Hydraulic Analysis Report

Clark Fork River Floodplain Study
Mineral County, MT

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MINERAL COUNTY
MONTANA

August 2018

MONTANA DNRC
MT DEPARTMENT OF NATURAL RESOURCES & CONSERVATION

Morrison Maierle
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U.S. DEPARTMENT OF HOMELAND SECURITY
FEMA

Contract Number: WO-MM-162
Mapping Activity Statement No. 2017-04

Clark Fork River Floodplain Study

Hydraulic Analysis Report

Mineral County, Montana

PREPARED FOR:

Montana Department of Natural Resources and Conservation

Federal Emergency Management Agency

August 16, 2018

PREPARD BY:

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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

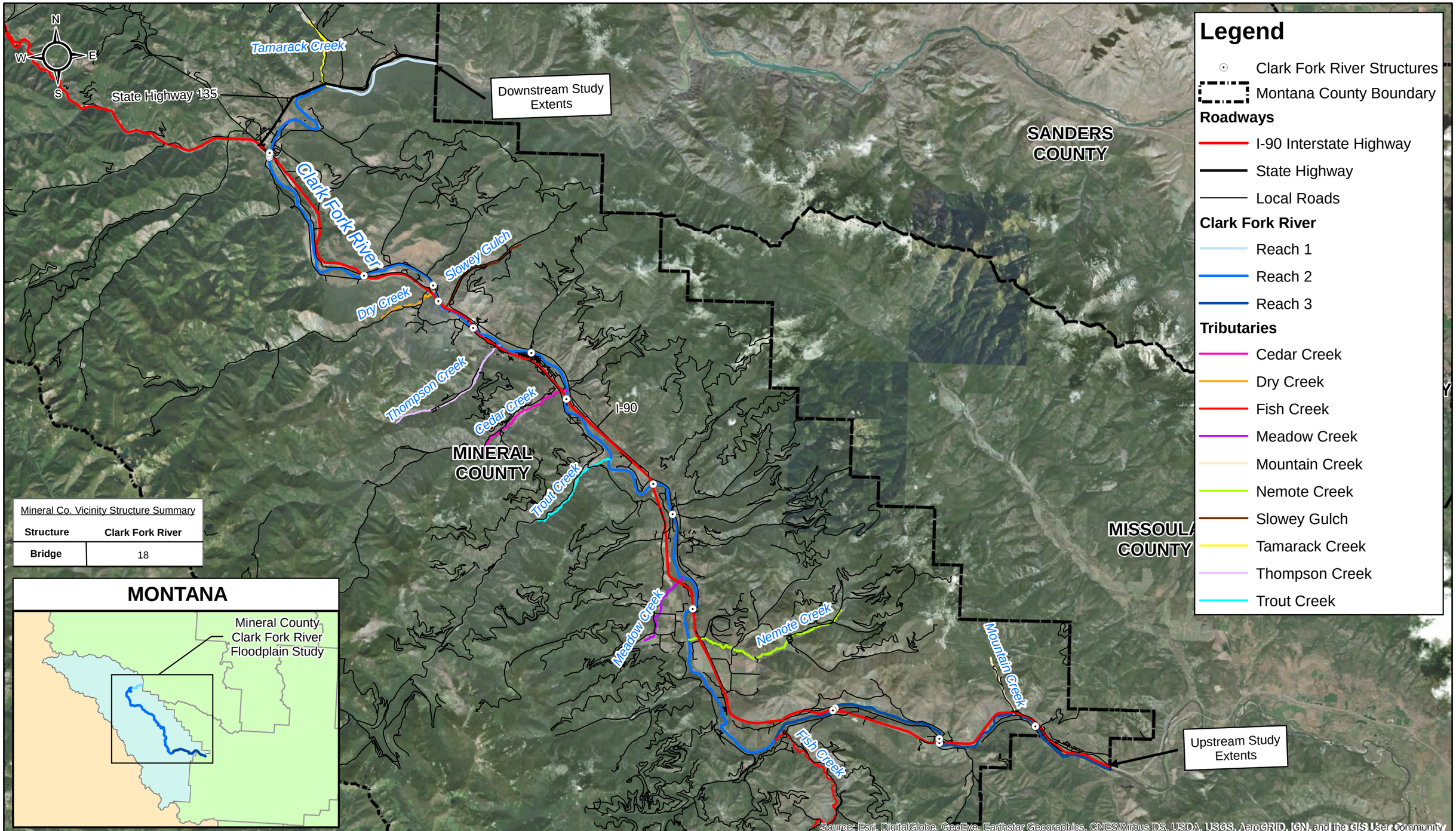
Morrison-Maierle has completed the hydraulic analysis for the Clark Fork River within Mineral County, Montana, as part of the Mapping Activity Statement (MAS) 2017-04, Mineral County Modernization, Phase II (FEMA 2017f). The Scope of Work is to computer model and create floodplain mapping along the Clark Fork River Mainstem reach in Mineral County, Montana from the respective downstream and upstream boundaries with Sanders and Missoula Counties. 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), Mineral County, and other stakeholders. The purpose of this report is to document the hydraulic analysis, and provide results for incorporation into floodplain mapping and a Flood Insurance Study (FIS).

The study limits, as shown on Figure 1, consists of an approximately 58.2 river mile segment within Mineral County from the downstream limit at the Sanders County Boundary to just east of the town of Alberton, Montana at the Missoula County Boundary. The project reach was divided into three model segments as summarized in Table 1 and shown on Figure 1. The Reach 1 and 3 segments are Enhanced Level Option E models with Zone AE delineations without a floodway. The Reach 2 segment is an Enhanced Level Option E segment with Zone AE delineations with a floodway including the towns of St. Regis and Superior, Montana.

Table 1. Clark Fork River Model Segments

River Reach	Segment	Analysis Approach	Length (miles)
1	Tamarack Creek to Sanders County Boundary	Enhanced Level Option E	4.6
2	Fish Creek to Tamarack Creek	Enhanced Level Option E with Floodway	40.1
3	Missoula County Boundary to Fish Creek	Enhanced Level Option E	13.5
Total			58.2

This Summary 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 best available information including LiDAR, bathymetric and structure surveys, and a new hydrologic analysis developed specifically for this mapping update. The LiDAR was obtained by Quantum Spatial Inc. (QSI) in 2017 (QSI 2017). The hydrologic analysis for Clark Fork River was completed by the Pioneer Technical Services, Inc. (Pioneer) in 2017 (Pioneer 2017a) and was approved by FEMA in 2017. The hydraulic bathymetric and structure surveys were completed by Pioneer in the summer of 2017 (Pioneer 2017b) and submitted to FEMA in August 2017.



Mineral Co. Vicinity Structure Summary

Structure	Clark Fork River
Bridge	18

0 2 4 8 12 16 Miles

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Mineral County Modernization, Phase II

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Clark Fork River Study Area

FIG. 1

The hydraulic analysis for the Clark Fork River within Mineral County, MT is summarized in this report. The flood study includes the 10%, 4%, 2%, 1%, 0.2%, and 1% plus annual-chance (AC) flood events. The 1% plus 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% annual-chance 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 National Flood Insurance Program.

1.1 Watershed Description

The Clark Fork River is within the Columbia River watershed and is located west of the continental divide in western Montana. It is a major tributary to the Pend Oreille River and uppermost headwaters of the Columbia River watershed. The Mainstem of the Clark Fork River begins at the confluence of Silver Bow Creek and Warm Springs Creek approximately 15 miles south of Deer Lodge, Montana, and flows northwest for approximately 310 miles where it enters Lake Pend Oreille in the Idaho Panhandle. The entire Clark Fork watershed encompasses approximately 22,905 square miles (Pioneer 2017a). The study watershed basin area from the Missoula County boundary to the Sanders County boundary is approximately 1,217 square miles.

The Clark Fork River basin elevations within the study area range from approximately 7,600-feet in the mountains to approximately 2,570-feet at St. Regis. The overall basin elevations range from over 10,000-feet at the continental divide to 2,060-feet near the confluence with Pend Oreille Lake (Pioneer 2017a). The terrain varies from a high alpine environment in its headwaters to a heavily cultivated landscape in the Deer Lodge valley with expansive irrigated pasture lands.

Land use in the Clark Fork River basin is primarily United States National Forest, undeveloped natural land, agricultural with irrigated farming and ranching operations. Most of the farmed land is located in the valleys adjacent to the Clark Fork River floodplain.

2.0 Previous Mapping

Flood Insurance Rate Maps (FIRM) were completed for Mineral County, MT in the early 1970s and do not include floodway analysis. The FIRM panels are noted to be converted by letter and have an effective date of November 1, 1996. The FIRM panel for the Town of Superior, Montana has an effective date of January 5, 2001. The flood hazard currently mapped for the Clark Fork River is Zone A for approximately 55 river-miles within Mineral County, Montana. Computer modeling was not completed to determine the Zone A delineations and a Flood Insurance Study (FIS) report was not published with the effective FIRM panels. This Floodplain Study update will be the first FIS report for the Clark Fork River in Mineral County.

Zone A flood maps are developed using approximate methodologies and have a flood hazard zone boundary without hydraulic modeling support and do not include Base Flood Elevations (BFEs). 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 Clark Fork River to Zone AE and will include BFE's on the Clark Fork River for Mineral County, MT.

3.0 Hydrology

This flood study, as shown on Figure 1, covers approximately 58.2 river-miles of the Clark Fork River within Mineral County, Montana. The hydrologic analyses for Clark Fork River was completed as part of the Mineral County Modernization Project, Phase I by Pioneer Technical Services, Inc. in 2017 (Pioneer 2017a).

Two active United States Geological Survey (USGS) gaging stations are located in the vicinity of the study area. USGS gage 12354500 Clark Fork River at St. Regis, Montana, is approximately 0.5-miles downstream of the confluence with the St. Regis River and has been in operation since 1911. USGS gage 12353000 Clark Fork River below Missoula, Montana is approximately 0.2-miles downstream of the confluence with the Bitterroot River and has been in operation since 1930. The summary data for the gages is listed in Table 2.

Table 2. USGS Gaging Stations

Gaging Station Number	Gaging Station Name	Period of Record	Number Of Annual Peaks	Drainage Area (square miles)	Maximum Peak Discharge (cfs / Year)	Minimum Peak Discharge (cfs / Year)
12354500	Clark Fork River at St. Regis, MT	1911 – 1923 1929 – 2016	101	10,728	68,900 / 1997	11,300 / 1977
12353000	Clark Fork River below Missoula, MT	1930 – 2016	87	9,017	55,100 / 1997	9,100 / 1977

cfs: cubic feet per second

To model the Clark Fork River, 14 main stem locations (flow nodes) of major tributary confluences and USGS gage locations were identified in the hydrologic analyses (Pioneer 2017a). Three methods were considered for estimating peak flood discharges at ungaged flow nodes: 1) Regional Regression; 2) Two Station Logarithmic Interpolation method; and 3) the Drainage Area Gage Transfer method.

The Regional Regression method for ungaged flow was not selected for the Clark Fork River Study reach due to the size of the drainage areas of the flow nodes, which were not within the range of values recommended for the Western Region. The Two Station Logarithmic Interpolation method was used at two gaged and nine ungaged flow node river stations on the Clark Fork River. This method was used at USGS gages 12354500 and 12353300 (Clark Fork River at Tarkio and Alberton, respectively) since each gage has only a six year period of record. The Drainage Area Gage Transfer method was used on the two flow node river stations located downstream of USGS gaging station 12354500 Clark Fork River at St. Regis.

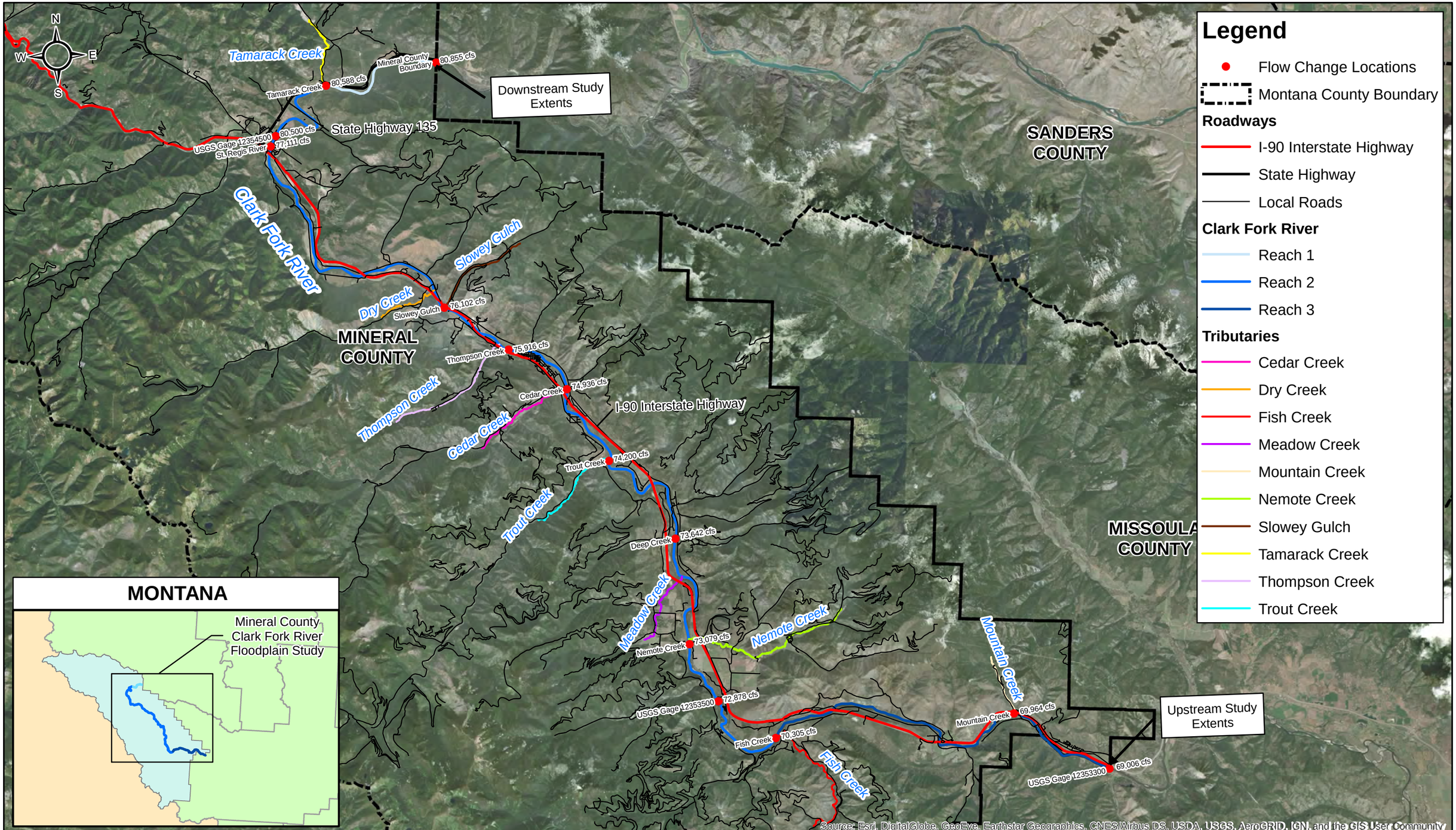
The summary of peak flow estimates at the USGS gaged and ungaged locations for the Clark Fork River in Mineral County, Montana are presented in Table 3 and the flow change locations are shown on Figure 2.

Table 3. Summary of Discharges for Clark Fork River

River Station (feet)	Location Description	Peak Discharge						
		Cubic Feet per Second (cfs)						
		50% Annual Chance	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance	1%+
		2-year	10-year	25-year	50-year	100-year	500-year	n/a
306,987	**USGS Gage 12353300 Clark Fork at Alberton, MT**	**31,064**	**50,068**	**58,295**	**63,863**	**69,006**	**79,843**	**78,136**
285,325	Mountain Creek[1]	31,523	50,809	59,135	64,766	69,964	80,902	79,194
231,061	Fish Creek	31,687	51,073	59,434	65,087	70,305	81,278	79,570
212,590	**USGS Gage 12353500 Clark Fork at Tarkio, MT**	**32,922**	**53,067**	**61,692**	**67,511**	**72,878**	**84,117**	**82,408**
199,726	Nemote Creek	33,019	53,222	61,869	67,700	73,079	84,338	82,629
176,778	Deep Creek[2]	33,290	53,660	62,363	68,231	73,642	84,959	83,250
150,900	Trout Creek	33,558	54,093	62,854	68,756	74,200	85,573	83,864
133,333	Cedar Creek	33,913	54,665	63,501	69,451	74,936	86,385	84,676
118,784	Thompson Creek	34,385	55,427	64,363	70,375	75,916	87,463	85,755
103,975	Slowey Gulch[3]	34,475	55,572	64,527	70,551	76,102	87,668	85,961
49,310	St. Regis River	34,962	56,357	65,415	71,502	77,111	88,778	87,071
47,308	**USGS Gage 12354500 Clark Fork at St. Regis, MT**	**36,600**	**59,000**	**68,400**	**74,700**	**80,500**	92,500	**90,800**
24,226	Tamarack Creek	36,645	59,068	68,477	74,783	80,588	92,598	90,899
0	Mineral County Boundary	36,780	59,274	68,711	75,034	80,855	92,897	91,201

Three flow change locations shown in Table 3 have been noted with different location descriptions than Clark Fork River Hydrologic Analysis Report (Pioneer 2017a) to be consistent with USGS mapping.

1. Reported as Sawmill Creek in Clark Fork River Hydrologic Analysis Report
2. Reported as Dry Creek in Clark Fork River Hydrologic Analysis Report.
3. Reported as Showey Gulch in Clark Fork River Hydrologic Analysis Report.



0 2 4 8 12 16 Miles

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Clark Fork River 1% Annual-Chance Flow Change Locations

FIG. 2

4.0 Hydraulics

The methods and techniques used to complete the hydraulic analysis for the Clark Fork River in Mineral County, Montana are presented in the following sections. The analysis utilized the LiDAR mapping, bathymetric and hydraulic structure surveys to develop the Enhanced Level Option E 1% AC Zone AE, floodway, and 0.2% AC mapping.

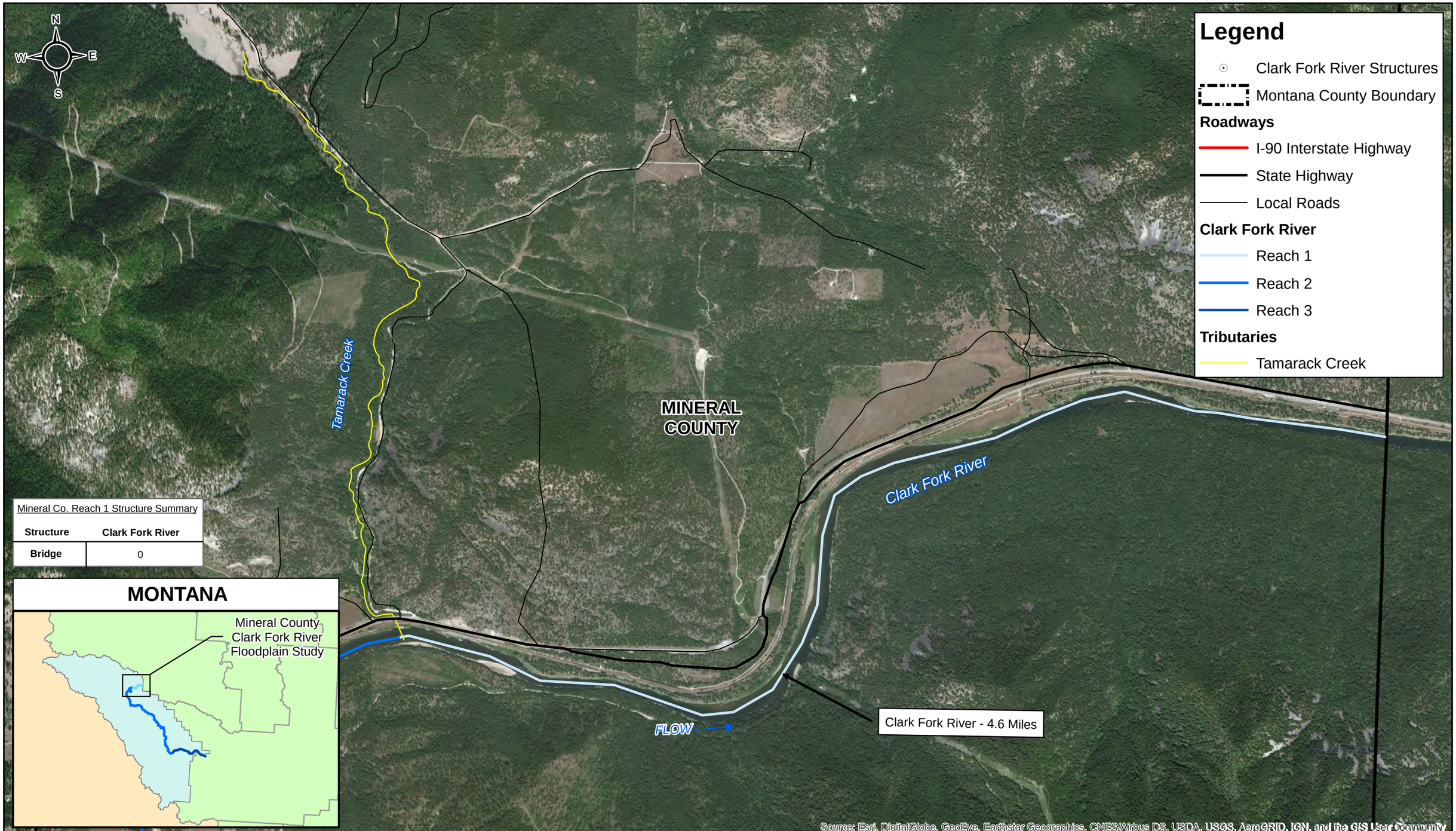
4.1 Hydraulic Analysis

This floodplain study for the Clark Fork River in Mineral County, MT, as shown on Figure 1, consists of the following three segments; Reach 1 - Tamarack Creek to Sanders County boundary, Reach 2 - Fish Creek to Tamarack Creek, and Reach 3 - Missoula County boundary to Fish Creek. Reach 1 begins at the Mineral and Sanders County boundary and extends west or upstream approximately 4.6 river-miles to the confluence of Tamarack Creek (Figure 3). Reach 2 begins at the termination of Reach 1 and extends east or upstream approximately 40.1 river-miles to the confluence of Fish Creek (Figure 4). Reach 3 begins at the termination of Reach 2 and extends 13.5 river-miles upstream to the Missoula County boundary (Figure 5). The length of each segment is summarized in Table 1.

One-Dimensional Hydraulics of FEMA Guidance for Flood Risk Analysis and Mapping (FEMA 2016e) were followed for the hydraulic model development. The water surface elevations (WSEL's) were calculated with HEC-RAS, version 5.0.3 hydraulic modeling software (USACE 2016a). Steady flow analysis approach in HEC-RAS performs the standard step energy balance calculation between cross sections starting at the most downstream cross section and moving upstream for a subcritical analysis. Cross sections were placed with the GeoHECRAS hydraulic computer modeling software (CivilGEO 2018).

4.2 Topographic Data Acquisition

The Montana Department of Natural Resource Conservation (DNRC) contracted with Quantum Spatial, Inc. (QSI) to acquire topographic Light Detection and Ranging (LiDAR) data for the project area. QSI performed a topographic and bathymetric LiDAR survey on the Clark Fork River within Mineral County for the DNRC between November 18th and November 26th 2016. Over 43,000 acres were surveyed by QSI with the upper survey extents beginning upstream of Alberton, MT and ending downstream of St. Regis, MT. The LiDAR survey included both near-infrared wavelength for the terrestrial topography and blue-green wavelength for the river bathymetry. The Clark Fork River LiDAR DEM was required to provide digital elevation data with an accuracy of root mean square error (RMSE) less than or equal to 30 centimeters (approximately one foot), (QSI 2017). To verify the LiDAR DEM data met the vertical accuracy criteria, QSI compared 67-gound measured bathymetric check points along the water's edge with the LiDAR DEM data at the same locations.



Mineral Co. Reach 1 Structure Summary

Structure	Clark Fork River
Bridge	0

0 0.5 1 2 Miles

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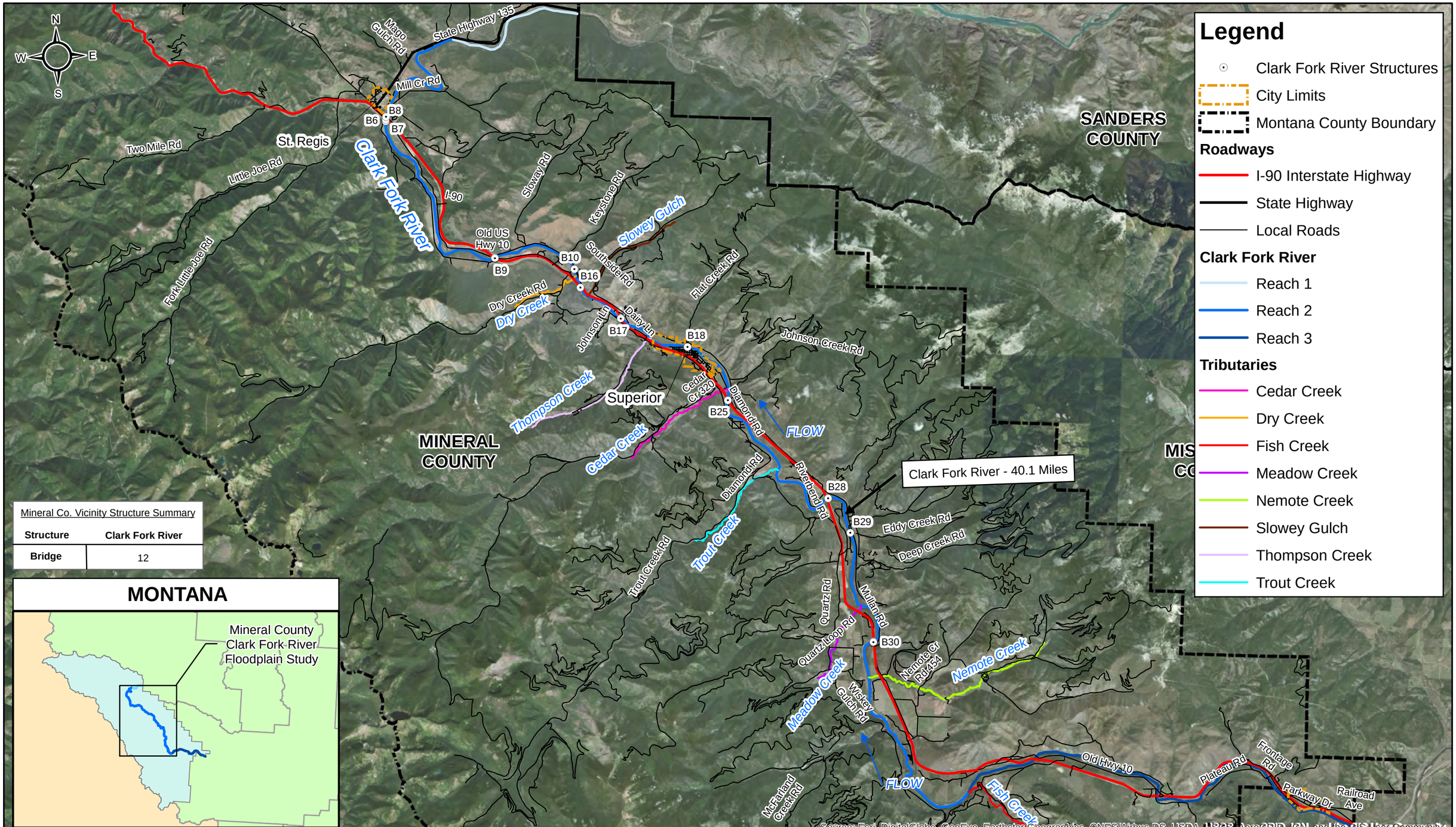
Clark Fork River Reach 1 Study Limits

FIG. 3



Mineral Co. Vicinity Structure Summary

Structure	Clark Fork River
Bridge	12

0 2.5 5 10 15 Miles

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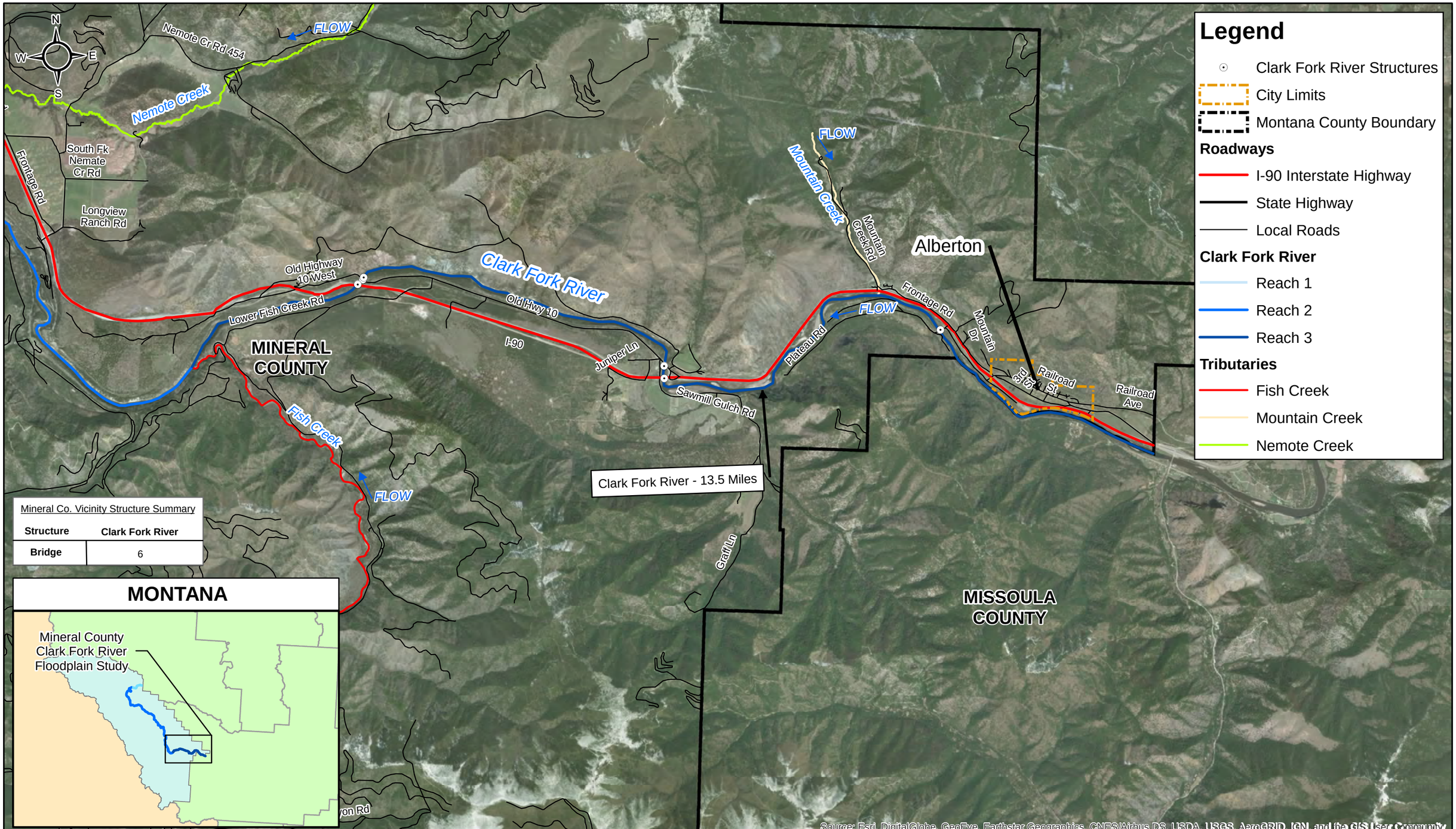
Clark Fork River Reach 2 Study Limits

FIG. 4



Mineral Co. Vicinity Structure Summary

Structure	Clark Fork River
Bridge	6

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Clark Fork River Reach 3 Study Limits

FIG. 5

Table 4 summarizes the LiDAR DEM data met the vertical accuracy statistics reported in Mineral County LiDAR Technical Data Report (QSI 2017).

Table 4. LiDAR Accuracy Statistics

Parameter	Result
Sample	67 Points
Average	-0.053 ft
Median	-0.047 ft
RMSE	0.186 ft
Standard Deviation	0.180 ft
95% Confidence (1.96*RMSE)	0.365 ft

The LiDAR deliverables included 3-feet grid bare earth digital elevation models (DEM) for the entire length of the Clark Fork River corridor (QSI 2017). The LiDAR data was collected with the following specifications:

Projection:	Montana State Plane	Units
Datum:	Horizontal – NAD83 (2011) FIPS 2500	International Feet
	Vertical – NAVD88, Geoid 12A	US Survey Feet

NAD: North American Datum
NAVD: North American Vertical Datum

4.3 Field Survey

A field survey of the hydraulic structures for the Clark Fork River study was performed by Pioneer Technical Services, Inc. (Pioneer 2017b). Pioneer performed on-the-ground bathymetric survey adjacent (upstream and downstream) to all crossings in the Mineral County Clark Fork River study reach between April 11, 2017 and July 31, 2017. In general, four bathymetric cross-sections zones per bridge were ground-surveyed. Table 5 is a summary of the number of cross sections and structures surveyed on the Clark Fork River.

Table 5. Structure Survey

ID No.	Bridge Structure	River Station	Cross Sections
B6	Old U.S. Highway 10	50,596	4
B7	I-90 Interstate Highway	50,977 & 51,055	4
B8	Pedestrian	51,278	4
B9	I-90 Interstate Highway	84,745 & 84,859	4
B10	Southside Road	99,476	4
B16	I-90 Interstate Highway	102,189 to 103,026	4
B17	I-90 Interstate Highway	110,765 to 111,105	4
B18	River Street	123,277	4
B25	I-90 Interstate Highway	134,867 to 135,417	4
B28	I-90 Interstate Highway	164,142	4
B29	Lonzeau Crossover Road	171,940 to 172,085	4

Table 5. (cont.). Structure Survey

ID No.	Bridge Structure	River Station	Cross Sections
B30	I-90 Interstate Highway	192,164	4
B43	I-90 Interstate Highway	243,846 to 244,037	4
B44	Old U.S. Hwy 10	244,440	4
B45	Abandoned railroad grade	244,479 to 244,599	4
B46	Old U.S. Hwy 10	266,411 to 266,623	4
B47	I-90 Interstate Highway	267,299 & 267,368	4
B48	Frontage Road	290,072	4

Trimble R8 Model 3 GNSS (R8) receivers were used for both static and Real Time Kinematic (RTK) Global Positioning System (GPS) applications. The R8 is capable of receiving satellite signals from all available satellites and when using RTK GPS procedures, it provides a 10 millimeter (mm) + 1 parts per million (ppm) horizontal accuracy and a 20 mm + 1 ppm vertical accuracy.

When terrain and conditions required conventional equipment, a Trimble S7 Robotic Total Station was used. The S7 employs robotic technology allowing for perfect alignment on the target prism, essentially eliminating pointing error. The direct reflector mode produces errors of 2 mm + 2 ppm.

4.4 Profile Baseline

The alignment of the Clark Fork River Profile Baseline was prepared by Pioneer during the hydrologic analysis for the Clark Fork River. To model the river, the locations of major tributary confluences and other flow change locations were identified. The DNRC coordinated with Pioneer to set the Profile Baseline as stream distance or river stationing in feet above the downstream intersection with the Mineral County Boundary. The flow change (flow nodes) within the main stem of the Clark Fork River were set at river station locations as summarized in Table 3. The Profile Baseline was also used to locate cross sections and key features along the river. The summary of key features along the Clark Fork River are presented in Table 6.

Table 6. Key Features along Clark Fork River

River Station (feet)	Feature	Description	1% AC Discharge (cfs)
0	Downstream Limit of Study	Beginning of Clark Fork River Reach 1 at Sanders County Boundary.	80,855
24,226	Flow Change Location & Reach Transition	Confluence of Tamarack Creek and transition from end of Reach 1 to beginning of Reach 2.	80,588
47,308	Flow Change Location	USGS Gage 12354500 Clark Fork at St. Regis, MT.	80,500
49,310	Flow Change Location	Confluence of St. Regis River.	77,111
50,596	Old U.S. Hwy 10	Bridge B6 – Seven span steel and concrete structure, total span approx. 795-feet.	76,102
50,977	I-90 Westbound Bridge	Bridge B7 – Seven span concrete structure, total span approx. 998-feet.	76,102
51,055	I-90 Eastbound Bridge	Bridge B7 – Six span concrete structure, total span approx. 881-feet.	76,102
51,278	Pedestrian Bridge	Bridge B8 – Six span steel and concrete structure, total span approx. 881-feet.	76,102
84,745	I-90 Eastbound Bridge	Bridge B9 – Eight span steel and concrete structure, total span approx. 1,283-feet.	76,102
84,859	I-90 Westbound Bridge	Bridge B9 – Seven span steel and concrete structure, total span approx. 1,145-feet.	76,102
99,476	Southside Road Bridge	Bridge B10 – Three span steel and concrete structure, total span approx. 425-feet.	76,102
102,189	I-90 Eastbound and Westbound Bridges	Bridge B16 – North abutment and concrete pier cross section for westbound bridge.	76,102
102,356		Bridge B16 – Concrete pier cross section for westbound and eastbound bridges.	76,102
102,524		Bridge B16 – Concrete pier cross section for westbound and eastbound bridges.	76,102
102,688		Bridge B16 – Concrete pier cross section for westbound and eastbound bridges.	76,102
102,854		Bridge B16 – Concrete pier cross section for westbound and eastbound bridges.	76,102
103,026		Bridge B16 – South abutment cross section.	76,102
103,975	Flow Change Location	Confluence of Slowey Gulch.	76,102
110,765	I-90 Eastbound and Westbound Bridges	Bridge B17 – North abutment and concrete pier cross section for eastbound bridge.	75,916
110,840		Bridge B17 – Concrete pier cross section for westbound bridge.	75,916
110,873		Bridge B17 – Concrete pier cross section for eastbound bridge.	75,916
110,941		Bridge B17 – Concrete pier cross section for westbound bridge.	75,916
111,000		Bridge B17 – Concrete pier cross section for westbound and eastbound bridges.	75,916
111,105		Bridge B17 – South abutment cross section.	75,916

Table 6 (cont.). Key Features along Clark Fork River

River Station (feet)	Feature	Description	1% AC Discharge (cfs)
118,784	Flow Change Location	Confluence of Thompson Creek.	75,916
123,277	River Street Bridge	Bridge B18 – Four span steel and concrete structure, total span approx. 425-feet	74,936
133,333	Flow Change Location	Confluence of Cedar Creek.	74,936
134,867	I-90 Eastbound and Westbound Bridges	Bridge B25 – North abutment cross section.	74,200
134,914		Bridge B25 – Concrete pier cross section for westbound bridge.	74,200
134,984		Bridge B25 – Concrete pier cross section for eastbound bridge.	74,200
135,008		Bridge B25 – Concrete pier cross section for westbound bridge.	74,200
135,090		Bridge B25 – Concrete pier cross section for eastbound bridge.	74,200
135,128		Bridge B25 – Concrete pier cross section for westbound bridge.	74,200
135,204		Bridge B25 – Concrete pier cross section for eastbound bridge.	74,200
135,241		Bridge B25 – Concrete pier cross section for westbound bridge.	74,200
135,329		Bridge B25 – Concrete pier cross section for eastbound and westbound bridges.	74,200
135,417		Bridge B25 – South abutment and concrete pier cross section for eastbound bridge.	74,200
150,900	Flow Change Location	Confluence of Trout Creek.	74,200
164,142	I-90 Eastbound and Westbound Bridges	Bridge B28 – Seven span steel and concrete structure, total span approx. 758-feet	73,642
171,940	Lonzeau Crossover Road Bridge	Bridge B29 – North abutment and concrete end pier cross section.	73,642
171,994		Bridge B29 – Concrete mid-span pier cross section.	73,642
172,053		Bridge B29 – Concrete mid-span pier cross section.	73,642
172,085		Bridge B29 – South abutment and concrete end pier cross section.	73,642
176,778	Flow Change Location	Confluence of Deep Creek.	73,642
192,164	I-90 Eastbound and Westbound Bridges	Bridge B30 – Seven span steel and concrete structure, total span approx. 825-feet.	73,079
199,726	Flow Change Location	Confluence of Nemote Creek.	73,079
212,590	Flow Change Location	USGS Gage 12353500 Clark Fork at Tarkio, MT.	72,878
231,061	Flow Change Location	Confluence of Fish Creek.	70,305

Table 6 (cont.). Key Features along Clark Fork River

River Station (feet)	Feature	Description	1% AC Discharge (cfs)
235,758	Reach Transition	Transition from end of Reach 2 to beginning of Reach 3.	69,964
243,846	I-90 Eastbound and Westbound Bridges	Bridge B43 – Concrete pier cross section for eastbound bridge.	69,964
243,918		Bridge B43 – Concrete pier cross section for eastbound and westbound bridges.	69,964
244,037		Bridge B43 – Concrete pier cross section for westbound bridge.	69,964
244,440	Old U.S. Hwy 10	Bridge B44 – Five span steel and concrete structure, total span approx. 420-feet.	69,964
244,479	Abandoned railroad grade	Bridge B45 – Concrete pier cross section.	69,964
244,599		Bridge B45 – Concrete pier cross section.	69,964
266,411	Old U.S. Hwy 10	Bridge B46 – Concrete pier cross section.	69,964
266,570		Bridge B46 – Concrete pier cross section.	69,964
267,299	I-90 Westbound Bridge	Bridge B47 – Nine span steel and concrete structure, total span approx. 762-feet.	69,964
267,368	I-90 Eastbound Bridge	Bridge B47 – Seven span steel and concrete structure, total span approx. 781-feet.	69,964
285,325	Flow Change Location	Confluence of Mountain Creek	69,964
290,072	Frontage Road	Bridge B48 – Three span steel and concrete structure, total span approx. 370-feet	69,006
306,987	Upstream Limit of Study	End of Clark Fork River Reach 3 at Missoula County Boundary.	69,006

4.5 Boundary Conditions

To perform the hydraulic analysis, HEC-RAS requires boundary condition input data at the first downstream cross section of the model reach. Per FEMA's One-Dimensional Hydraulics Guidance for Flood Risk Analysis and Mapping (FEMA 2016e), the downstream boundary condition in a one-dimensional, steady flow, step-backwater model should be taken from a previously established water surface elevation (WSEL), if available. A previously established WSEL is not available for the Clark Fork River floodplain study, since this is the first study for Mineral County and the delineation on the adjacent downstream county is a Zone A without hydraulic modeling and BFE's.

Therefore, normal depth energy slopes for Reach 1 were used for the starting downstream boundary condition. The normal depth slope is the slope of the Hydraulic Grade Line (HGL) which is estimated by measuring the average slope of the channel bottom. The HGL is close to being parallel with the channel bottom for the first river mile of Reach 1 and the first 2,000 feet was used to calculate the slope of the HGL for Reach 1. The WSEL from the Reach 1 was the downstream boundary condition for Reach 2 and WSEL for Reach 2 was the downstream boundary condition for Reach 3. Additional downstream cross sections are included at the overlap of modeling segments to dampen the numerical instability that can occur near model boundaries.

A summary of the boundary conditions established for each model segment for the Clark Fork River floodplain study in Mineral County are summarized in Table 7.

Table 7. Boundary Condition Summary

River Reach	Segment	Boundary Condition Source
1	Tamarack Creek to Sanders County boundary	Normal Depth Slope = 0.00007 ft/ft
2	Fish Creek to Tamarack Creek	WSELs at RS 23,363
3	Missoula County boundary to Fish Creek	WSELs at RS 233,323

4.6 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 and diversion structure locations. Cross sections were filtered to less than 500 points per cross section as required by HEC-RAS.

Cross section spacing are on the order of 15- to 500-feet. Reaches 1 and 3 are Enhanced Level Option E without floodway and Reach 2 reach is an Enhanced Level Option E with floodway. The standard practice for cross section spacing is within this range.

Bathymetric survey data was collected by using two different methods, water penetrating LiDAR by QSI and survey data collected at bridge structure locations using GPS survey and

depth sounding equipment by Pioneer Technical Services, Inc. (Pioneer, 2017b). The water penetrating LiDAR was not always able to provide accurate returns for the entire channel, consequently Morrison-Maierle needed to approximate a channel bottom in these areas.

Morrison-Maierle compared 22 areas lacking quality bathymetric data with the bathymetric survey data from Pioneer to develop a channel bottom approximation approach for the hydraulic analysis. QSI provided a shapefile '*CF_Bathy_Coverage*' that outlined the areas with poor returns. Cross sections cut from the LiDAR data were supplemented with survey data in the area of no LiDAR data using the extents of the '*CF_Bathy_Coverage*' shapefile. To determine the average shape and depth below the LiDAR data, the modified cross-sections were compared with the original LiDAR data as shown in Figure 6. The analysis found that channel depth was highly variable in areas that lacked quality data. On average, the maximum depth below the lacking quality data was 2.7 feet and was typically either parabolic or triangular in shape. In six of the areas, the survey data was equal to or higher than the LiDAR data. The areas with increases were typically in riffle sections. Three of the areas were significantly deeper than the rest, all of these areas were near bridges on river bends, and ranged from seven to fifteen feet deeper than the LiDAR data.

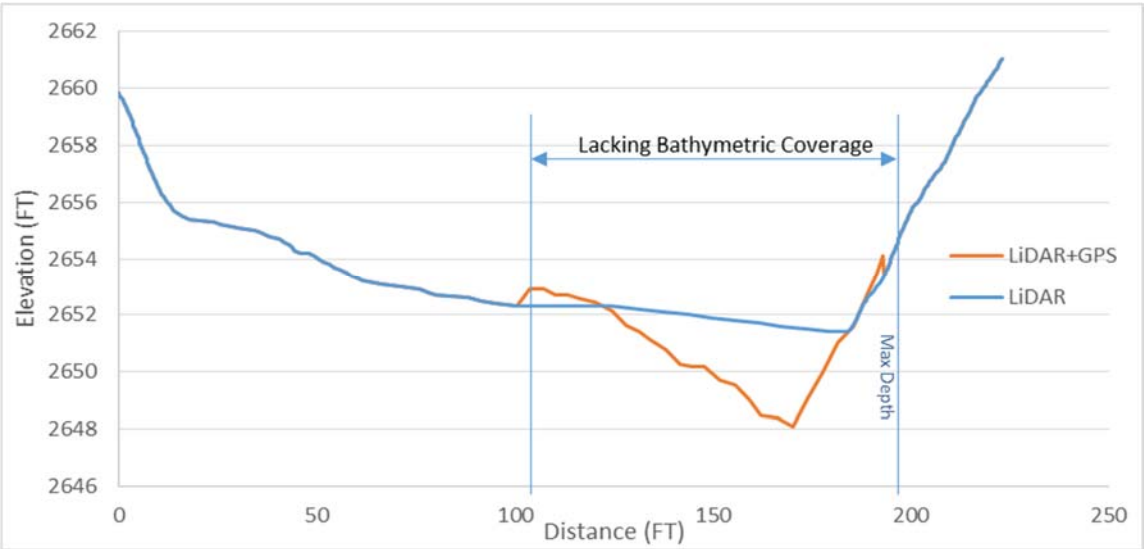


Figure 6. Comparison between LiDAR data and LiDAR with GPS Survey Data.

Morrison-Maierle completed a two part approach to modeling of the areas lacking quality bathymetric data. For reaches where there were no nearby structures, a trapezoidal channel bottom was added to the LiDAR derived cross section using the data shapefile for the horizontal extent. The inserted channel bottom has 6H: 1V side slopes and an approximate depth of 1.8 feet (two-thirds of the average maximum depth), as shown in Figure 7. Using two-thirds the maximum depth allows the use of a trapezoidal channel rather than a triangular or parabolic channel while providing approximately the same conveyance area.

The second modeling approach approximated channel depths and side slopes at individual cross sections based on site specific interpretation of the river and available nearby survey data. These cross sections were critically reviewed and manually adjusted to eliminate surcharging or negative slopes in the hydraulic modeling profiles.

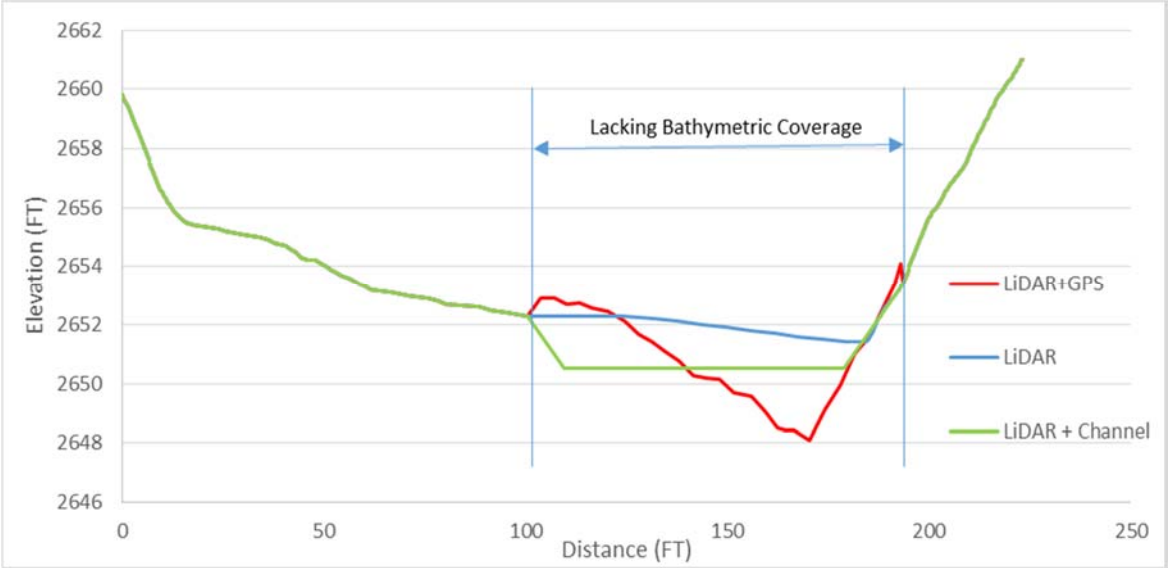


Figure 7. Channel Cut Section comparison to LiDAR with GPS Survey Data.

The second modeling approach was also used in areas with nearby structures. In these areas, the surveyed data was examined and the depth and shape of the channel below the LiDAR data and adjusted individually based site specific interpretation of the river and available survey data in the immediate vicinity.

The cross section locations are shown on the Hydraulic work maps provided in Appendix A and a list of the cross sections that required these adjustments is provided in Table 8.

Table 8. Cross Section Adjustment Summary

River Reach	Cross Section Number Reaches
1	-1275 to 4658, 6467 to 9035, 11890, 13199, 14873 to 16160, 17504 to 21025, 24012.
2	29222 to 29724, 36521 to 37991, 41277 to 42502, 44793, 48044 to 49310, 56366 to 57187, 57935 to 58861, 59323 to 60148, 60421 to 65197, 66267 to 67299, 71768 to 74251, 75244 to 76081, 76410 to 76734, 79217 to 80210, 82693 to 84643, 85672 to 86656, 87147 to 90590, 91574 to 92558, 96000 to 98460, 100506 to 101766, 102031 to 104740, 104963 to 112841, 114327 to 115813, 117794 to 119775, 124256 to 125316, 125706, 127654 to 128628, 131550 to 137934, 139481 to 141028, 142337 to 144555, 147484, 148460 to 151388, 151874 to 152625, 154820 to 158746, 159236 to 163597, 164663 to 167353, 169520, 173767 to 177261, 179810 to 180786, 181559 to 184809, 186087 to 186924, 187346 to 189864, 190615 to 235758.
3	236202 to 239704, 240015 to 267320, 267829 to 270864, 271166 to 278954, 278990 to 289856, 290032 to 296178, 296687 to 306488

4.7 Hydraulic Structures

The geometries of hydraulic structures were modeled with the data obtained from the survey of the hydraulic structures and the as-built drawings. The as-built drawings were utilized for obtaining structure data for the HEC-RAS model. Differences between structure data and the HEC-RAS model are due to truncation of the structure for structures elevated well above the floodplain. A total of twenty seven hydraulic structures are located within the study limits. Each structure crossing was assigned an identification code that included a ‘B’

for bridge and a number corresponding to the order of the structure along the Clark Fork River, beginning at the downstream extent of the study reach and progressing upstream. Structure numbers were assigned to structures along the main stem as well as structures on the tributaries. Structures along the Clark Fork River were identified as structures B6-B48 and the I-90 structures have the same number for both the eastbound and westbound lanes. There are nine I-90 structure crossings and nine road and street crossings for a total of eighteen numbered structures as summarized in Table 9. The structure numbers do not start at B1-B5 since those structures are located on the Clark Fork River tributaries which is discussed in an independent report.

A summary of the bridge structures and hydraulic model settings for each structure are summarized in Tables 9 and 12, respectively. The structure data reported is from the as-built drawings for each structure. Photos of typical structures in the study are presented in Photographs 1 through 6 with photographs of all the structure crossings in Appendix C.

Table 9. Summary of Bridge Structures

ID No.	Roadway Bridge Structure	River Reach	River Station (feet)	Spans	Total Span* (feet)	Deck Width (feet)	Pier Widths (feet)	Appendix C Photo Page #
B6	Old U.S. Highway 10	2	50,596	7	795	31	5, 7, 8	1
B7	I-90 Interstate Westbound	2	50,977	7	998	41	4, 8, 10	2
	I-90 Interstate Eastbound	2	51,055	6	881	41	4, 8, 10	2
B8	Pedestrian	2	51,278	6	583	14	3, 11, 14	3
B9	I-90 Interstate Eastbound	2	84,745	8	1,283	43	5	4
	I-90 Interstate Westbound	2	84,859	7	1,145	43	5	4
B10	Southside Road	2	99,476	3	425	34	4	5
B16	I-90 Interstate Westbound	2	102,524	6	1,092	42	10	6
	I-90 Interstate Eastbound	2	102,688	6	1,092	42	10	6
B17	I-90 Interstate Eastbound	2	110,873	4	545	44	4, 10	7
	I-90 Interstate Westbound	2	110,941	5	621	40	4, 10	7
B18	River Street	2	123,277	4	426	42	4, 6	8
B25	I-90 Interstate Westbound	2	135,128	6	801	34	4, 10	9
	I-90 Interstate Eastbound	2	135,204	6	801	32	4, 10	9
B28	I-90 Interstate Highway	2	164,142	7	758	32	4, 8	10
B29	Lonzeau Crossover Road	2	171,994	7	455	19	2, 4	11
B30	I-90 Interstate Highway	2	192,164	7	825	32	4, 8	12
B43	I-90 Interstate Eastbound	3	243,846	5	807	44	4, 10	13
	I-90 Interstate Westbound	3	244,037	7	867	32	4, 10	13
B44	Old U.S. Highway 10	3	244,440	5	420	25	2, 5	14
B45	Abandon Railroad Grade	3	244,539	4	591	24	6, 8, 12	15
B46	Old U.S. Highway 10	3	266,490	5	514	26	4, 5	16
B47	I-90 Interstate Westbound	3	267,299	9	762	32	3, 4, 8	17
	I-90 Interstate Eastbound	3	267,368	7	781		5, 6, 8	17
B48	Frontage Road	3	290,072	3	370	19	4, 8	18

* Total Span given from bridge set to bridge seat along top chord as stated in As-Build plans. Model may be truncated due to structure elevation above floodplain.

The structures crossing the Clark Fork River include highway crossings along I-90 and roadway crossings along Old Highway 10, Southside Road, and the Lonzeau Crossover. One street crossing is located at River Street within the town of Superior Montana. One pedestrian bridge near St. Regis Montana and one abandoned railroad grade approximately 9.5 river miles west of Alberton Montana are also included in the study.

The geometry for the hydraulic structures were modeled with the data obtained from the field survey and as-built drawings. Note data summarized in the Tables is full extent of the structure and the model is truncated due to the height of structures above the floodplain. Expansion and contraction coefficients are set at the natural channel value of 0.1 and 0.3. This hydraulic modeling approach deviates from the standard practice of setting the expansion and contraction coefficients at 0.3 and 0.5 to account for the increased head loss associated with the relatively abrupt transitions and varying velocities that accompany the expansion and contraction of flows at a bridge. The bridge crossings on this reach of the Clark Fork River are constructed to span the natural channel and floodplain width and are elevated well above the flood flow water surface. No encroachment of the floodplain occurs at the structure crossings. A sensitivity analysis was completed on this modeling practice. By setting the encroachment coefficients at 0.3 and 0.5 the WSEL's were increased approximately 0.2 to 0.3 feet. No expansion and contraction of flood flows would occur between these structure crossings and this approach is recommended to more reasonably model this reach of the Clark Fork River and has been noted in the hydraulic model at each bridge crossing description. These non-standard encroachment coefficient values were reviewed and approved by FEMA regional representative as required in FEMA Guidance (Appendix G).

Two of the structure crossings along Interstate 90 (I-90) have been modeled as one structure since they are tandem structures with very little separation between the eastbound and westbound lanes and have similar pier sizes and locations. Additionally, due to the incised floodplain and narrow gap between structures, contraction and expansion of flow would not occur between the two structures (USACE, 2016b).

Six bridge crossings located along Clark Fork River are multi-span structures at skew angles greater than 30-degrees. Backwater is caused by each bridge foundation feature independently creating flow restriction with respect to the other bridge foundation elements. Modeling bridges with high skew using the bridge routine forces backwater to be calculated for all bridge substructure elements simultaneously and results in overly conservative WSELs. The blocked area option in HEC-RAS was utilized to model the piers at the pier locations. This technique used to analyze each bridge element independently provides reasonable backwater evaluation for significantly skewed bridges (USACE 2016b). The bridge crossing structures at a skew angle greater than 30-degrees are summarized in Table 10.

The Lonzeau Crossover Road (structure number B29) has a skew angle of 27-degrees. This bridge crossing was modeled with the blocked area methodology since the roadway alignment is parallel to the river alignment outside of the bridge superstructure and would result in overlap of hydraulic cross sections, which is not allowed in a one-dimensional analysis. The cross section alignments modeled with the HEC-RAS bridge model option would cross due to the orientation of the hydraulic crossing centerline to the river channel. The blocked area methodology at each pier independently creates a hydraulic restriction of

each respective pier and no ineffective flow area is necessary for the 1D model, since there is no constructed embankment restriction within the natural channel or overbanks flow areas.

Table 10. High Skew Angle Bridge Crossings

ID No.	River Station (feet)	Crossing Location	Skew Angle	Number Piers
B16	102,189 103,026	I-90 Westbound I-90 Eastbound	65°	W. – 5 E. – 5
B17	110,765 111,105	I-90 Eastbound I-90 Westbound	40°	E. – 3 W. – 4
B25	134,867 135,417	I-90 Westbound I-90 Eastbound	45°	W. – 5 E. – 5
B29	171,994	Lonzeau Crossover Road	27°	6
B43	243,846 244,037	I-90 Eastbound I-90Westbound	45°	E. – 4 W. – 6
B45	244,539	Abandoned railroad grade	45°	3
B46	266,490	Old Highway 10	45°	2

The bridge modeling approach was set for both high and low flow methods based on the bridge configuration. The high flow method was limited to the Energy method, as Pressure/Weir flow conditions do not occur due to the significant freeboard conditions at all the bridge crossings. Photographs 1 through 6 are typical of the bridge crossings in this study.

The low flow methods include the Energy, Momentum or Yarnell methodologies. The Energy method was utilized if the bridge was a 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 requires an input for the Drag Coefficient (CD), and the Yarnell equation using a K Coefficient based on the pier shape. The option to allow HEC-RAS to select the highest energy answer was implemented to yield reasonably conservative WSELs for each profile.

The pier shapes for the bridge structures consisted of round and square nose piers, and elongated piers with a semi-circle round or 90° angle triangular nose. The CD and K coefficients used for the different pier shapes are summarized in Table 11.

Table 11. Pier CD and K Coefficients

Pier Shape	C_D	K
Round Piers	1.2	0.9
Square Piers	2.0	1.25
Semi-Circular Round	1.33	0.9
Triangular Nose with 90° Angle	1.60	1.05

Table 12. Summary of Bridge Model Settings

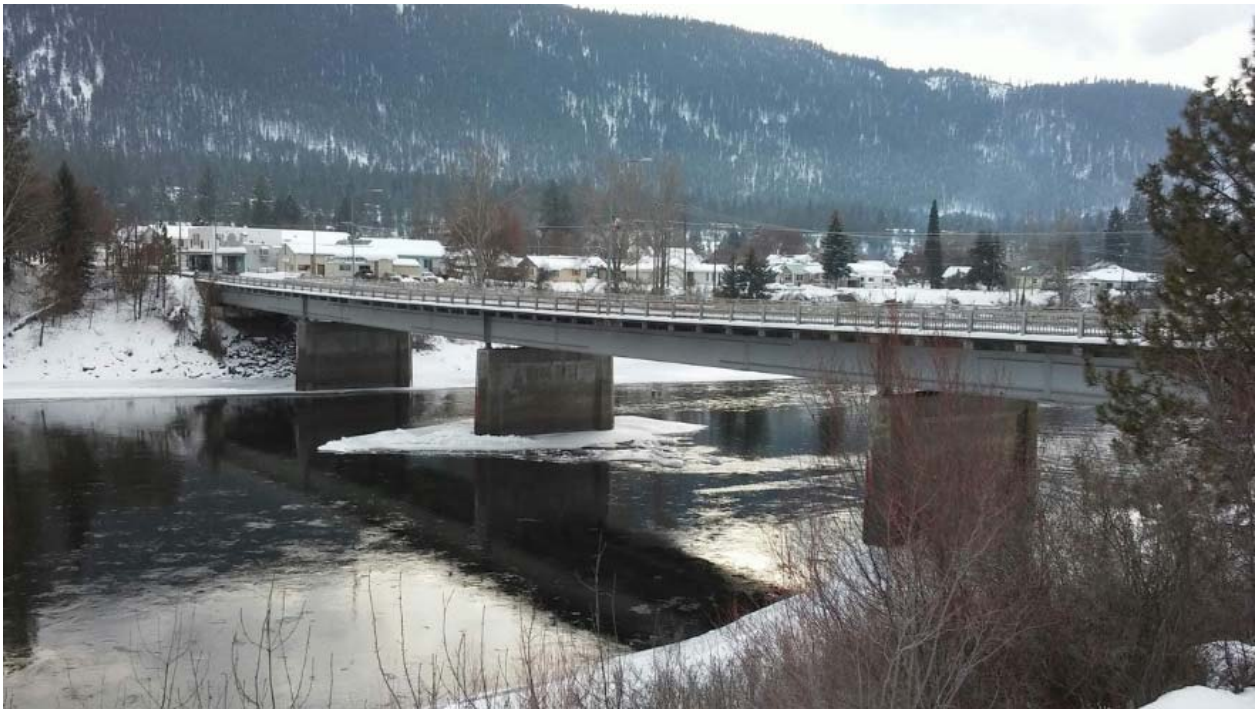
ID No.	Roadway Bridge Structure	River Reach	River Station (feet)	Contraction Coefficient	Expansion Coefficient	Low Flow Method	High Flow Method
B6	Old U.S. Highway 10	2	50,596	0.1	0.3	Energy, Momentum, Yarnell	Energy
B7	I-90 Interstate Westbound	2	50,977	0.1	0.3	Energy, Momentum, Yarnell	Energy
	I-90 Interstate Eastbound	2	51,055	0.1	0.3	Energy, Momentum, Yarnell	Energy
B8	Pedestrian	2	51,278	0.1	0.3	Energy, Momentum, Yarnell	Energy
B9	I-90 Interstate Eastbound	2	84,745	0.1	0.3	Energy, Momentum, Yarnell	Energy
	I-90 Interstate Westbound	2	84,859	0.1	0.3	Energy, Momentum, Yarnell	Energy
B10	Southside Road	2	99,476	0.1	0.3	Energy, Momentum, Yarnell	Energy
B16	I-90 Interstate Westbound	2	102,524	0.1	0.3	Blocked obstruction option at pier locations	
	I-90 Interstate Eastbound	2	102,688	0.1	0.3	Blocked obstruction option at pier locations	
B17	I-90 Interstate Eastbound	2	110,873	0.1	0.3	Blocked obstruction option at pier locations	
	I-90 Interstate Westbound	2	110,941	0.1	0.3	Blocked obstruction option at pier locations	
B18	River Street	2	123,277	0.1	0.3	Energy, Momentum, Yarnell	Energy
B25	I-90 Interstate Westbound	2	135,128	0.1	0.3	Blocked obstruction option at pier locations	
	I-90 Interstate Eastbound	2	135,204	0.1	0.3	Blocked obstruction option at pier locations	
B28	I-90 Interstate Highway	2	164,142	0.1	0.3	Energy, Momentum, Yarnell	Energy
B29	Lonzeau Crossover Road	2	171,994	0.1	0.3	Blocked obstruction option at pier locations	
B30	I-90 Interstate Highway	2	192,164	0.1	0.3	Energy, Momentum, Yarnell	Energy
B43	I-90 Interstate Eastbound	3	243,846	0.1	0.3	Blocked obstruction option at pier locations	
	I-90 Interstate Westbound	3	244,037	0.1	0.3	Blocked obstruction option at pier locations	
B44	Old U.S. Highway 10	3	244,440	0.1	0.3	Energy, Momentum, Yarnell	Energy
B45	Abandon Railroad Grade	3	244,539	0.1	0.3	Blocked obstruction option at pier locations	
B46	Old U.S. Highway 10	3	266,490	0.1	0.3	Blocked obstruction option at pier locations	
B47	I-90 Interstate Westbound	3	267,299	0.1	0.3	Blocked obstruction option at pier locations	
	I-90 Interstate Eastbound	3	267,368	0.1	0.3	Blocked obstruction option at pier locations	
B48	Frontage Road	3	290,072	0.1	0.3	Energy, Momentum, Yarnell	Energy

Photograph 1: Old U.S. Highway 10 - ID No. B6 (RS 50,596)

Photograph 2: I-90 Interstate Highway - ID No. B7 (RS 50,977)

Photograph 3: Pedestrian - ID No. B8 (RS 51,278)

Photograph 4: Southside Road - ID No. B10 (RS 99,476)



Photograph 5: River Street in Town of Superior – ID No. B18

Photograph 6: Lonzeau Crossover Road – ID No. B29 (RS 171,984)

4.8 Manning's 'n' Values

Manning's 'n' values are roughness coefficients representing the frictional resistance acting on water when flowing overland or through a channel. The coefficients are used in the calculations to determine water surface elevations. Four land classes were developed for the study area to establish Manning's 'n' values based on ground and cover conditions. The land classes were developed through interpretations of aerial photographs and location photographs from the field survey task. Manning's 'n' values assigned within the hydraulic model were determined based on aerial photography and the USGS publication, 'Guide to Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains' (USGS 1982).

The USGS guide was 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 13. Manning's 'n' values were evaluated at each cross-section and adjustments were made to fit roughness area with the physical area represented by the cross section.

The USGS publication, 'Roughness Characteristics of Natural Channels' (USGS 1987) was also used to evaluate the Manning's 'n' value of the main channel. This publication performed a Manning's 'n' value calculation for the Clark Fork River and determined a value of 0.028 at the USGS St. Regis gage location. This Manning's 'n' value along with values ranging from 0.028 to 0.069 were developed using the USGS guide and were used for the main channel.

Table 13. Manning's 'n' Values

Roughness Area Land Class Type	Manning's 'n' Values	Description
Main Channel	0.028 – 0.069	Gravel, cobbles, well-rounded boulders and bedrock sections.
Pasture	0.054	Grasses, alfalfa, intermixed with weeds.
Willows	0.073	Willows with stems of herbaceous vegetation.
Urban areas	0.086	Herbaceous & woody vegetation with manmade structures.
Forested Banks	0.12	Vegetation is primarily trees and shrubs.

4.9 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 have limited or non-conveyance in the downstream direction. For these areas, the ineffective flow area method was implemented to model and calculate the total effective conveyance area for each cross section. Review of the modeled cross sections in HEC-RAS identified depression areas that are not hydraulically connected to the stream body. These areas were also classified as ineffective flow areas for the model to correctly calculate the appropriate conveyance area at the cross section.

Areas of flow expansion and contraction at the cross sections bounding structures were also assigned areas of non-conveyance to represent the head loss due to two-dimensional flow

contraction and expansion in a one-dimensional steady state model. The flow contraction and expansion areas were calculated in a stream wise to lateral direction using a 1:1 (upstream) and a 2:1 (downstream) ratio, respectively. The ratios of expansion and contraction were developed using the cross sectional velocities as recommended in the HEC-RAS Reference Manual (USACE 2016b).

The areas of non-conveyance included the following:

- Backwater and ponded areas.
- Flow constriction or expansion.
- Areas isolated by non-accredited earthen berms or railroad and highway embankments.
- High topography either upstream or downstream that eliminates flow in a topographically low area.

Engineering judgement may also be exercised for areas that are not well connected to the main channel or primary floodplain conveyance. The ineffective flow area was used in the left overbank between RS 267,829 and RS 271,166 along the natural high ground and constructed roadway embankment. The 1% base flood, the 1% plus, and 0.2% AC flow conveyance for these left overbank flood flow areas is limited to the amount of flow exiting the primary floodplain over high ground and re-joining the primary conveyance over high ground. The overbank areas are essentially ponded and it is reasonably conservative to assume the overbank does not convey flow. Therefore, the ineffective flow area option was an appropriate model technique for this portion of the Clark Fork River.

4.10 Critical Depth & Profile Smoothing

Critical depths have been allowed to remain in the model at two locations in Reach 3 where a critical or supercritical flow regime is hydraulically reasonable and have been reported with visual observation (Table 14). Generally, these locations are at significant changes in channel width and/or profile drops where a flow regime change occurs. At these locations, the expansion and contraction coefficients were set at 0.3 and 0.5, respectively as discussed in Section 4.11 of this report

Table 14. 1% AC Critical Depth Calculations in Hydraulic Model

River Reach	River Station (feet)	Reason for Critical Depth
3	239,704	Cross section upstream of significant channel width change.
3	278,954	Cross section upstream of significant channel width and flow regime change due to armoring to bedrock depth.

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 typically checked carefully and adjusted to remove the drawdown. In some cases, especially around structures and at cross sections between tandem structures, a hydraulic jump downstream may reasonably occur. In these cases the flood profile was smoothed to present reasonable water surface elevations.

Smoothing was completed in accordance with FEMA Guidance *Flood Profiles* (FEMA 2016d). Locations where smoothing was completed are shown in Table 15 below for the 1% AC regulatory 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 profiles.

Table 15. 1% AC Profile Smoothing River Stations

River Reach	River Station (feet)	Reason for Profile Smoothing
2	50,977	Drawdown within I-90 Westbound bridge crossing. Smoothed to downstream calculation node water surface.
2	84,859	Drawdown within I-90 Westbound bridge crossing. Smoothed to downstream calculation node water surface.
2	192,164	Drawdown within I-90 bridge crossing. Smoothed to downstream calculation node water surface.
3	244,440	Drawdown within Old U.S. Highway 10 bridge crossing. Smoothed to downstream calculation node water surface.

4.11 Expansion and Contraction Coefficients

Expansion and contraction coefficients for riverine cross sections without a structure crossing were set at 0.3 and 0.5, respectively, to model the hydraulics from the significant contraction of the Clark Fork River channel known as the 'Alberton Gorge'. The contraction reach is between cross sections 279,346 and 279,156 and the expansion reach is between cross sections 278,990 and 278,846 in Reach 3. This modeling approach was discussed with COMPASS and the DNRC during a conference call on June 1, 2018.

4.12 Model Calibration

Selected peak discharges at the USGS Gaging Station 12352500 located at St. Regis, Montana were used to calibrate the GeoHECRAS model for this hydraulic analysis. Reference marks for the USGS gage were surveyed in March 2018 by Pioneer Technical Services, Inc., (Pioneer). Water surface elevations were calculated for selected high flow records based on the gage datum elevation and USGS gage height records. The highest available peak flow rates (Table 16) were developed into a stage discharge curve as shown on Figure 8.

Table 16. USGS Gage Station 12352500 Stage Discharge for Highest Recorded Flow Events

Date	Gage Height (feet)	Stream Flow (cfs)	WSEL NAVD88 (feet)
5/30/1913	19.2	63,500	2623.3
5/29/1917	18.5	59,100	2622.6
5/24/1948	19.96	68,900	2624.0
5/24/1956	18.98	62,000	2623.0
6/10/1964	18.54	60,900	2622.6
6/03/1972	19.5	63,900	2623.6
6/18/1974	19.39	63,100	2623.4
5/18/1997	20.27	68,900	2624.3

The 4% AC (25-year) peak discharge flow rate at USGS Gage Station 12352500 is 68,400-cfs for this study. This flow rate has a stage elevation of 2,623.9-feet using the Pioneer survey stage discharge curve and equation shown on Figure 8. The WSEL of the GeoHECRAS model results at USGS Gage Station 12352500 (RS 47,308) is 2,624.4-feet. This is a difference of 0.5 feet for the 4% AC recurrence interval and indicates that the WSELs calculated in the HEC-RAS modeling fit the measured data reasonably well.

Note the direct measurement at the gage during the 4% AC (25-year) peak discharge event in 1997 was 2,624.3-feet which is a calibration of 0.1-feet for a more recent survey. This justifies that the HEC-RAS modeling for the Clark Fork River calibrates well for a more current high flow event.

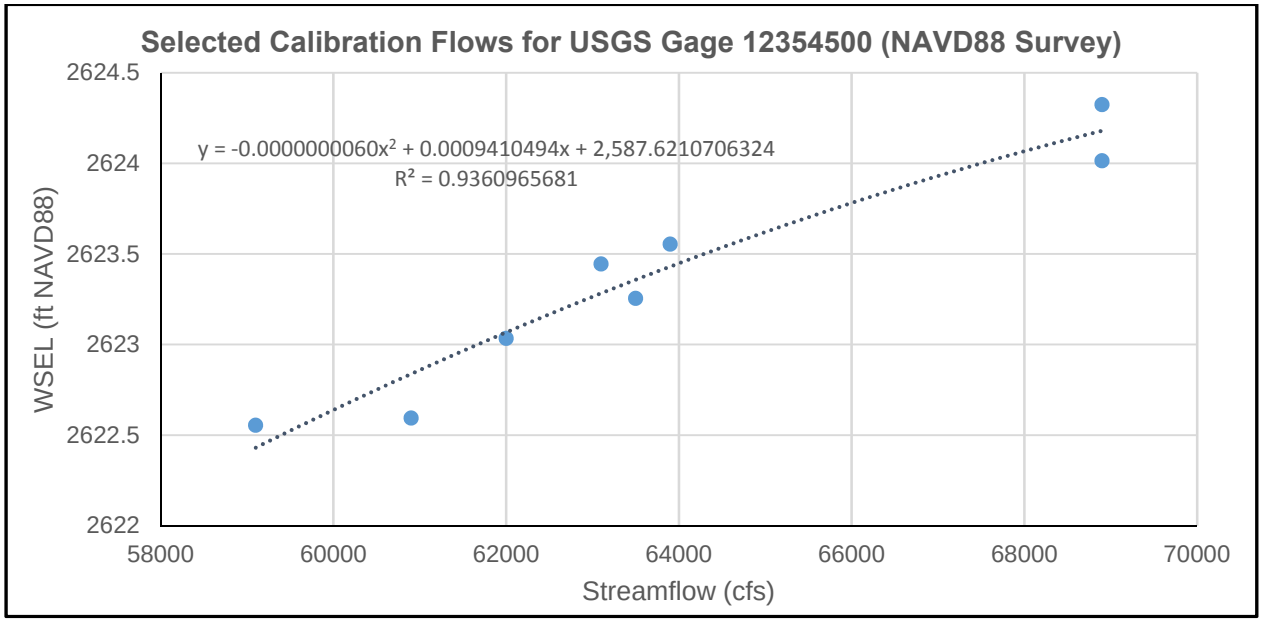


Figure 8. USGS Gage Station 12352500 Stage Discharge Curve for Highest Recorded Flow Events

The Montana Department of Transportation (MDT) was also contacted and asked to review their library of aerial photographs taken during the high water events near St. Regis, Superior, and Alberton Montana. MDT reviewed their aerial image database and provided aerial photographs taken along I-90 on April 29, 2002. The average flow rate of 8,060-cfs was recorded on the Clark Fork River at the USGS Gaging Station 12352500 located at St. Regis. These images were geo-referenced and placed in the GeoHECRAS model to compare modeled flood extents for the reach in the vicinity of St. Regis after the flow change at the confluence with St. Regis River approximately RS 49,000.

The comparison of WSEL's was done in straight river segments with relatively uniform flow conditions located away from the hydraulic influence of structures. The differences in WSEL's were estimated by observing the extents of the high water on the 2002 imagery and comparing to the contour information from the LiDAR mapping. As shown in Table 17, the differences in the detailed study reach model ranged from minimum of 0.1-feet to a maximum of 0.8-feet.

Table 17. Model Calibration

River Reach	River Station (feet)	Modeled WSEL (feet)	Appx. WSEL 2002 MDT Imagery (feet)	Δ (feet)
2	46,802	2,611.8	2,612.0	0.2
2	47,308	2,612.1	2,612.0	0.1
2	47,804	2,612.2	2,613.0	0.8
2	48,291	2,612.0	2,612.3	0.3
2	48,829	2,612.3	2,613.0	0.7

Based on the comparison of 4% AC (25-year) water surface elevations at the USGS Gage 12352500 and from the 2002 images to the WSELs developed by the HEC-RAS modeling for lower peak discharge rates, the modeling results are reasonably calibrated for the purposes of a floodplain study.

The DNRC Missoula Regional Office was also contacted to inquire about previous flood event data near the towns of St. Regis, Superior, and Alberton Montana. Flood event images were located for the St. Regis River but no images were found for the Clark Fork River. Therefore, the calibration for the Clark Fork River hydraulic modeling is based on: 1) selected peak discharges at the USGS Gaging Station 12352500 located at St. Regis, Montana, and 2) the 2002 images obtained from the MDT.

4.13 Floodways

Floodway encroachments were computed for the Clark Fork River Reach 2 at each cross section. 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).

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 majority of the floodway delineation along the Clark Fork River is similar to the width of the 50% AC (2-year recurrence interval) flow. The incised channel has minimal overbank areas which would allow for encroachment into the floodplain. The floodway delineation smoothly transitions into and out of the river segments that have overbank areas while meeting the 0.5-foot surcharge allowance. 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.

4.14 cHECk-RAS

FEMA's automated review software cHECk-RAS, Version 2.0.1 (FEMA 2011a) was utilized to verify the acceptability of the hydraulic analyses described above. Files from the HEC-RAS version 5.0.3 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 cHECk-RAS reads HEC-RAS 5.0.3 data. These messages were checked to verify that a cHECk-RAS read error exists and are noted on the cHECk-RAS report.

cHECk-RAS checks 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 Clark Fork River model 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.

5.0 Floodplain Mapping

Floodplain mapping was prepared using GeoHECRAS mapping tools and ESRI ArcMap 10.5 (ESRI 2016). The GeoHECRAS application generates the raw floodplain area by intersecting the LiDAR Digital Elevation Model with a separate Digital Elevation Model (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.

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 2015 NAIP aerial photograph. Along with the flooding extents, the work map also displays the stream profile baseline along with the cross sections utilized during the hydraulic analysis. 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 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, non-mapped cross sections are noted as NL/NM-for not labeled & not-mapped. Zone AE symbolized polygons are the floodplain delineated for the regulatory floodplain.

Typically, islands that were determined to be higher than the adjacent 1% annual-chance water surface profile and less than one-acre in size were not delineated. Boundary delineation of large backwater areas that extended through multiple cross sections were modified to represent the elevation associated with the location where the backwater initiates from the effectively conveying floodplain. These two adjustments provide a slight variance in the mapped widths versus the top widths described by the HEC-RAS mode at selected locations. A table of the 1% AC flood event backwater elevations and the corresponding profile baseline station is included in Table 18.

Table 18. Backwater Elevation Summary

River Reach	River Station	1% AC
2	39,772	2,620
2	46,302	2,625
2	49,310	2,628
2	98,955	2,670
2	150,800	2,714
2	231,200	2,812
3	278,284	2,928

5.2 Map Tie-in Locations

The downstream mapping tie-in at the Sanders County boundary is to transition from the effective Sanders County FIRM panel 30089C1900D 1% AC floodplain width to the proposed Mineral County cross section 0 floodplain width. The gap between the effective map limit and Mineral County cross section 0 is approximately 80-feet long. The transition was made from the termination of effective Zone A Sanders County map to the start of the profile baseline which was established for the Mineral County floodplain study in previously accepted tasks.

The proposed upstream mapping tie-in at the Missoula County boundary is within the 0.5-foot of the BFE and 5% mapping scale width FEMA tie-in guidelines. The Missoula County Boundary extends from above cross-section 291,991 to the Reach 3 upstream termination cross section 306,987 which has been aligned with cross section A of the effective Missoula County FIS (FIRM panel 300663C1125E) to facilitate the mapping tie-in. The mapping of the tie-in for Missoula County has been clipped to the effective Missoula County floodplain map.

5.3 Floodplain Boundary Smoothing

Floodplain Boundary Smoothing was completed in compliance with the May 2016 FEMA FIRM Database Schema and FEMA Database Verification Tool parameters applicable at the time this project contract was signed in November of 2016. 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. The QC process for floodplain boundary preparation was documented in a review checklist which has been included in Appendix F.

5.4 Changes Since Last FIRM Mapping

Changes Since Last FIRM (CLSF) mapping was completed as requested by the DNRC and included with study products. CSLF mapping products and work maps assist public entities and landowners in interpreting the changes to the floodplain mapping proposed for the new study compared to the effective study to be replaced. Work map pages and spatial files are provided in the Supplemental Data folder of the digital submission.

5.5 Letters of Map Change

A review was made of the Letters of Map Change along the Clark Fork River 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. This review identified one effective Letter of Map Change (LOMC) for the Clark Fork River in Mineral County, Montana.

A Letter of Map Revision (LOMR) with Case Number 07-08-0408P was issued for the Town of Superior, MT with an effective date of July 25, 2007. The LOMR made changes to FIRM Panel No 300128 0005A along the Clark Fork River from approximately 3,300 feet upstream to approximately 6,000 feet upstream of River Street. The floodplain Zone A was not changed and no revisions to the Flood Insurance Study Report were issued.

5.6 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 must be within +/- 1 foot of the ground elevation. More than 99% of the test points passed the audit criteria for this project. Test points were deleted from the floodplain boundary at study termination where the boundary was perpendicular to the flood flow direction. Test points were also not included along the match line between Mineral County and Missoula County since the boundary is generally along the river centerline so the flood boundary does not intersect with the ground surface. The FBS Audit summary report has been included in Appendix F and the test points shapefile has been included in the Supplemental Data folder of the digital submission.

5.7 Depth Grids

Depth Grids were prepared for each profile included in the hydraulic model (10%, 4% 2%, 1%, 1plus, & 0.2% AC). They were prepared in accordance with the FEMA Guidance *Flood Depth and Analysis Grids* and have been included in the Supplemental Data folder of the digital submission.

6.0 Flood Insurance Study Products

Digital profiles for the 10%, 4%, 2%, 1%, 1%+, and 0.2% annual-chance water surface elevations were created using FEMA's RASPLOT software (FEMA 2013). The HEC-RAS 5.0.3 data files could not be imported directly into RASPLOT. Instead, RASPLOT was used to create an empty database editable in Microsoft Access. HEC-RAS output data was manually extracted, organized in Microsoft Excel prior to importing in the database using Microsoft Access. Minor edits and corrections were then completed in RASPLOT following the typical workflow process and the profile plots were created in .dxf file format. Additional information, edits and formatting were made using AutoCAD. Profiles were developed following Flood Profiles FEMA Guidance for Flood Risk Analysis and Mapping (FEMA 2016d). The profiles illustrating the results of the study are provided in Appendix B. The draft FIS report including Section 5.2 and the Floodway Data Tables were prepared and provided in Word file.

7.0 References

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APPENDICES

Appendix A – Hydraulic Work Maps

Appendix B – Water Surface Profiles

Appendix C – Structure Photographs

Appendix D – Floodway Data Table

Appendix E – cHECk-RAS Checklists

Appendix F – QA/QC Checklists

Appendix G – FEMA Regional Approval for Atypical Contraction/Expansion Coefficients

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