are less than 500 feet. Below is a summary description for the key hydraulic features associated with each tributary studied.

4.1.1 Rock Creek

The Rock Creek one-dimensional (1D) hydraulic model begins from the north termination point at the confluence with the Clark Fork River and extends upstream to the south for approximately 52.1 creek-miles (Figure 3). Rock Creek was broken up into five models covering reach 1, 2, 3, 4 and 5.

Rock Creek Reach 1 is approximately 12.6 creek-miles and has four hydraulic structure crossings. No split flow or tributary reaches to Rock Creek were included in the modeling of this reach. Reach 1 assumes a normal depth slope of 0.005 ft/ft as the downstream boundary condition. Rock Creek Reach 1 includes a Floodway analysis which is described in section 4.15. The downstream end of Rock Creek Reach 1 includes a USGS gage that was used to calibrate the model which is described in section 4.14.

Rock Creek Reach 2 is approximately 8 creek-miles in length and has one hydraulic structure crossing. No split flow or tributary reaches to Rock Creek were included in the modeling of this reach. The upper reach uses a known water surface elevation as the downstream boundary condition. The water surface elevations were provided from the tie-in cross section 66,303.

Rock Creek Reach 3 is approximately 1 creek-mile in length and has one hydraulic structure crossing. No split flow or tributary reaches to Rock Creek were included in the modeling of this reach. Reach 3 uses a known water surface elevation as the downstream boundary condition. The water surface elevations were provided from the tie-in cross section 107,921. Rock Creek Reach 3 includes a Floodway analysis which is described in section 4.15.

Rock Creek Reach 4 is approximately 21 creek-miles in length and has 5 hydraulic structure crossings. The upper reach uses a known water surface elevation as the downstream boundary condition. The water surface elevations were provided from the tie-in cross section 112,660.

Rock Creek Reach 5 includes Rock Creek from the end of Reach 4 upstream to the confluence of West Fork Rock Creek and Middle Fork Rock Creek. The confluences of Maukey Gulch and Ross Fork with West Fork Rock Creek are also included in the model. The mainstem of Rock Creek is 10 creek-miles in length and had 10 hydraulic structure crossings that were modeled.

Rock Creek Reach 5 includes two short mainstem sub-reaches where a worst-case analysis was performed. The worst-case analysis was modelled using two scenarios: in scenario 1 the roadway embankments were modeled as intact with the landward flood fringe inaccessible for flood conveyance in the following areas (RS 230,930-234,045 and RS 255,550-256,892); in scenario 2 these roadway embankments were modeled as having failed with unconstrained flood flow conveyance landward of the road embankments. The intact embankments in scenario 1 reduce the amount of flow that can reach the overbanks, forcing more flow in the narrower floodplain and increasing water surface elevations in accessible floodplain. The Scenario 1 model yields reasonably conservative (higher) flood elevations and was used to prepare mapping and profile products. Montana DNRC collaborated in the review of the worst-case analysis and concurred with the decision to prepare flood risk products from the Scenario 1 modeling results.

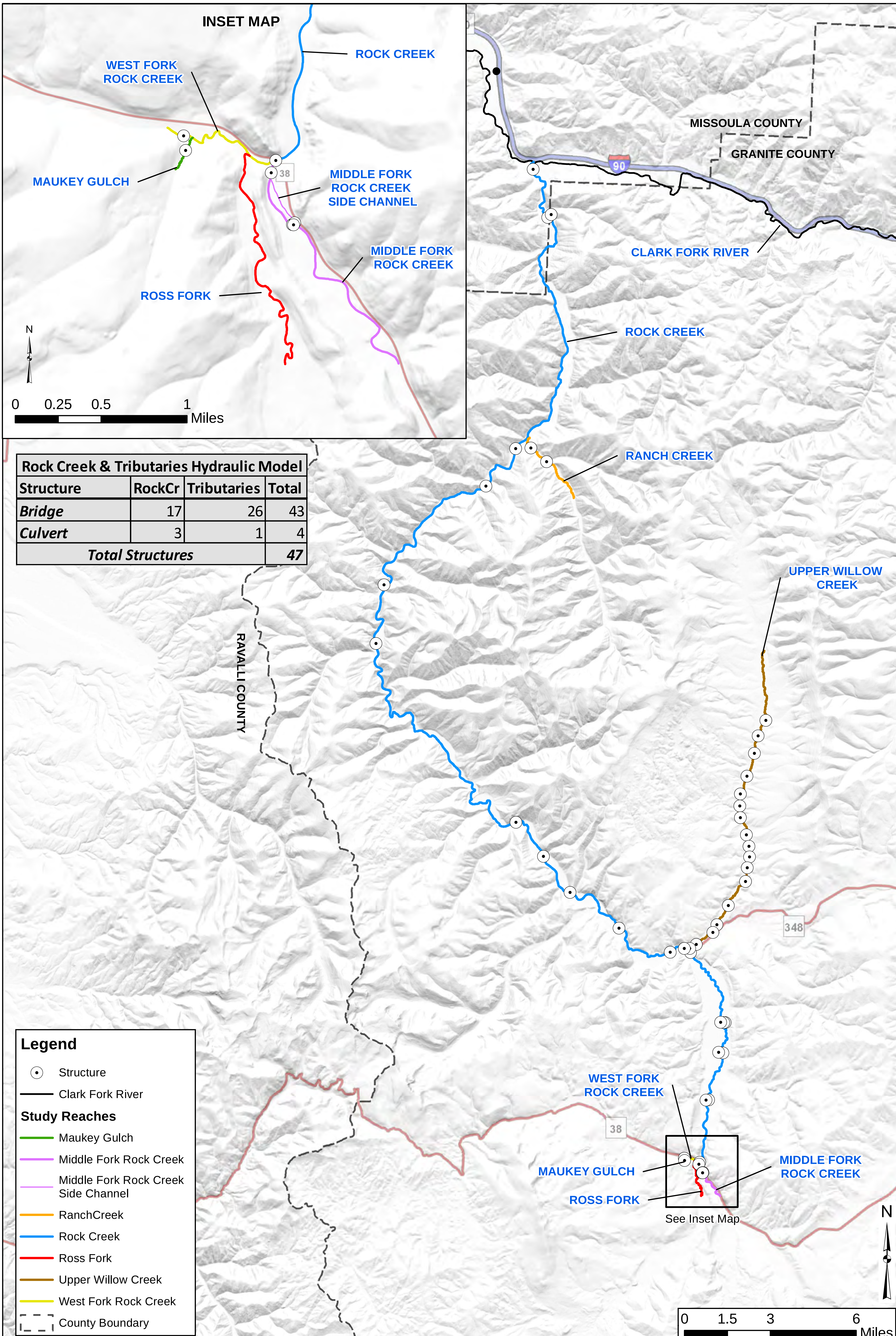
Maukey Gulch begins at the confluence with West Fork Rock Creek and continues upstream for 0.2 miles. The Maukey Gulch model includes one modeled structure. Middle Fork Rock Creek begins at the confluence with West Fork Rock Creek and continues upstream for 1.6 miles. It was determined that a split flow channel with a lateral weir (Middle Fork Side Channel) was appropriate to model the eastern side channel. Middle Fork Rock Creek included three structures on the primary channel and one structure on the Middle Fork Side Channel. West Fork Rock Creek includes one modeled hydraulic structure. Rock Creek Reach 5 uses a known water surface elevation as the downstream boundary condition. The water surface elevations were provided from the tie-in cross section 225,577.

4.1.2 Ranch Creek

The Ranch Creek 1D hydraulic model begins at the confluence with the Rock Creek floodplain and extends upstream to the east for approximately 3.1 creek-miles (Figure 5). The downstream study extents were extended into the Rock Creek floodplain far enough that several Ranch Creek cross sections are within the water surface elevations of larger floods from the Rock Creek floodplain. This approach was selected to ensure flood risk mapping fully overlapped at the floodplain confluence of Rock Creek and Ranch Creek. The tributary reach has a normal depth slope boundary condition of approximately 0.0083 feet/feet. No split flow or tributary reaches to Ranch Creek were necessary to model this reach of stream. The Ranch Creek study reach includes two hydraulic structure crossings.

4.1.3 Upper Willow Creek

The Upper Willow Creek 1D hydraulic model begins at the confluence with Rock Creek and extends upstream to the east for approximately 13.1 creek-miles (Figure 5). The tributary reach uses a normal depth slope boundary condition of approximately 0.00373 feet/feet. No split flow or tributary reaches to Upper Willow Creek were necessary to model this reach. This reach of Upper Willow Creek includes 18 hydraulic structure crossings. Two lateral weirs were included along the channel bank of Rock Creek to model the loss of flood flow to the Rock Creek mainstem channel. The flood risk for the remainder of the flood flows are routed along the Willow Creek flood flow path to the confluence with the Rock Creek floodplain approximately 1,100 feet below the first flow loss to the Rock Creek mainstem channel.



Rock Creek & Tributaries Hydraulic Model

Structure	RockCr	Tributaries	Total
Bridge	17	26	43
Culvert	3	1	4
Total Structures			***47***

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Rock Creek & Tributaries Structure Inventory

Missoula-Granite PMR
Rock Creek & Tribs Floodplain Study

PROJECT NO.
1447.054

Figure 6

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4.2 Topographic Data Acquisition

The Montana DNRC contracted with Quantum Spatial, Inc. (QSI) to acquire topographic Light Detection and Ranging (LiDAR) data for the project area. QSI performed a LiDAR topographic survey on Rock Creek and Tributaries within Missoula and Granite Counties for the DNRC between September 27, 2018 and September 19, 2019. The LiDAR survey included near-infrared wavelength for terrestrial topography for the study reaches. The specifications for the LiDAR Digital Elevation Model (DEM) required digital elevation data with a root mean square error (RMSE) less than or equal to 10 centimeters (approximately 4 inches), (QSI 2019). To verify the LiDAR DEM data met the vertical accuracy criteria, QSI compared ground measured check points with the LiDAR DEM data at vegetated, non-vegetated and control point locations. The LiDAR DEM data met the relative vertical accuracy statistics reported in Clark Fork Bitterroot, Montana QL1 LiDAR Technical Data Report as summarized in Table 11 (QSI 2019).

Table 11. LiDAR Relative Vertical Accuracy

Parameter	Result
Sample	180 flight line surfaces
Average	0.105 feet
Median	0.112 feet
RMSE	0.114 feet
Standard Deviation	0.023 feet
95% Confidence (1.96*RMSE)	0.044 feet

The LiDAR deliverables included 1-foot grid bare earth DEM for the entire length of the Rock Creek and Tributaries study corridors (QSI 2019).

4.3 Bathymetric Survey

A bathymetric survey of Rock Creek within Enhanced Level Option E with Floodway study reaches was performed by DOWL (DOWL 2019a) in July and August of 2019. DOWL surveyed cross-sections approximately every 2,500 ft with four additional cross-sections at each of the mainstem bridges. The bathymetric survey was used to develop a typical low-flow channel which was built into the hydraulic modeling to enhance the representation of the flood conveyance and flood risk. DOWL also completed bathymetric survey of selected accessible locations in the non-floodway reaches of Rock Creek in July and August of 2020. The targeted bathymetric survey was used to estimate channel conveyance area below the water surface in the LiDAR DEM topography. The channel waterway area of all cross sections in these reaches was increased by the typical amount developed from the available targeted bathymetric survey data.

4.4 Field Structure Survey

A field survey of the hydraulic structures for the Rock Creek and Tributaries study was performed by Pioneer Technical Services, Inc. between October 2019 and May 2020 (Pioneer 2020c). A total of four structures were surveyed on Rock Creek mainstem within Enhanced Level Option E with Floodway study reaches. Structures included in the hydraulic modeling on the floodway reaches of Rock Creek are summarized in Table 12.

Table 12. Field Structure Survey

ID No.	Structure Type	River Reach	Roadway	River Station (feet)
S141	Bridge	Rock Creek Reach 1	Stage Station Road	1,666
S142	Bridge	Rock Creek Reach 1	Valley of the Moon Road	14,011
S143	Bridge	Rock Creek Reach 1	Valley of the Moon Road	14,011
S144	Bridge	Rock Creek Reach 3	Trout Haven Road	110,473

4.5 Field Structure Inventory

A Field Structure Inventory of the hydraulic structures for the Rock Creek and Tributaries study was performed by Pioneer Technical Services, Inc. (Pioneer 2020b). Table 13 is a summary of the structures inventoried on Rock Creek and Tributaries.

Table 13. Field Structure Inventory

Tributary Reach	ID No.	Structure Type	Roadway	River Station (feet)
Maukey Gulch	S065**	Bridge	Private Foot Bridge	-
Maukey Gulch	S066	Bridge	Private Drive	497
Middle Fork Rock Creek	S056	Bridge	Private Road	341
Middle Fork Irrigation Ditch	S057	Culvert	Private Road	-
Middle Fork Irrigation Ditch	S058	Culvert	Private Road	-
Middle Fork Irrigation Ditch	S059	Culvert	Private Road	-
Middle Fork Rock Creek	S060**	Diversion	Private Road	-
Middle Fork Rock Creek	S060a**	Culvert	Private Road	-
Middle Fork Rock Creek	S061	Bridge	Woodland Lane	2,225
Middle Fork Side Channel	S062	Bridge	Woodland Lane	1,564
Middle Fork Rock Creek	S063	Bridge	Eagle Canyon Lane	2,265
Ranch Creek	S033	Bridge	Rock Creek Road	2,202
Ranch Creek	S034	Bridge	Grizzly Camp Road	6,521
Rock Creek	S001	Bridge	Private Road	66,158
Rock Creek	S002	Bridge	USFS Footbridge	77,554
Rock Creek	S003	Bridge	Idle Hour Drive West	123,306
Rock Creek	S004	Bridge	Williams Gulch Loop	181,947
Rock Creek	S005**	None Found	-	-
Rock Creek	S006	Bridge	Walberg Ranch Lane	191,284
Rock Creek	S007	Bridge	Upper Rock Creek Road	200,346
Rock Creek	S008**	Bridge	-	-
Rock Creek	S009	Bridge	Private Road	214,158
Rock Creek	S010**	Bridge	Irrigation Ditch	-
Rock Creek	S011**	Culvert	Irrigation Ditch	-

Table 13. Field Structure Inventory (Cont.)

Tributary Reach	ID No.	Structure Type	Roadway	River Station (feet)
Rock Creek	S012	Bridge	Private Road	228,030
Rock Creek	S013**	Culvert	Irrigation Ditch	-
Rock Creek	S014**	Culvert	Irrigation Ditch	-
Rock Creek	S016	Bridge	Marshall Creek Road	232,633
Rock Creek	S017**	Culvert	Irrigation Ditch	-
Rock Creek	S018**	Culvert	Irrigation Ditch	-
Rock Creek Irrigation Ditch	S019**	Culvert	Irrigation Ditch	-
Rock Creek Irrigation Ditch	S020**	Culvert	Irrigation Ditch	-
Rock Creek	S021	Bridge	Private Road	249,789
Rock Creek	S022	Bridge	Private Road	249,789
Rock Creek Irrigation Ditch	S024	Bridge	Private Road	256,378
Rock Creek	S025	Bridge	Private Road	256,378
Rock Creek	S026**	Diversion	None	-
Rock Creek	S027**	Culvert	Irrigation Structure	-
Rock Creek Irrigation Ditch	S028**	Culvert	East Rocking J Ranch Lane	-
Rock Creek	S029	Bridge	East Rocking J Ranch Lane	266,453
Middle Fork Irrigation Ditch	S030**	Bridge	Skalkaho Road Foot Bridge	-
Rock Creek	S031	Bridge	Skalkaho Road	279,278
Middle Fork Irrigation Ditch	S032	Culvert	Skalkaho Road	-
Upper Willow Creek	S035	Bridge	Jimmy Lee Gulch Lane	529
Upper Willow Creek	S015**	Culvert	Jimmy Lee Gulch Lane	-
Upper Willow Creek	S036	Bridge	Private Road	1,745
Upper Willow Creek	S037**	Diversion	None	-
Upper Willow Creek Irrigation Ditch	S038**	Culvert	Private Road	-
Upper Willow Creek	S039	Bridge	Private Road	3,367
Upper Willow Creek	S040	Bridge	Private Road	7,437
Upper Willow Creek	S041	Bridge	Private Road	9,570
Upper Willow Creek	S042	Bridge	Lamer Lane	13,984
Upper Willow Creek	S043	Bridge	Scotchman Gulch Road	20,452
Upper Willow Creek	S044	Bridge	Private Road	23,257
Upper Willow Creek	S045	Bridge	Private Road	25,638
Upper Willow Creek	S046**	Diversion	Private Road	-
Upper Willow Creek	S047	Bridge	Private Road	27,966
Upper Willow Creek	S048	Bridge	Private Road	30,367
Upper Willow Creek	S049	Bridge	Private Road	34,310
Upper Willow Creek	S050	Bridge	Private Road	36,889
Upper Willow Creek	S051	Bridge	Miners Gulch Road	39,301
Upper Willow Creek	S052	Bridge	Private Road	43,233
Upper Willow Creek	S053	Bridge	Private Road	48,022
Upper Willow Creek	S054	Bridge	Private Road	51,663
Upper Willow Creek	S055	Bridge	Private Road	55,050
West Fork Rock Creek	S064	Bridge	Maukey Gulch Lane	3,617

**Structure not modeled.

4.6 Profile Baseline

The alignment of the initial Rock Creek and Tributaries Profile Baselines were prepared by Pioneer during the hydrologic analysis for the study streams (Pioneer 2020a). To appropriately model the streams, the locations of major tributary confluences and other flow change locations were identified as noted in hydrology section of this report. The DNRC coordinated with Pioneer to set the Profile Baselines as stream distance (river stationing) in feet above the respective downstream limit. The flow change locations (flow nodes) of the Rock Creek and Tributaries were set at creek station locations which are summarized in Table 14. The Profile Baselines were also used to locate cross sections and key features along the streams.

The S_Wtr_Ln alignment prepared in the Hydrology task by Pioneer for Upper Willow Creek followed the stream centerline. The stream centerline for Upper Willow Creek is very sinuous and the channel frequently flows perpendicularly and even opposed to the valley flood flow direction. This degree of main channel meander makes regular cross section reach length placement very challenging. Preliminary modeling development demonstrated the majority of the flood flows for the 1% AC and the 0.2% AC profiles would be routed down the valley floor along a general flow line rather than following the meandered low-flow channel. Therefore, a generalized profile baseline following the valley floor was developed for the Upper Willow Creek study reach. The profile baseline was developed with some meander following the lower portion of the valley floor. Cross sections were generally placed where the profile baseline overlaid the creek channel parallel to the flood flow direction. At locations where additional cross sections were required to meet maximum cross section reach lengths, bank stations were placed adjacent to the profile baseline to maintain appropriate channel reach lengths. For these cross sections, Manning’s roughness reflected the actual overbank and channel stations along the cross section and did not correlate with portion of the cross section bounded by the assigned bank stations.

Profile Baselines were added during the hydraulic analysis of the Rock Creek and Tributaries to include flow reaches as required to appropriately account for hydraulic flow distribution and to prepare the preliminary floodplain mapping.

Table 14. Profile Baseline Key Features

Reach	River Station (feet)	Type	Description
Ranch Creek	0	Confluence	Confluence with Rock Creek
Ranch Creek	16,277	Flow Change	Flow Node 100
Ranch Creek	2,202	Structure Crossing	Rock Creek Road
Ranch Creek	6,521	Structure Crossing	Grizzly Camp Road
Ranch Creek	16,277	Study Limit	Limit of Study, Approximately 3.1 River Miles above Confluence with Rock Creek
Rock Creek	0	Confluence	Confluence with Clark Fork River
Rock Creek	22,131	Flow Change	Flow Node 12334510
Rock Creek	1,666	Structure Crossing	Stage Station Road
Rock Creek	14,011	Structure Crossing	Valley of the Moon Road
Rock Creek	50,969	Flow Change	Flow Node 200
Rock Creek	29,990	Boundary	Missoula/Granite County Boundary

Table 14. Profile Baseline Key Features (Cont.)

Reach	River Station (feet)	Type	Description
Rock Creek	64,839	Flow Change	Flow Node 300
Rock Creek	77,206	Flow Change	Flow Node 400
Rock Creek	66,308	Boundary	Effective Floodway Mapping Boundary End
Rock Creek	66,158	Structure Crossing	Private Road
Rock Creek	103,591	Flow Change	Flow Node 500
Rock Creek	77,554	Structure Crossing	USFS Footbridge
Rock Creek	133,966	Flow Change	Flow Node 600
Rock Creek	108,559	Boundary	Effective Floodway Mapping Boundary Start
Rock Creek	110,473	Structure Crossing	Trout Haven Road
Rock Creek	112,913	Boundary	Effective Floodway Mapping Boundary End
Rock Creek	123,306	Structure Crossing	Idle Hour Drive West
Rock Creek	165,158	Flow Change	Flow Node 700
Rock Creek	175,615	Flow Change	Flow Node 800
Rock Creek	209,447	Flow Change	Flow Node 900
Rock Creek	181,947	Structure Crossing	Williams Gulch Loop
Rock Creek	191,284	Structure Crossing	Walberg Ranch Lane
Rock Creek	200,346	Structure Crossing	Upper Rock Creek Road
Rock Creek	214,158	Structure Crossing	Private Road
Rock Creek	228,030	Structure Crossing	Private Road
Upper Willow Creek	19,262	Flow Change	Flow Node 200
Upper Willow Creek	144	Confluence	Confluence with Rock Creek
Upper Willow Creek	259	Structure Crossing	Jimmy Lee Gulch Lane
Upper Willow Creek	1,745	Structure Crossing	Private Road
Upper Willow Creek	529	Structure Crossing	Private Road
Upper Willow Creek	7,437	Structure Crossing	Private Road
Upper Willow Creek	9,570	Structure Crossing	Private Road
Upper Willow Creek	13,984	Structure Crossing	Lamer Lane
Upper Willow Creek	44,808	Flow Change	Flow Node 300
Upper Willow Creek	20,452	Structure Crossing	Scotchman Gulch Road
Upper Willow Creek	23,257	Structure Crossing	Private Road
Upper Willow Creek	25,638	Structure Crossing	Private Road
Upper Willow Creek	27,966	Structure Crossing	Private Road
Upper Willow Creek	30,367	Structure Crossing	Private Road
Upper Willow Creek	34,310	Structure Crossing	Private Road
Upper Willow Creek	36,889	Structure Crossing	Private Road
Upper Willow Creek	39,301	Structure Crossing	Miners Gulch Road
Upper Willow Creek	43,233	Structure Crossing	Private Road
Upper Willow Creek	69,346	Flow Change	Flow Node 400
Upper Willow Creek	48,022	Structure Crossing	Private Road
Upper Willow Creek	51,663	Structure Crossing	Private Road
Upper Willow Creek	55,050	Structure Crossing	Private Road
Upper Willow Creek	69,346	Study Limit	Limit of Study, Approximately 13.1 River Miles above Confluence with Rock Creek
Rock Creek	231,232	Flow Change	Flow Node 1000

Table 14. Profile Baseline Key Features (Cont.)

Reach	River Station (feet)	Type	Description
Rock Creek	232,633	Structure Crossing	Marshall Creek Road
Rock Creek	249,789	Structure Crossing	Private Road
Rock Creek	256,378	Structure Crossing	Private Road
Rock Creek	259,870	Flow Change	Flow Node 1100
Rock Creek	266,453	Structure Crossing	East Rocking J Ranch Lane
Rock Creek	279,278	Structure Crossing	Skalkaho Road
Rock Creek	279,341	Flow Change	Flow Node 1200
Rock Creek	279,571	Confluence	Beginning of Rock Creek at Confluence of Middle Fork Rock Creek and West Fork Rock Creek
Middle Fork Rock Creek	0	Confluence	Confluence with Rock Creek and West Fork Rock Creek
Middle Fork Rock Creek	341	Structure Crossing	Private Road
Middle Fork Rock Creek Side	0	Convergence	Convergence with Middle Fork Rock Creek
Middle Fork Rock Creek Side	1,564	Structure Crossing	Woodland Lane
Middle Fork Rock Creek Side	1,591	Divergence	Divergence with Middle Fork Rock Creek
Middle Fork Rock Creek	2,225	Structure Crossing	Woodland Lane
Middle Fork Rock Creek	2,265	Structure Crossing	Eagle Canyon Lane
Middle Fork Rock Creek	8,575	Flow Change	Flow Node 500
Middle Fork Rock Creek	8,575	Study Limit	Limit of Study, Approximately 1.6 River Miles above Confluence with Rock Creek and West Fork Rock Creek
West Fork Rock Creek	0	Confluence	Confluence with Rock Creek and Middle Fork Rock Creek
West Fork Rock Creek	604	Flow Change	Flow Node 600
Ross Fork	0	Confluence	Confluence with West Fork Rock Creek
Ross Fork	8,590	Flow Change	Flow Node 800
Ross Fork	8,590	Study Limit	Limit of Study, Approximately 1.5 River Miles above Confluence with West Fork Rock Creek
Maukey Gulch	0	Confluence	Confluence with West Fork Rock Creek
Maukey Gulch	497	Structure Crossing	Private Road
Maukey Gulch	1,140	Study Limit	Limit of Study, Approximately 0.2 River Miles above Confluence with West Fork Rock Creek
Maukey Gulch	1,244	Flow Change	Flow Node 900
West Fork Rock Creek	3,617	Structure Crossing	Maukey Gulch Lane
West Fork Rock Creek	4,184	Flow Change	Flow Node 700
West Fork Rock Creek	4,184	Study Limit	Limit of Study, Approximately 0.8 River Miles above Confluence with Middle Fork Rock Creek and Rock Creek

4.7 Boundary Conditions

To perform a hydraulic analysis in HEC-RAS, a boundary condition is specified at the first downstream cross section of the model reach. Per FEMA's One-Dimensional Hydraulics Guidance for Flood Risk Analysis and Mapping (FEMA 2016c), the downstream boundary condition in a 1D, steady flow, step-backwater model should be taken from a previously established water surface elevation (WSEL), if available. No previously established WSELs were available for Rock Creek or the Tributaries, therefore, a normal depth boundary condition was used for Rock Creek Reach 1, Ranch Creek and Upper Willow Creek. Rock Creek Reaches 2-5 used a known WSEL taken from the downstream model for the boundary condition.

To address the use of coincident peaks between the study tributaries and the Rock Creek mainstem, Pioneer referenced the FEMA guidance requirements. For the use of coincident peaks to be appropriate FEMA guidance documents (FEMA, 2016b) require the following criteria be met:

1. The ratio of the drainage areas lies between 0.6 and 1.4.
2. The arrival times of flood peaks are similar for the two combining watersheds.
3. The likelihood of both watersheds being covered by the storm is high.

The Rock Creek and Tributaries do not meet the above listed criteria, therefore, known water surface elevations were not used as the downstream boundary condition for the tributary models. The normal depth energy slope method was used for the starting downstream boundary condition for the two tributary reaches that were modeled separately. The normal depth slope is the slope of the Hydraulic Grade Line (HGL) which is calculated by iterative model runs resulting in convergence at the HGL slope.

A summary of the boundary conditions established for each model segment for the Rock Creek and Tributaries floodplain study in Missoula-Granite Counties are summarized in Table 15.

Table 15. Boundary Condition Summary

Tributary Reach	Model Segment	Boundary Condition
Upper Willow Creek	Upper Willow Creek	Normal Depth Slope = 0.00373 ft/ft
Ranch Creek	Ranch Creek	Normal Depth Slope = 0.0083 ft/ft
Rock Creek	Reach 1	Normal Depth Slope = 0.005 ft/ft
	Reach 2	10% AC Known WSE = 3919.49 ft
		4% AC Known WSE = 3920.09 ft
		2% AC Known WSE = 3920.51 ft
		1% AC Known WSE = 3920.93 ft
		0.2% AC Known WSE = 3921.93 ft
		1%+ AC Known WSE = 3921.87 ft
	Reach 3	10% AC Known WSE = 4184.45 ft
		4% AC Known WSE = 4184.89 ft
		2% AC Known WSE = 4185.19 ft
		1% AC Known WSE = 4185.45 ft

Table 15. Boundary Condition Summary (Cont.)

Tributary Reach	Model Segment	Boundary Condition
Rock Creek	Reach 3	0.2% AC Known WSE = 4185.98 ft
		1%+ AC Known WSE = 4185.95 ft
	Reach 4	10% AC Known WSE = 4212.41 ft
		4% AC Known WSE = 4213.02 ft
		2% AC Known WSE = 4213.43 ft
		1% AC Known WSE = 4213.79 ft
		0.2% AC Known WSE = 4214.52 ft
		1%+ AC Known WSE = 4214.48 ft
	Reach 5	10% AC Known WSE = 4873.37 ft
		4% AC Known WSE = 4873.6 ft
		2% AC Known WSE = 4873.76 ft
		1% AC Known WSE = 4873.87 ft
		0.2% AC Known WSE = 4874.11 ft
		1%+ AC Known WSE = 4874.10 ft
	Maukey Gulch	Junction at Confluence with West Fork Rock Creek
	Middle Fork Rock Creek	Junction at Confluence with West Fork Rock Creek at beginning of Rock Creek
	Middle Fork Side Channel	Junction at Convergence with Middle Fork Rock Creek
	Ross Fork	Junction at Confluence with West Fork Rock Creek
	West Fork Rock Creek	Junction at Confluence with Middle Fork Rock Creek at beginning of Rock Creek

4.8 Cross Section Development

The hydraulic model was predominately based on the terrain data provided by Quantum Spatial, Inc. (QSI). Utilizing the cross section module tool within GeoHECRAS, cross sections were placed perpendicular to flow and along estimated equipotential lines. End points for all cross sections were established as required to capture the boundaries of the 0.2% AC (500-year) floodplain. Cross sections were placed at key locations along the reach including: breaks in channel slope, abrupt changes in floodplain width, and at bridge, culvert and diversion structure locations. Cross sections were filtered to less than 500 points per cross section as required by HEC-RAS.

Manual cross section elevation edits within the low-flow stream channels were also performed based on structure inventory photos and measurements. This was needed to allow modeling of structures and roadway elevations in accordance with field measured data rather than the LiDAR topography on small streams. This type of edit was typically needed for narrow and shallow streams where the LiDAR DEM data set appeared to have simplified the ground topography as part of the elevation model raster development process or was influenced by water in the stream.

Low-flow channels were created on Rock Creek and West Fork Rock Creek based on targeted bathymetric data collected by DOWL. It was determined that a low-flow channel was not necessary on the rest of the tributaries. To determine the size of the low-flow channel, the area between the LiDAR and the bathymetric data was calculated. For

Rock Creek, the low-flow channel is broken into reach segments based on where the bathymetric data was surveyed and where the flow node changes were to account for the decreases in flow area as the flows decrease in the upstream direction.

4.9 Hydraulic Structures

The geometries of hydraulic structures were modeled based on data collected during the Structure Field Survey (Pioneer 2020b and Pioneer 2020c). The data package included field measurements for 66 hydraulic structures listed in Table 13 and four GPS surveyed structures located within the study limits as listed in Table 12. Each structure was assigned an identification code that started with an ‘S’ for structure and a number generally corresponding to the order of the structures beginning at the downstream extent of the tributary stream study reach and progressing upstream. The structures crossing Rock Creek and Tributaries include roadway crossings along County, Forest Service and includes private roadway and irrigation crossings.

Expansion and contraction coefficients assignments at the two upstream and one downstream bridge cross sections were used to model bridge/culvert/diversion constrictions and were generally increased from the values for natural channels of 0.1 and 0.3, to 0.3 and 0.5, respectively. This standard hydraulic modeling practice was employed to account for the increased head loss associated with the relatively abrupt transitions and increasing/decreasing velocities that accompany the expansion and contraction of flows at hydraulic conveyance structures. These values are recommended in the HEC-RAS model documentation and reference manuals.

The bridge modeling approach was set for both high and low-flow methods based on the bridge configuration. High flow methods were either the Energy (Standard Step) or Pressure/Weir flow methods. The Energy method (Standard Step) was utilized when there was freeboard to the bridge low-chord and/or when the road elevation approaching the bridge was lower than the crossing producing a bridge that was perched above the roadway elevation in the overbanks. Otherwise, the Pressure/Weir flow method was the high flow method used when flood waters would impact and/or overtop the bridge structure.

The low-flow methods include the Energy, Momentum or Yarnell methodologies. Only the Energy method was utilized for clear-span structure with no piers. The Momentum Balance and Yarnell equation methods were evaluated if the structure was constructed with mid-span piers. The Momentum and Yarnell methods are low-flow methods used to account for the hydraulic losses due to water moving around the piers. The momentum method required an input for the drag coefficient (C_D), and the Yarnell equation required a pier shape coefficient (K).

The pier shapes for the bridge structures consisted of square nose piers, circular piers and elongated piers with 90° angle triangular or semicircular nose and tail geometry. The C_D and K coefficients used for the different pier shapes are summarized in Table 16.

Table 16. Pier CD and K Coefficients

Pier Shape	C_D	K
Triangular nose with 90° angle	1.6	1.05
Elongated piers with semi-circular ends	1.33	0.9
Circular piers	1.2	1.05
Ten pile trestle bent	2.0	2.5
Square piers	2.0	1.25

A summary of the bridge structure and hydraulic model settings for each structure are summarized in Tables 17 and 18, respectively.

Culvert crossings were modeled using field measurements of roadway fill above the culvert, culvert infill when applicable, and roadway overtopping information. Overbank data was extracted from the LiDAR terrain data. In this study, culvert barrel inverts were commonly below the bounding channel elevations due to LiDAR averaging in narrow streams or LIDAR influenced by water in the stream. Internal hydraulic structure cross sections were adjusted as needed to fit with field measured data and field photograph interpretation. This approach more closely matched culvert invert depth below the roadway deck and provided reasonable backwater elevations controlled by the channel elevations bounding the structure. A summary of culvert structure hydraulic model settings is provided in Tables 19 and 20.

The following sections describe the unique conditions for hydraulic structure crossings for Rock Creek and tributary reaches. All other hydraulic structures were modeled using standard engineering and HEC-RAS practice.

4.9.1 Rock Creek

The Rock Creek reaches have 20 modeled hydraulic structure crossings and the Rock Creek Reach 5 tributaries contain an additional six structures that were modeled. Several small pedestrian bridges were determined to be insignificant because it was likely that they would float away or be destroyed during the regulatory flood. Also, there were many irrigation crossings that were surveyed that were not within the flood flow path and therefore they were not included in the model.

The structure crossing Private Road at station 214,158 in Rock Creek Reach 4 was denied access by the landowner during the Structure Inventory performed by Pioneer. The bridge was modeled by assuming dimensions using the aerial photography, LiDAR data, and review of similar crossings on Rock Creek to determine a probable bridge opening.

The irrigation structure crossing the Private Road at station 256,373 in Rock Creek Reach 5 was described by Pioneer in the Structure Inventory report as a bridge. However, review of the structure data and photos indicated that the structure could be represented as an embedded box culvert or a three-sided culvert and that the structure would be best represented as a box culvert in the model.

The structure crossing Woodland Lane at station 1,564 of Middle Fork Side Channel in Rock Creek Reach 5 was described by Pioneer in the Structure Inventory report as a bridge. However, review of the structure data and photos indicated that the structure could be interpreted as an embedded box culvert or a three-sided culvert. It was determined that the structure would be best represented as a box culvert in the model.

The bridge and culvert crossing structure and modeling data are summarized in Tables 17, 18, 19 and 20.

4.9.2 Ranch Creek

Ranch Creek has two hydraulic structure crossings. The two crossing structures and modeling data for Ranch Creek are summarized in Tables 17, 18, 19 and 20.

4.9.3 Upper Willow Creek

Upper Willow Creek has 18 hydraulic structure crossings that were included in the model. One low-head irrigation diversion, which was included in the field structure inventory (S046 & S046a), was determined to be insignificant because it was below the banks of the small channel and poorly aligned with flood flows. Another small irrigation diversion or overbuilt fence line is visible in publicly available aerial imagery in the vicinity of RS 42,300 but was not included in the field structure inventory. Neither of these structures were included in the hydraulic modeling since they have insufficient resiliency or were too small to affect regulatory flood risks. Two small culverts (S015) were included in the field structure inventory along the west bank of Rock Creek near the confluence of Upper Willow Creek. These culverts were incorporated into the lateral weir geometry at RS 1,303 which was used to compute flow lost from the Upper Willow Creek floodplain to the mainstem Rock Creek channel upstream of the floodplain confluence between Rock Creek and Upper Willow Creek. The bridge crossing structures and modeling data for Upper Willow Creek are summarized in Tables 17, 18, 19 and 20.

Table 17. Summary of Bridge Structures

Stream Reach	ID No.	Roadway	River Station (feet)	Spans	Total Span (feet)	Deck Width (feet)	Pier Widths (feet)	Appendix C Photo Page #
Maukey Gulch	S066	Private Road	497	1	14.1	16.3	-	143-144
Middle Fork Rock Creek	S056	Private Road	341	1	66	16	-	120-121
Middle Fork Rock Creek	S061	Woodland Lane	2,225	1	36.5	13	-	133-134
Middle Fork Rock Creek	S063	Eagle Canyon Lane	2,265	1	48.5	10.4	-	137-138
Ranch Creek	S033	Rock Creek Road	2,202	1	27.7	16.8	-	72-73
Ranch Creek	S034	Grizzly Camp Road	6,6521	1	24.6	15.2	-	74-76
Rock Creek	S001	Private Road	66,157	1	125.4	8.6	-	1-3
Rock Creek	S002	Pedestrian Footbridge	77,554	3	25.9, 98.8, 30.6	2.5	1,7.7, 8.3,1	4-6
Rock Creek	S003	Idle Hour Drive West	123,360	3	40, 41.1, 39.5	10	1, 1	7-8
Rock Creek	S004	Williams Gulch Loop	181,947	2	64.9, 39.1	11.5	5,5	9-10
Rock Creek	S006	Walberg Ranch Lane	191,284	2	42.6, 35.5	14.0	1,1	11-12
Rock Creek	S007	Upper Rock Creek Road	200,346	1	87.8	20.0	-	13-14
Rock Creek	S009*	Private Road	214,158	2	34, 34	12	2,2	-
Rock Creek	S012	Private Road	228,030	1	98.1	14.2	-	19-28
Rock Creek	S016	Marshall Creek Road	232,633	1	96.6	27.2	-	29-30
Rock Creek	S021	Private Road	249,789	1	61.8	10.4	-	45-46
Rock Creek	S022	Private Road	249,789	1	27.4	10.4	-	47-48
Rock Creek	S141	Stage Station	1,666	1	100.4	17.1	-	145-147
Rock Creek	S142	Valley of the Moon	14,011	1	48	12.5	-	148-149
Rock Creek	S143	Valley of the Moon	14,011	1	77.9	12.5	-	150
Rock Creek	S144	Trout Haven Road	110,473	1	119.1	13.5	-	151-152
Rock Creek	S025	Private Road	256,378	1	46.8, 53.1	16.2	7	53-54
Rock Creek	S029	East Rocking J Ranch Lane	266,453	3	29.7, 33.9, 30.4	23.7	2.4,2.4	64-65
Rock Creek	S031	Skalkaho Road	279,278	3	34, 68, 35	30.9	1.5,1.5,4,4	68-69
Upper Willow Creek	S035	Jimmy Lee Gulch Lane	529	1	16.9	14.2	-	77-78
Upper Willow Creek	S036	Private Road	1,745	1	14	16.8	-	79-80

Table 17. Summary of Bridge Structures (Cont.)

Stream Reach	ID No.	Roadway	River Station (feet)	Spans	Total Span (feet)	Deck Width (feet)	Pier Widths (feet)	Appendix C Photo Page #
Upper Willow Creek	S039	Private Road	3,367	1	14.6	16.7	-	83-84
Upper Willow Creek	S040	Private Road	7,437	1	13.9	16.1	-	85-87
Upper Willow Creek	S041	Private Road	9,570	1	17.9	11.8	-	88-89
Upper Willow Creek	S042	Lamer Lane	13,984	1	23.5	14.2	-	90-91
Upper Willow Creek	S043	Scotchman Gulch Road	20,452	1	37	16	-	92-93
Upper Willow Creek	S044	Private Road	23,257	1	20	16.2	-	94-95
Upper Willow Creek	S045	Private Road	25,638	1	18	16.5	-	96-97
Upper Willow Creek	S047	Private Road	27,966	1	24.2	14	-	102-103
Upper Willow Creek	S048	Private Road	30,367	1	20.7	14	-	104-105
Upper Willow Creek	S049	Private Road	34,310	1	34.5	14	-	106-107
Upper Willow Creek	S050	Private Road	36,889	1	22.5	12	-	108-109
Upper Willow Creek	S051	Miners Gulch Road	39,301	1	30	15.3	-	110-111
Upper Willow Creek	S052	Private Road	43,233	1	24.3	15	-	112-113
Upper Willow Creek	S053	Private Road	48,022	1	26.5	16.1	-	114-115
Upper Willow Creek	S054	Private Road	51,663	1	16	16	-	116-117
Upper Willow Creek	S055	Private Road	55,050	1	17.5	16.1	-	118-119
West Fork Rock Creek	S064	Maukey Gulch Lane	3,617	1	34.5	16.1	-	141-142

Table 18. Summary of Bridge Model Settings

Stream Reach	ID No.	Roadway	River Station (feet)	Contraction Coefficient	Expansion Coefficient	Low Flow Method	High Flow Method
Maukey Gulch	S066	Private Road	497	0.3	0.5	Energy	Pressure &/ Weir
Middle Fork Rock Creek	S056	Private Road	341	0.3	0.5	Energy	Pressure &/ Weir
Middle Fork Rock Creek	S061	Woodland Lane	2,225	0.3	0.5	Energy	Pressure &/ Weir
Middle Fork Rock Creek	S063	Eagle Canyon Lane	2,265	0.3	0.5	Energy	Pressure &/ Weir
Ranch Creek	S033	Rock Creek Road	2,202	0.3	0.5	Energy	Energy-Only
Ranch Creek	S034	Grizzly Camp Road	6,521	0.3	0.5	Energy	Energy-Only
Rock Creek	S001	Private Road	66,158	0.3	0.5	Energy	Energy-Only
Rock Creek	S002	USFS Footbridge	77,554	0.3	0.5	Energy, Momentum, Yarnell	Energy-Only
Rock Creek	S003	Idle Hour Drive West	123,306	0.3	0.5	Energy, Momentum, Yarnell	Pressure &/ Weir
Rock Creek	S004	Williams Gulch Loop	181,947	0.3	0.5	Energy, Momentum, Yarnell	Pressure &/ Weir
Rock Creek	S006	Walberg Ranch Lane	191,284	0.3	0.5	Energy, Momentum, Yarnell	Energy-Only
Rock Creek	S007	Upper Rock Creek Road	200,346	0.3	0.5	Energy	Pressure &/ Weir
Rock Creek	S009*	Private Road	214,158	0.3	0.5	Energy, Momentum, Yarnell	Energy-Only
Rock Creek	S012	Private Road	228,030	0.3	0.5	Energy	Energy-Only
Rock Creek	S016	Marshall Creek Road	232,633	0.3	0.5	Energy, Momentum, Yarnell	Pressure &/ Weir
Rock Creek	S021	Private Road	249,789	0.3	0.5	Energy	Energy-Only
Rock Creek	S022	Private Road	249,789	0.3	0.5	Energy	Energy-Only
Rock Creek	S025	Private Road	256,378	0.3	0.5	Energy, Momentum, Yarnell	Energy-Only
Rock Creek	S029	East Rocking J Ranch Lane	266,453	0.3	0.5	Energy, Momentum, Yarnell	Pressure &/ Weir
Rock Creek	S031	Skalkaho Road	279,278	0.3	0.5	Energy, Momentum, Yarnell	Pressure &/ Weir

Table 18. Summary of Bridge Model Settings (Cont.)

Stream Reach	ID No.	Roadway	River Station (feet)	Contraction Coefficient	Expansion Coefficient	Low Flow Method	High Flow Method
Rock Creek	S031	Skalkaho Road	279,278	0.3	0.5	Energy, Momentum, Yarnell	Pressure &/ Weir
Rock Creek	S141	Stage Station	1,666	0.3	0.5	Energy	Energy-Only
Rock Creek	S142	Valley of the Moon	14,011	0.3	0.5	Energy Momentum	Pressure &/ Weir
Rock Creek	S143	Valley of the Moon	14,011	0.3	0.5	Energy Momentum	Pressure &/ Weir
Rock Creek	S144	Trout Haven Road	110,473	0.3	0.5	Energy, Momentum, Yarnell	Energy-Only
Upper Willow Creek	S035	Jimmy Lee Gulch Lane	529	0.3	0.5	Energy	Pressure &/ Weir
Upper Willow Creek	S036	Private Road	1,745	0.3	0.5	Energy	Energy-Only
Upper Willow Creek	S039	Private Road	3,367	0.3	0.5	Energy	Energy-Only
Upper Willow Creek	S040	Private Road	7,437	0.3	0.5	Energy	Energy-Only
Upper Willow Creek	S041	Private Road	9,570	0.3	0.5	Energy	Energy-Only
Upper Willow Creek	S042	Lamer Lane	13,984	0.3	0.5	Energy	Pressure &/ Weir
Upper Willow Creek	S043	Scotchman Gulch Road	20,452	0.3	0.5	Energy	Pressure &/ Weir
Upper Willow Creek	S044	Private Road	23,257	0.3	0.5	Energy	Energy-Only
Upper Willow Creek	S045	Private Road	25,638	0.3	0.5	Energy	Pressure &/ Weir
Upper Willow Creek	S047	Private Road	27,966	0.3	0.5	Energy	Energy-Only
Upper Willow Creek	S048	Private Road	30,367	0.3	0.5	Energy	Energy-Only
Upper Willow Creek	S049	Private Road	34,310	0.3	0.5	Energy	Pressure &/ Weir
Upper Willow Creek	S050	Private Road	36,889	0.3	0.5	Energy	Energy-Only
Upper Willow Creek	S051	Miners Gulch Road	39,301	0.3	0.5	Energy	Pressure &/ Weir
Upper Willow Creek	S052	Private Road	43,233	0.3	0.5	Energy	Energy-Only
Upper Willow Creek	S053	Private Road	48,022	0.3	0.5	Energy	Pressure &/ Weir
Upper Willow Creek	S054	Private Road	51,663	0.3	0.5	Energy	Energy-Only
Upper Willow Creek	S055	Private Road	55,050	0.3	0.5	Energy	Pressure &/ Weir
West Fork Rock Creek	S064	Maukey Gulch Lane	3,617	0.3	0.5	Energy	Energy-Only

Table 19. Summary of Culvert Crossings

Stream Reach	ID No.	Roadway	River Station (feet)	Culvert Shape	Culvert Type	Culvert Length (feet)	Culvert Size (feet)	Appendix C Photo Page #
Middle Fork Side Channel	S062*	Woodland Lane	1,564	Box	RCB	20.2	12.6x7.5	135-136
Rock Creek	S012a	Private Road	228,030	Circular	CSP	35.8	4	21-22
Rock Creek	S012b	Private Road	228,030	Circular	CSP	35.8	4	23-24
Rock Creek	S012c	Private Road	228,030	Circular	CSP	40	4	25-26
Rock Creek	S012d	Private Road	228,030	Circular	CSP	40	4	27-28
Rock Creek	S020	Private Road	249,789	Circular	CSP	23.1	3	43-44
Rock Creek	S024*	Private Road	256,378	Box	RCB	20	4.4	51-52
Rock Creek	S028	Private Road	266,453	Circular	CSPA	32.3	4.3	62-63

* Bridge structure modeled as a culvert.

Culvert Types:

CSPA – Corrugated Steel Pipe Arch,

CSP – Corrugated Steel Pipe

RCB – Reinforced Concrete Box (culverts in this project are wood modeled as RCB with manning’s adjusted for wood)

Table 20. Summary of Culvert Model Settings

Stream Reach	ID No.	Roadway	River Station (feet)	Inlet Loss Coefficient	Outlet Loss Coefficient	Low Flow Method	High Flow Method
Middle Fork Side Channel	S062	Woodland Lane Culvert	1,564	0.5	1	Energy	Energy-Only
Rock Creek	S012a	Private Road	228,030	0.9	1	Energy	Energy-Only
Rock Creek	S012b	Private Road	228,030	0.9	1	Energy	Energy-Only
Rock Creek	S012c	Private Road	228,030	0.9	1	Energy	Energy-Only
Rock Creek	S012d	Private Road	228,030	0.9	1	Energy	Energy-Only
Rock Creek	S020	Private Road	249,789	0.5	1	Energy	Energy Only
Rock Creek	S024	Private Road	256,378	0.5	1	Energy	Energy Only
Rock Creek	S028	Private Road	266,453	0.7	1	Energy	Energy Only

Photographs 1 thru 5 illustrate the different types of roadway hydraulic conveyance structures that were modeled for the Rock Creek and Tributaries Flood Risk Project. Photographs of all the modeled bridge, culvert, and diversion structures which were evaluated during the structure inventory are provided in Appendix C.

Photograph 1: Rock Creek – Stage Station Road at RS 1,666 (S141)

Photograph 2: Rock Creek – Private Road at RS 256,378 (S025)

Photograph 3: Middle Fork Rock Creek – Woodland Ln at RS 2,225 (S061)

Photograph 4: Ranch Creek – Rock Creek Rd at RS 2,202 (S033)

Photograph 5: Upper Willow Creek – Miners Gulch Road at RS 39,301 (S051)

4.10 Manning's 'n' Values

Manning's 'n' values are coefficients representing the frictional resistance (surface roughness) acting on water when flowing overland or through a channel. The coefficients are used in the calculations to determine water surface elevations. Five land classes were developed for the study area to establish Manning's 'n' values based on ground and cover conditions. Manning's 'n' values assigned within the hydraulic model were determined based on aerial photography, structure inventory photographs, and the USGS publication, 'Guide to Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains' (USGS 1982). The US Forest Service (USFS) publication, General Technical Report RMRS-GTR-323, on steeply sloped streams S ≥ 0.002 (USFS 2014) was also referenced due to the steep and moderately steep channel gradients found on some portions of the tributary channels.

The USGS and USFS guides were used to develop minimum, maximum, and initial Manning's 'n' values for each land class. The range of Manning's 'n' values used in the study are shown in Table 21. Manning's 'n' values for the channel were evaluated based on the reach and the overbanks were evaluated at each cross section and adjustments were made to fit roughness area land class with the terrain data represented by the cross section.

Table 21. Manning's 'n' Values

Roughness Area Land Class Type	Manning's 'n' Value Range	Initial Value	Description
Main Channel	0.028 – 0.111	0.048	Gravel, cobbles, well-rounded boulders, and bedrock sections.
Pasture	0.036 – 0.142	0.067	Grasses, alfalfa, intermixed with weeds.
Willows	0.051 – 0.148	0.085	Willows with stems of herbaceous vegetation.
Urban-Developed	0.042 – 0.143	0.084	Herbaceous & woody vegetation with manmade structures.
Forest	0.052 – 0.129	0.080	Vegetation is primarily trees and shrubs.

4.11 Areas of Non-Conveyance

As indicated on the Hydraulic work maps in Appendix A, there are reaches where no flow or backwater conditions exist. These conditions provide limited or no-conveyance in the downstream direction. For these areas, the ineffective flow area method was implemented to calculate the total effective conveyance for each cross section in the hydraulic simulation.

The areas of non-conveyance included the following:

- Backwater and ponded areas.
- Flow constriction or expansion.
- Areas isolated by non-accredited earthen berms or embankments.
- Presence of high topography either upstream or downstream that eliminates flow in a topographically low area.
- Non-conveyance related to profiles exceeding the 1% AEP flow where needed to compute reasonable profiles.

The permanent option for ineffective areas was utilized occasionally throughout the hydraulic models. The permanent option was utilized as part of the suite of variable adjustments necessary to yield reasonable relationships between the profiles. When the permanent ineffective flow option was used, the water surface elevation for the 1% AEP profile was reviewed to ensure the permanent option did not appreciably alter the regulatory water surface elevation. Where ineffective areas have been set in the hydraulic models, a comment was included in the cross section model node description noting the reason the ineffective area was utilized. This method of documentation was selected to aid in both hydraulic model review for this flood study and to provide future model users with easy access to the purpose of the ineffective flow setting at each model node.

Review of the modeled cross sections in HEC-RAS identified connected backwater depression areas that are not hydraulically connected to the stream body. These areas were also classified as ineffective flow areas so that the model calculated the appropriate conveyance at the cross section. The river stations where connected backwater occurs are discussed in more detail in Section 5.1.

The blocked obstruction feature in HEC-RAS was also utilized on the Rock Creek Reach 4 hydraulic model between RS 172,580 and RS 173,520. The purpose of the blocked obstruction was to fill in the low topographic area of the DEM surface at a ponded water body. Inclusion of the low area over the pond resulted in unreasonable increases in cross section conveyance area that would not be accessible for much of the flood flow routed by the model due to topographic constraints bounding the ponded area. The combined use of ineffective areas to reasonably represent available cross-sectional conveyance area through this sub-reach resulted in reasonable flood profile relationships and floodplain continuity. The use of the blocked obstruction feature was documented in each model node as described for the ineffective areas.

4.12 Split Flow Modeling

During the hydraulic analysis, a split flow reach was identified on Middle Fork Rock Creek. The Middle Fork Rock Creek split flow reach was modeled using the 1D model as described in section 4.12.1 below. The Upper Willow Creek floodplain spills flow to the Rock Creek mainstem channel across the first 1,100 feet of the Upper Willow Creek floodplain above the confluence with Rock Creek. A lateral weir approach was judged to be a reasonable approach to model the portion of flow lost from the Upper Willow Creek floodplain, allowing computation and mapping of reasonably representative flood risks along the interface of the Upper Willow Creek valley with the Rock Creek floodplain.

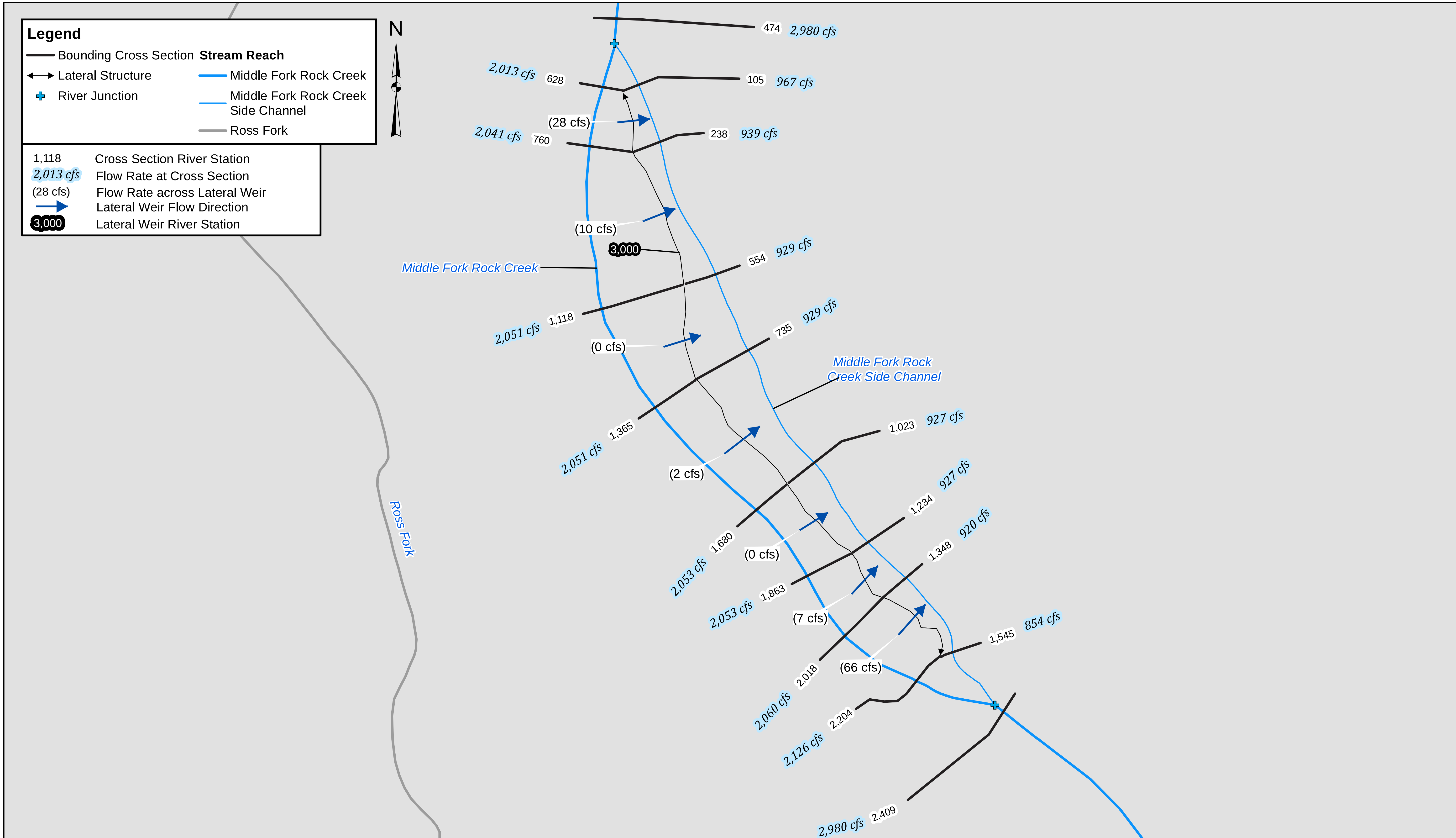
4.12.1 Middle Fork Rock Creek Split Flow

The Middle Fork Rock Creek split flow was caused by a natural island that breaks the main channel of the Middle Fork Rock Creek into two channels at RS 2409. The main creek channel and side channel are separated by natural high ground and controlled by three separate hydraulic structures on the upstream end of the split flow reach, precluding the option to simply model the high ground as a divided cross section. A HEC-RAS model junction node for a flow split was used to balance the energy equation at the Split flow location. The automatic junction optimization routine in HEC-RAS was used to calculate the split flows to each reach. A lateral weir was also used along the natural high ground of the island to calculate flow sharing. Flood flows were routed down each flow split until the floodplains converged near Middle Fork Rock Creek RS 474. The flow split discharges are summarized in Table 22.

Table 22. Middle Fork Rock Creek Split Flow Flood Discharges

Stream Segment	Hydraulic River Station	Estimated Discharge (cfs)					
		10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance	1% + Annual Chance
		10-year	25-year	50-year	100-year	500-year	100-year +
Middle Fork Rock Creek A	2409	2130	2500	2750	2980	3480	3450
Middle Fork Rock Creek B	628	1488	1715	1855	2013	2307	2290
	760	1494	1728	1874	2041	2348	2331
	1118	1494	1728	1877	2051	2395	2375
	1365	1494	1728	1877	2051	2398	2378
	1680	1494	1728	1877	2053	2405	2384
	1863	1494	1728	1877	2053	2411	2390
	2018	1494	1729	1879	2060	2434	2412
	2204	1517	1768	1922	2126	2561	2536
Middle Fork Side Channel	105	642	785	895	967	1173	1160
	238	636	772	876	939	1132	1119
	554	636	772	874	929	1085	1075
	735	636	772	874	929	1082	1072
	1023	636	772	873	927	1075	1066
	1234	636	772	873	927	1069	1060
	1348	636	771	871	920	1046	1038
	1545	613	732	828	854	919	914
Middle Fork Rock Creek C	2409	2130	2500	2750	2980	3480	3450

cfs: cubic feet per second.



1 inch = 200 feet

0 100 200 400 Feet

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APPR. BY: LDC
DATE: 6/25/2021

Flow Diagram Map

Middle Fork Rock Creek and Middle Fork Rock Creek Side Channel Convergence

PROJECT NO. 1447.054

Figure 7

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4.12.2 Upper Willow Creek

The valley mouth of Upper Willow Creek is relatively wide and there is substantial topographic slope from the southern end of the valley mouth to the low-flow stream channel confluence of Upper Willow Creek with Rock Creek. Development of 1D cross sections following FEMA guidance of fully containing flood profiles through the 0.2% AC event would require extension of the cross section across the Rock Creek mainstem channel for the first 1,100 feet of the Upper Willow Creek floodplain. Since the Rock Creek channel is large and deep relative to the Upper Willow Creek channel and floodplain, inclusion of the Rock Creek mainstem channel would improperly under-estimate flood risk at the Upper Willow Creek valley mouth.

Using the blocked obstruction setting to fill the Rock Creek mainstem channel to the intersection with the valley floor was considered. However, the blocked obstruction approach would yield total cross section area wider than would be reasonably accessible by flood flows on Upper Willow Creek and would also tend to underestimate the flood risk in the valley mouth area. Use of blocked obstruction or ineffective areas extended vertically above the flood water surface elevations was also considered. However, this option assumes all flow is retained within the Upper Willow Creek floodplain and may be unreasonably conservative. Additionally, the cross sections would not meet typical FEMA guidance or engineering best practice of cross section end points above the 0.2% AC flood event. Another modeling alternative is the use of optimized lateral weirs along the overflow area to the Rock Creek mainstem channel was considered. This alternative better aligns with FEMA guidance and engineering best practices for estimating flow leaving a model reach where cross sections do not fully contain flood profiles through the 0.2% AC event.

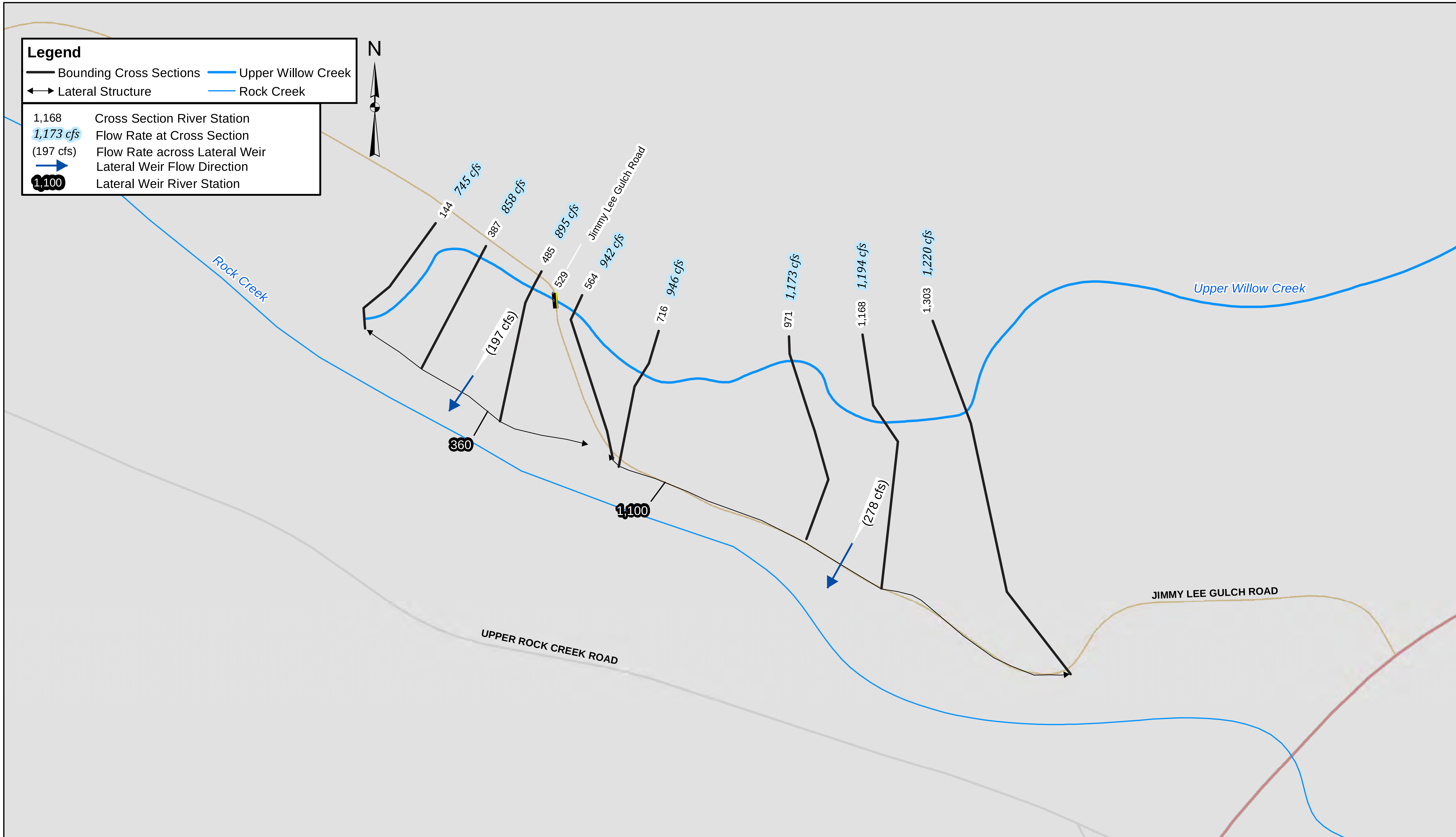
Since flood coincidence between Upper Willow Creek and Rock Creek is not likely (Pioneer 2020a) and the discharge is an order of magnitude less than the Rock Creek flood flows, the flow discharging across the lateral weirs was discarded from the hydraulic model. The lateral weir crests were extracted from the topography. A weir coefficient of 0.39 was selected since the overtopping ground is most like the non-elevated overbank lateral flow condition referenced in available literature. Two lateral weirs were required in the hydraulic model since there was a bridge over the Upper Willow Creek channel within the overflow zone and HEC-RAS 1D hydraulic model logic does not allow multiple structure types between any two cross sections.

As mentioned above, the automatic optimization routine in HEC-RAS was selected to allow the model to compute the energy head and flow relationship between the lateral weirs and the adjacent cross sections. When the optimization routine is active, the HEC-RAS model automatically tracks flow changes at each model node and balances the energy and flow relationships for both the cross sections and the lateral weirs. Nearly 40 percent of the 1% AC flood flow is lost from the Upper Willow Creek floodplain above the confluence of the Upper Willow Creek and Rock Creek channels. The flow split discharges are summarized in Table 23 and the flow changes for the 1% AC flood profile are shown in the flow diagram above (Figure 7). Minor discrepancies in flow conservation occur between lateral weir discharge values and cross section discharges do occur. However, these discrepancies are less than a couple cubic feet per second (cfs) and are within the typical tolerance for HEC-RAS 1D hydraulic modeling optimization routine convergence for all profiles.

Table 23. Upper Willow Creek Split Flow Flood Discharges

Stream	Hydraulic River Station	Estimated Discharge (cfs)					
		10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance	1% + Annual Chance
		10-year	25-year	50-year	100-year	500-year	100-year +
Upper Willow Creek	1,303	668	868	1,040	1,220	1,640	1,900
	1,167	667	863	1,026	1,195	1,586	1,827
	971	663	854	1,012	1,174	1,549	1,778
	716	523	675	807	946	1,256	1,444
	564	522	673	805	942	1,250	1,437
	544	522	673	805	942	1,248	1,433
	508 (bridge)	No lateral structure					
	485	522	673	805	942	1,248	1,433
	386	498	629	742	858	1,114	1,269
	144	427	542	641	745	976	1,116

cfs: cubic feet per second.



1 inch = 150 feet

0 75 150 300 Feet

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CHK'D BY: LDC
APPR. BY: LDC
DATE: 6/25/2021

Flow Diagram Map

Upper Willow Creek and Rock Creek Confluence

PROJECT NO. 1447.054

Figure 8

4.13 Critical Depth & Profile Smoothing

Critical depths have been allowed to remain in the model at locations where a critical or supercritical flow regime is hydraulically reasonable and follows the research results that the USFS has published for moderately steep and steep streams (USFS 2014). Generally, these critical depths are at locations where the channel profile drops at a significant gradient or where a flow regime change could occur. As this model has been completed using sub-critical calculation routines in HEC-RAS, a super-critical profile is not provided in the model.

Profile smoothing is required where minor modeling numerical idiosyncrasy or, structural effects result in a water surface elevation higher than the upstream calculation node. As this type of hydraulic jump is less conservative than a water surface profile that is flat or increases upstream, the numerical model is checked and adjusted to remove the drawdown. In some cases, especially around structures, a hydraulic jump downstream may reasonably occur; in these cases, the flood profile is smoothed to present reasonable water surface elevations. Smoothing was completed in accordance with FEMA Guidance *Flood Profiles* (FEMA 2016b). Locations where smoothing was completed are shown in Table 24 for the 1% AC regulatory flood profile. The hydraulic model is adjusted for the 1% AC flood profile. Other profiles were smoothed both at the locations noted below and at other locations where model inputs resulted in a drawdown for the non-regulatory flood profile.

Table 24. 1% AC Profile Smoothing River Stations

Tributary Reach	River Station (feet)	Reason for Profile Smoothing
Rock Creek	110,473	Drawdown within structure
Rock Creek	191,284	Drawdown within structure
Rock Creek	256,378	Drawdown within structure
Rock Creek	266,453	Drawdown within structure
Ranch Creek	6,521	Drawdown within structure
Upper Willow Creek	529	Drawdown within structure
Upper Willow Creek	20,452	Drawdown within structure

4.14 Model Calibration

Stream gage data at USGS gage 12334510 Rock Creek near Clinton, Montana was used to compare the HEC-RAS model for the Rock Creek analysis. Reference marks for the USGS gage were surveyed in August 2019 by DOWL, (DOWL). Water surface elevations were calculated for the highest available flow records based on the USGS gage height records and the 2019 DOWL survey in NAVD88 datum. The Rock Creek model water surface was within 0.33 feet for the peak flow rate of 6,500-cfs recorded on June 1, 1972. The Rock Creek reach 1 model water surface was within 0.02 feet for the

2017 and 2018 flooding events. The modeling results for Rock Creek are reasonably calibrated for the purposes of a floodplain study.

Table 25. Rock Creek Calibration Results

Event Year	Gage Height (FT)	Peak Streamflow (CFS)	Gage Elevation (FT)	Model Elevation (FT)	Difference (Model-Gage)
1972	8.5	6500	3531.69	3532.02	0.33
2018	8.63	5830	3531.82	3531.8	-0.02
2017	8.53	5540	3531.72	3531.71	-0.01

cfs: cubic feet per second.
ft: feet

This was the only gage calibration data available for the Rock Creek and Tributaries flood study. The other four Rock Creek reaches and the Tributary reaches were generally similar in land use and geomorphic setting to Rock Creek. Therefore, the modeling parameters selected for Rock Creek were also applied to the other four tributaries as the best available information for model verification and validity. Additionally, the resulting floodplain mapping was compared with aerial imagery acquired during the 2011 flood and terrain using engineering judgement. The floodplain mapping generally appeared to be consistent with the imagery and terrain floodplain interpretation.

4.15 Floodways

The Rock Creek and Tributaries project contains two separate reaches, Rock Creek Reach 1 and Rock Creek Reach 2 that include a floodway analysis. Floodway encroachments were computed for Rock Creek at each cross section within these reaches. Between cross sections, the floodway boundaries were interpolated. The results of the floodway computations are tabulated for lettered cross sections and are presented in the Floodway Data Tables in Appendix D. The work maps show only the floodway boundary in cases where the floodway and 1% AC floodplain are either close together or collinear.

In Montana, the designated floodway is developed using a 0.5-foot surcharge instead of the Federal maximum of 1.0-foot (DNRC 2014). The state criteria takes precedence over the minimum Federal criteria for purposes of regulating development in the floodplain, as set forth in the Code of Federal Regulations, 44 CFR, 60.3cd (2).

The floodway is developed using the HEC-RAS encroachment analysis method 4 for the initial analysis and then fine tuning the encroachments using method 1. Development of the full 0.5-feet of surcharge allowance is not always possible at all cross sections. The 0.5-foot allowance is a maximum limit that cannot be exceeded at any cross section throughout the study reach. The floodway modeling may produce a surcharge at an upstream cross section that exceeds the 0.5-foot maximum limit. Therefore, some cross sections, as shown in the Floodway Data Table, have surcharges of less than the 0.5-foot allowable maximum because of the effect that a greater encroachment at these locations would have on adjacent cross sections. The floodway encroachments were also set outside of ineffective flow areas and must include the bank stations of each cross section to meet the State of Montana and FEMA guidelines.

4.16 Flood Profiles

Flood profile panels were developed in accordance with FEMA Guidance and Standards. The moderately steep to very steep stream gradient and the amount of variation in gradient of the Rock Creek and Tributary streams was not conducive to fit to a consistent scale for all stream reaches in this study. Horizontal and vertical scales were selected at 1”:400’ and 1”:5’ respectively for Rock Creek. Horizontal and vertical scales were selected at 1”:200’ and 1”:5’ respectively for Middle Fork Rock Creek, Middle Fork Rock Creek Side Channel, Ross Fork, West Fork Rock Creek, and Upper Willow Creek. The selected scale for Ranch Creek was 1”:100’ Horizontal and 1”:5’ vertical. The selected scale for Middle Fork Side Channel was 1”:200’ Horizontal and 1”:2’ vertical. The horizontal and vertical scales were selected to provide profile panels where all six profiles could be distinguished in most locations.

The scale for Maukey Gulch is a non-standard 30 foot horizontal scale with a two foot vertical scale. The 30H:2V non-standard scale approach provides very good legibility for all profiles throughout the stream reach. The non-standard scale was approved by Montana DNRC as the best product for community use.

There are a few locations where the profile panels overlap in river station to allow all segments of all six profiles to be presented on the profile panels (e.g. Maukey Gulch profile panels 001P-002P). The selected scale and panel layout were chosen to provide easily interpretable flood profiles for public review and community floodplain administration. Flood profiles for all stream segments are provided in Appendix B.

Following standard practice, drawdowns and crossing profiles within the structures were smoothed on the profile. There is one crossing profile on West Fork Rock Creek between the 0.2% AC profile and the 1%+ AC profile that is a result of the hydrology discussed in Section 3.2.5. This crossing profile occurs between RS 266 and RS 377 on reach A of West Fork Rock Creek. The hydraulic modeling is tuned to reasonably represent the regulatory (1% AC) profile. Drawdowns in non-regulatory profiles occur occasionally in the hydraulic modeling. The drawdowns were smoothed in the flood profile products to present reasonable hydraulic relationships in accordance with FEMA guidance and engineering standard practice.

The 0.2% AC and 1%+ AC profiles are shown as coincident for all of Rock Creek, Middle Fork Rock Creek, and Middle Fork Rock Creek Side Channel. Instead of adding an arrow at the top of the page with a label stating that the profiles were coincident; a note was added to the legend with an asterisk on the 1%+ AC profile. The profile for Rock Creek does not include a backwater elevation from the Clark Fork River. This will need to be added to the profiles after the updated Clark Fork River Hydraulics task has been approved by FEMA.

4.17 cHECk-RAS

FEMA's automated review software cHECk-RAS, Version 2.0.1 (FEMA 2011) was utilized to verify the acceptability of the hydraulic analyses described above. Files from the HEC-RAS version 5.0.7 analyses were uploaded into cHECk-RAS. Several messages in cHECk-RAS are incorrect and appear to be related to the loss of output reading functionality when the current version of cHECk-RAS reads HEC-RAS 5.0.7 data. These messages were checked to verify that a cHECk-RAS read error exists and are noted on the cHECk-RAS report.

cHECk-RAS evaluates the following five categories of the hydraulic modeling:

- NT (Manning's roughness coefficients and transition loss coefficients)
- XS (Cross sections)
- Floodways
- Structures
- Profiles

The cHECk-RAS output messages for the Rock Creek and Tributaries models were reviewed and each issue was either resolved or investigated to confirm that the modeling was correct and that the cHECk-RAS message was not applicable. Appendix E includes the list of cHECk-RAS messages and responses to each message for each modeled stream reach.

5.0 Floodplain Mapping

Floodplain mapping was prepared using GeoHECRAS mapping tools and ESRI ArcMap 10.7 (ESRI 2019). The GeoHECRAS application generates the raw floodplain delineation by intersecting the LiDAR DEM with a separate DEM representing the water surface elevations of the 1% and 0.2% AC events. The results of the hydraulic modelling and topographic data are used to create products for end users that are described in the following sections. Two separate FIRM databases were created one for Missoula County and Granite County. Since the floodplain crosses the Missoula-Granite County boundary multiple times the profile baseline is not clipped to county boundary each time but instead includes the overlapped area.

5.1 Hydraulic Work Maps

The resulting floodplains from the 1% and 0.2% AC flood events are displayed on the hydraulic work maps provided in Appendix A. The base map used for the hydraulic work map is the 2017 NAIP aerial imagery. Along with the flooding extents, the stream profile baseline along with the cross sections utilized during the hydraulic analysis are displayed on the work maps. The layout of the cross sections and structures under existing conditions are presented on the work maps. At some locations, modeled cross sections have been removed from the work maps for clarity due to the dense placement required for the numerical model. Node names have been recorded in the model to assist the user when reviewing the model and the work maps; lettered cross sections are named with the appropriate letter label, mapped non-lettered cross sections are noted as NL-not labeled and non-mapped cross sections are noted as NL/NM-for not labeled and not-mapped. Zone AE symbolized polygons are the floodplain delineated for the regulatory floodplain.

Typically, islands that were marginally higher than the adjacent 1% AC water surface profile and less than one-half acre in size were not delineated. Exceptions to this approach were made for existing building structures visible in the aerial imagery and above the computed base flood elevation surface used for floodplain map boundary development. Large backwater areas that extended through multiple cross sections were also modified to represent the elevation associated with the location where the backwater initiates from the main channel. These two adjustments provide a slight variance in the mapped widths versus the top widths described by the HEC-RAS model at selected locations. A table of the 1% AC flood event backwater elevations and the corresponding profile baseline station is included in Table 26.

Table 26. Backwater Elevation Summary

Tributary Reach	River Station (feet)	1% AC (WSE)
Rock Creek	31,898	3699
Rock Creek	55,024	3839
Rock Creek	118,968	4252
Rock Creek	163,965	4513
Rock Creek	186,844	4641
Rock Creek	274,477	5222
Upper Willow Creek	56,862	5411
West Fork Rock Creek	3,235	5295

WSE: water surface elevation.

5.2 Map Tie-in Locations

The Rock Creek and Tributaries study ties in on the downstream to the Clark Fork River in Missoula County. The Missoula-Granite PMR project includes study of the Clark Fork River at the confluence of Rock Creek. Future project tasks will require resolution of proposed floodplain mapping from both flooding sources for preparation of new Flood Insurance Rate Maps. The floodplain mapping products included with this submittal fully exceed the effective mapped stream lengths for this area of Missoula and Granite Counties and will replace all effective flood zones floodplain mapping for Rock Creek and Tributaries to Rock Creek.

Zone break lines were developed as appropriate to indicate which flooding source represents the greater flood risk in the confluence areas between Upper Willow Creek and Rock Creek. It was determined that the confluence between Ranch Creek and Rock Creek did not require a zone break line.

5.3 Floodplain Boundary Smoothing

Floodplain Boundary Smoothing was completed in compliance with the February 2019 FEMA FIRM Database Schema and FEMA Database Verification Tool parameters applicable at the time this project contract was signed in September of 2019. Floodplain smoothing was conducted using several automated processing tools and manually corrected after processing to ensure floodplain widths, fringe widths, polygon gaps, and polygon overlaps all met FEMA criteria and standard engineering practices.

Due to the narrow and steep topography of much of the Rock Creek and Tributaries study reaches, final regulatory mapped widths were expanded to a minimum of 50 feet (5% of the FIRM panel scale). Most of the 0.2% AC floodplain is a very narrow fringe along the regulatory floodplain and will be removed from the final mapping. This was necessary to provide mapping visible at the FIRM panel scale of 1:1000.

Two exceptions to the typical practice described above are included in the final mapping.

- At a few locations, the standard practice for floodplain widths (and gaps/slivers) necessary for viewing at the FIRM map scale conflicted with FEMA Standards requiring mapped widths to match the modeled widths at cross sections. At these locations, the requirement for mapped width at the cross section was prioritized over typical standard practices for gaps or dry slivers included in the floodplain mapping.

The Quality Control process for floodplain boundary preparation was documented in review checklists which are included in Appendix F.

5.4 Floodplain Islands and Disconnected Ponding

Floodplain islands were included in the floodplain mapping. Typically, these areas were relatively large, blocky areas of natural high ground that is elevated above the computed flood water surface elevation by more than one foot. Small, skinny, or minor elevation (<1 foot) areas above the rough floodplain mapping were included within the mapped floodplain area. Exceptions to this approach are anticipated for existing building structures visible in the aerial imagery and above the computed base flood elevation surface used for floodplain map boundary development.

Generally, disconnected ponding across anthropogenic high ground (e.g. dikes, berms, old road grades or embankments) was shown as connected to the floodplain with a continuous floodplain map boundary. Where the disconnected ponding occurs across an active roadway, the ponding was shown as a separate polygon to provide map users with information on what routes are expected to remain traversable during a flood event. Where the disconnected ponding across an anthropogenic berm is parallel to the flood flow direction, the floodplain mapping was matched to the active conveyance flood water elevation. In most cases, the location of the hydraulic connection between the disconnected low area and the active floodplain is unknown and mapping the area assuming that a culvert connected the active floodplain with the disconnected low area at each cross section represents the potential worst-case backwater condition throughout the disconnected low area (e.g. Rock Creek RS 266,484 to 269,861).

5.5 Changes Since Last FIRM Mapping

Changes Since Last FIRM (CSLF) mapping products assist public entities and landowners in interpreting the changes to the floodplain mapping proposed for the new study compared to the effective mapping being replaced. CLSF mapping was completed as requested by the DNRC and is included with the study products deliverables. CSLF spatial files are provided in the Supplemental Data folder of the Floodplain Mapping submission.

5.6 Letters of Map Change

A review was made of the Letters of Map Change (LOMC) along the Rock Creek and Tributaries within the study area to identify locations where previously issued LOMC may need to be considered in the context of the changes proposed by this updated study. Eleven LOMC/Letter of Map Amendment (LOMA) records were found along the Rock Creek and Tributaries study reaches in a search of FEMA records.

Table 27. FEMA Records for Rock Creek and Tributaries Study Reach LOMC/LOMA Case Numbers

LOMC/LOMA ID		
12-08-0099V	12-08-0460A	12-08-0501A
13-08-1177A	14-08-0657A	14-08-0112A
14-08-0275A	19-081069A	01-08-222A
19-08-0491A	03-08-0245A	

5.7 Floodplain Boundary Standard Audit

A Floodplain Boundary Standard (FBS) Audit was completed as part of the Floodplain Mapping Task scope of work. The FBS Audit is a standardized self-review of the regulatory floodplain boundary to be carried into final mapping products. This project was within risk class C, which requires at least 85% of the test points to be within +/- 1 foot of the ground elevation. Test points were deleted from the floodplain boundary at study termination where the boundary was perpendicular to the flood flow direction. When the initial FBS Audit results in a pass rate greater than the required 85% threshold, the 38-foot radius horizontal tolerance additional check will not be completed. FBS Audit summary reports are included in Appendix E and test point shapefiles are included in the Supplemental Data folder of the digital submission as part of the Floodplain Mapping Task scope of work.

5.8 Depth & WSE Grids

Depth and WSE Grids were prepared for each profile included in the hydraulic model (10%, 4% 2%, 1%, 1%+, and 0.2% AC). The grid data are raw depth grids ready for further processing in accordance with the FEMA Guidance *Flood Depth and Analysis Grids* once the final mapping products have been approved. These grid data products are included in the Supplemental Data folder of the digital submission as part of the Floodplain Mapping Task scope of work.

6.0 Flood Insurance Study Products

Digital profiles for the 10%, 4%, 2%, 1%, 1%+, and 0.2% AC water surface elevations were created using FEMA's RASPLOT software (FEMA 2015). Additional information, edits and formatting were made using the .dxf editing tools within RASPLOT for this Hydraulics Task submittal. Final profiles were converted to AutoCAD dwg files for final flood risk product delivery through the project review and approval progression. Profiles were developed using the guidance found in FEMA Guidance for Flood Risk Analysis and Mapping: Flood Profiles (FEMA 2016a). The water surface profiles illustrating the results of the study are provided in Appendix B and in the Flood Insurance Study (FIS) Report folder under the Rock Creek folder of the digital submission.

7.0 References

1. Arcement Jr, George J.; Schneider, Verne R. *Guide for selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains, United States Geologic Survey (USGS) Water-Supply Paper 2339.* USGS, March 1982, Denver CO.
2. Brunner, Gary W, CEIWR – HEC. *HEC-RAS 2D Modeling User's Manual, Version 5.0.* United States Army Corps of Engineers (USACE), February 2016a, Davis CA
3. Brunner, Gary W. *HEC-RAS Hydraulic Reference Manual, Version 5.0*. United States Army Corps of Engineers (USACE), February 2016b, Davis CA.
4. Brunner, Gary W, CEIWR – HEC. *HEC-RAS User's Manual, Version 5.0*. United States Army Corps of Engineers (USACE), February 2016c, Davis CA.
5. Chow, Ven Te. *Open-channel Hydraulics.* McGraw-Hill, 1959, New York.
6. CivilGEO Engineering Software, (CivilGEO). *GeoHECRAS.* CivilGEO, Copyright ©, 2020, Middleton WI.
7. DOWL. *Rock Creek Near Missoula Bathymetric Cross Section Survey Report*. Montana DNRC, October 2019a, Helena MT.
8. DOWL. *Rock Creek Near Missoula USGS Stream Gage Report.* Montana DNRC, October 2019b, Helena MT.
9. Environmental Systems Research Institute (ESRI). *ArcGIS Desktop: Release 10.7.* ESRI, June 2019, USA.
10. Federal Emergency Management Agency (FEMA). *cHECk-RAS, Version 2.0.1*, FEMA, Copyright © 2013, Washington D.C.
11. Federal Emergency Management Agency (FEMA). *RASPLOT, Version 3.0*. FEMA, Copyright © April 2015, Washington D.C.
12. Federal Emergency Management Agency (FEMA). *Flood Insurance Study, Granite County, Montana and Incorporated Areas*. FEMA, April 19,2016, Washington DC.
13. Federal Emergency Management Agency (FEMA). *Flood Insurance Study, Missoula County, Montana and Incorporated Areas*. FEMA, March 7,2019, Washington DC.
14. Federal Emergency Management Agency (FEMA). *Guidance for Flood Risk Analysis and Mapping, Flood Profiles.* FEMA, November 2016a, Washington DC.
15. Federal Emergency Management Agency (FEMA). *Guidance for Flood Risk Analysis and Mapping, General Hydraulics Considerations,* FEMA, November 2016b, Washington DC.
16. Federal Emergency Management Agency (FEMA). *Guidance for Riverine Flooding Analyses and Mapping, Hydraulics: One-Dimensional Analysis.* FEMA, November 2016c, Washington DC.
17. Federal Emergency Management Agency (FEMA). *State of Montana DNRC Cooperating Technical Partners (CTP) Flood Risk Project Mapping Activity Statement (MAS): MAS No. 2019-02 (Missoula-Granite PMR).* Montana DNRC, June 27, 2019, Helena MT.

18. Goodell, Chris. “The RAS Solution Forum: Kleinschmidt.” *The RAS Solution*, Copyright ©, Kleinschmidt Group 2019, www.kleinschmidtgroup.com/the-ras-solution-forum/.

19. Jarrett, Robert D. *Determination of roughness coefficients for streams in Colorado, Water Resources Investigation Report 85-4004*. United States Geologic Survey (USGS),1985, Lakewood CO.

20. Montana Department of Natural Resources and Conservation (DNRC). *2014 Model Regulations*, Montana DNRC, February 20, 2014, Helena MT.

21. Pioneer Technical Services, Inc. (Pioneer). *Missoula-Granite PMR, MAS No. 2019-02 Missoula and Granite Counties, Montana Hydrologic Analysis Report.* Montana DNRC, July 9, 2020a, Helena MT.

22. Pioneer Technical Services, Inc. (Pioneer). *Missoula-Granite PMR, Field Reconnaissance and Hydraulic Structure Assessment Report*. Montana DNRC, May 27, 2020b, Helena MT

23. Pioneer Technical Services, Inc. (Pioneer). *Missoula-Granite PMR, MAS No. 2019-2 Structure Survey Report*. Montana DNRC, May 27, 2020c, Helena MT.

24. Quantum Spatial, Inc. (QSI). *Clark Fork Bitterroot, Montana QL1 LiDAR Technical Data Report.* Montana DNRC, October 24, 2019, Helena MT.

25. Robinson, Dusty; Zundel, Alan; Kramer, Casey; Nelson, Royd; deRosset, Will; Hunt, John; Hogan, Scott; Lai, Yong. *Two-Dimensional Hydraulic Modeling for Highways in the River Environment*. Federal Highway Administration (FHWA), October 2019, Austin TX.

26. Sando, Steven K.; Sando, Roy; McCarthy, Peter M.; Dutton, DeAnn M. *Adjusted peak-flow frequency estimates for selected streamflow-gaging stations in or near Montana based on data through water year 2011.* Chapter D of Montana StreamStats, U.S. Geological Survey (USGS) Scientific Investigations Report (SIR) *2015-5019-D,* Version 1.1, USGS, February 2018, Reston VA.

27. Sando, Steven K.; Sando, Roy; McCarthy, Peter M.; Dutton, DeAnn M. *Methods for estimating peak-flow frequencies at ungaged sites in Montana based on data through water year 2011.* Chapter F of Montana StreamStats, Scientific Investigations Report (SIR) 2015-5019-F, Version 1.1, United States Geologic Survey (USGS), February 2018, Reston VA.

28. Sando, Steven K.; McCarthy, Peter M. *Methods for peak-flow frequency analysis and reporting for streamgages in or near Montana Based on data through water year 2015*. United States Geological Survey (USGS) Scientific Investigations Report (SIR) 2018-5046, USGS, 2018, Reston VA.

29. United States Army Corps of Engineers (USACE). *HEC-RAS 5.0.7.* USACE, March 2019a, Davis CA.

30. United States Army Corps of Engineers (USACE). *HEC-RAS Release Notes, Version 5.0.7*. USACE, March 2019b, Davis CA.

31. United States Department of Agriculture (USDA). *National Agricultural Imagery Program (NAIP)*, *aerial photographs 2017*. USDA, 2017, Salt Lake UT.

32. United States Geologic Survey (USGS). *NLCD 2016 Land Cover (CONUS).* (https://www.mrlc.gov/data/nlcd-2016-land-cover-conus), USGS, December 03, 2018, Sioux Falls SD.

33. United States Geologic Survey (USGS). *Peak-flow frequency analysis for 11 selected streamgages in Missoula-Granite County, Montana, based on data through water year 2017: U.S. Geological Survey data release, https://doi.org/10.5066/P9TK3KFE*, 2019, Helena MT.

34. Yochum, Steven E.; Comiti, Francesco; Wohl, Ellen; David, Gabrielle C.L.; Mao, Luca. *Photographic Guidance for Selecting Flow Resistance Coefficients in High-Gradient Channels (S ≥ 0.02)*, *United States Forest Service (USFS) General Technical Report RMRS-GTR-323*. United States Department of Agriculture (USDA), July 2014, Fort Collins CO.

APPENDICES

Appendix A – Hydraulic Work Maps

Appendix B – Water Surface Profiles

Appendix C – Structure Photographs

Appendix D – Floodway Data Tables

Appendix E – cHECk-RAS Checklists

Appendix F – QA/QC Checklists