Hydraulic Analysis and Floodplain Mapping Report

Prickly Pear Creek and Tributaries Floodplain Study
Jefferson County, MT

February 5, 2021

Contract Number: WO-MM-180
Mapping Activity Statement No. 2018-02

Prickly Pear Creek and Tributaries Floodplain Study

Hydraulic Analysis and Floodplain Mapping Report

Jefferson County, Montana

JEFFERSON COUNTY
MONTANA

PREPARED FOR:

Montana Department of Natural Resources and Conservation

Federal Emergency Management Agency

February 2021

PREPARD BY:

Morrison Maierle
engineers · surveyors · planners · scientists

P.O. Box 6147
Helena, MT 59604
Telephone: (406) 442-3050
www.m-m.net

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.

Luke D. Carlson, PE, CFM

MONTANA
LUKE D.
CARLSON
30602 PE
2/5/2021
REGISTERED
PROFESSIONAL ENGINEER

R:\1447\052_Mad_Jeff_Riv_Surv_PPC_Map\04 Design\Reports\Hyd Summary Report\Prickly_Pear_Cr&Tribs_Summary_Report.docx

Table of Contents

List of Tables

List of Figures

Appendices

1.0 Introduction and Background

Morrison-Maierle completed the hydraulic analysis for the Prickly Pear Creek and Tributaries within Jefferson County, Montana, as part of the Mapping Activity Statement (MAS) 2018-02, Jefferson Countywide – Modernization (FEMA 2018). 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), Jefferson County and other stakeholders. The purpose of this report is to document the hydraulic analysis and preliminary floodplain mapping 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 Prickly Pear Creek and four Tributary segments within Jefferson County with a total length of approximately 27.5 miles. The analysis approach is an Enhanced without Floodway flood study. Five model segments are included in the portion of the Jefferson Countywide - Modernization project and documented in this report as summarized in Table 1 and shown on Figure 1. All five reaches were evaluated as Enhanced Level Option E models with Zone AE delineations without a floodway. Prickly Pear Creek is modeled from the north termination point at the at the boundary between Jefferson County and Lewis and Clark County to the termination of terrain data at the upstream scope of work boundary. Each tributary segment was modeled from its confluence with Prickly Pear Creek to the termination of terrain data at the upstream scope of work boundary.

Table 1. Prickly Pear Creek Tributary Model Segments

Reach	Tributary	Analysis Approach	Length (miles)
1	Prickly Pear Creek	Enhanced Level Option E	18.7
2	Unnamed Tributary	Enhanced Level Option E	0.3
3	Warm Springs Creek	Enhanced Level Option E	3.6
4	Buffalo Creek	Enhanced Level Option E	3.8
5	Clancy Creek	Enhanced Level Option E	1.1
		Total	27.5

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 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 Jefferson County Map Modernization Project was completed by the Pioneer Technical Services, Inc. in October 2019 (Pioneer 2019a) and was approved by FEMA in 2019. The hydraulic structure and bathymetric survey was completed by Pioneer in the May of 2019 (Pioneer 2019b) and was approved by FEMA in 2019.

The hydraulic analysis for the five reaches includes the 10%, 4%, 2%, 1%, 0.2%, and 1% plus 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% 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 requirements of the National Flood Insurance Program.

1.1 Basin Description

1.1.1 Prickly Pear Creek Mainstem

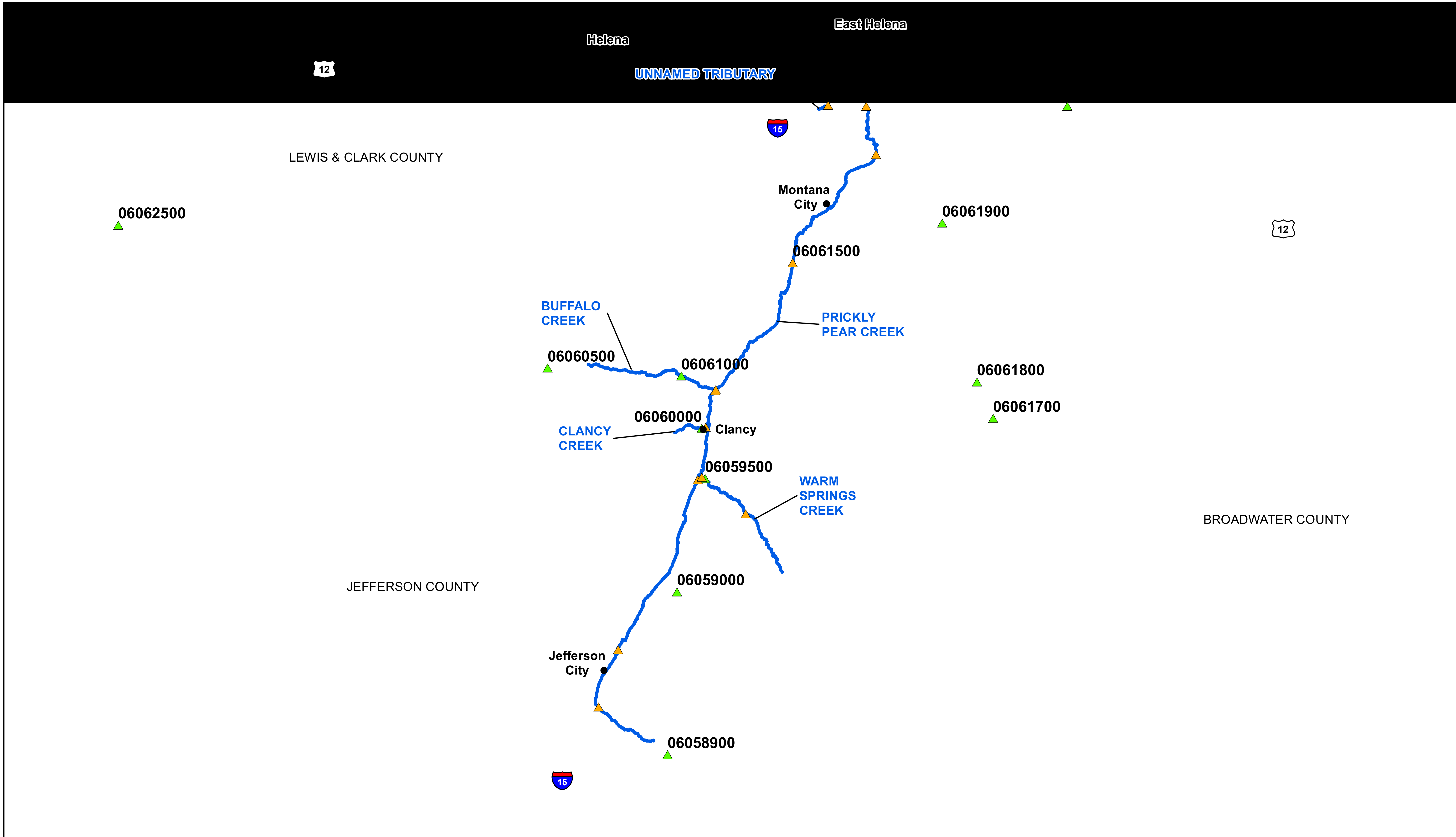
Prickly Pear Creek mainstem begins in the Elkhorn Mountains and flows northwest approximately 8 miles before turning northeast, then flows approximately 18 miles before turning north, and then flows approximately 8 miles before terminating at Lake Helena (Pioneer 2019a). Lake Helena flows into the Missouri River, located east of the Continental Divide in western Montana. The Prickly Pear Creek mainstem watershed area encompasses approximately 247 square miles. The terrain varies from a high alpine environment in its headwaters to narrow inter-mountain valleys. The hydrology of the basin is primarily snowmelt driven.

Land use in the study reach is largely rural with small communities along the Prickly Pear Creek mainstem. Interstate 15 (I-15) also runs southwest to northeast along the canyon created by the Prickly Pear Creek. The primary communities are Jefferson City, Clancy, and Montana City. Figure 1 shows the Prickly Pear Creek mainstem study reach.

1.1.2 Prickly Pear Creek Tributaries

All four Prickly Pear Creek Tributary study reaches discharge to Prickly Pear Creek which is a major tributary to Lake Helena and discharges into the Hauser Reservoir on the Missouri River. The study watershed for the Prickly Pear Creek tributaries encompasses approximately 98 square miles (Pioneer 2019a). The tributaries and watershed are formed in the eastern Boulder Range and the northern Elkhorn Range. 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 small communities along the Prickly Pear Creek tributaries. The primary community along a Prickly Pear Creek Tributary study reach is Clancy, MT. Figure 1 shows the Prickly Pear Creek Tributary study reaches.



Legend

- USGS Stream Gage
- HUC 8 Boundaries
- Prickly Pear Creek Study Reaches
- Streams

[redacted]

1 Engineering Place
Helena, MT 59602

Phone: (406) 442-3050
Fax: (406) 442-7862

R:\1447\052_Mad_Jeff_Riv_Surv_PPC_Map\GIS\Exhibits\Hyd Summary Report\Figure_1.mxd

DRAWN BY: BNC
CHK'D BY: KKM
APPR. BY: KKM
DATE: 1/6/20

Prickly Pear Creek Study Area

Prickly Pear Creek and Tributaries Floodplain Study

PROJECT NO.
1447.052

Figure 1

2.0 Previous Mapping

Flood Insurance Rate Maps (FIRM's) were completed for the Prickly Pear Creek in Jefferson County, MT in 1986. The flood hazard currently mapped for Prickly Pear Creek is Zone A for approximately one-half creek-miles at the Jefferson County and Lewis and Clark county boundary within Jefferson 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 Prickly Pear Creek in Jefferson County.

Zone A flood maps are developed using approximate study 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 initially map or change the flood zones on the maps of the Prickly Pear Creek and the four tributaries to Zone AE and will include BFE's for these streams.

3.0 Hydrology

This flood study, as shown on Figure 1, covers approximately 27.5 creek-miles of the Prickly Pear Creek and Tributaries within Jefferson County, Montana. The hydrologic analyses for Prickly Pear Creek and Tributaries was completed as part of the Jefferson County Map Modernization Project, hydrology provided by Pioneer Technical Services, Inc. in October 2019 (Pioneer 2019a).

3.1 Prickly Pear Creek Mainstem

Seven flow nodes on the Prickly Pear Creek mainstem study reach were identified as having significant changes in streamflow or being at critical locations (Pioneer 2019a). Of the seven flow nodes on the study reach, one is located at an active USGS stream gaging station. The study extents in this report were based on the Jefferson County Modernization Study Area Map provided by the DNRC. The river stations used in this report were based on the Prickly Pear Creek mainstem delineated by Pioneer based on imagery provided by Google. Prickly Pear Creek mainstem alignment begins at the boundary of Jefferson County with Lewis and Clark County. The upstream extent of the study reach ends near the headwaters in the Elkhorn Range.

3.1.1 Prickly Pear Creek USGS Stream Gage Analysis

One active United States Geological Survey (USGS) gaging stations is located in the vicinity of the study area for the mainstem of Prickly Pear Creek and the summary data for this gage is listed in Table 2. The USGS gaging station Prickly Pear Creek near Clancy, MT (06061500) is located at river mile 5.1 on the Prickly Pear Creek mainstem. The gage record dates to 1911 and is currently active.

Table 2. Prickly Pear Creek Mainstem USGS Gaging Station

USGS Station Number	Station Name	Regulation Status as of 2014	Period of Record	Number of Annual Peaks	Drainage Area (square miles)	Maximum Peak Discharge (cfs/Year)	Minimum Peak Discharge (cfs/Year)
06061500	Prickly Pear Creek near Clancy, MT	U	1911-1916 1923-1933 1946-1953 1955-1969 1975 1979-2002 2006-2017	77	192	2,300/1981	100/1985

cfs: cubic feet per second.
U: Unregulated stream.

3.1.2 Prickly Pear Creek USGS Gage Station Regression Equations Analysis

The USGS performed a gage analysis and a weighted with regional Regression Equations analysis for the Prickly Pear Creek Gaging Station (Pioneer 2019a). Table 3 shows the results of the Annual Equivalent Peak (AEP) discharges for systematic and weighted flood frequency estimates with regional regression equations for the gage located on the Prickly Pear Creek mainstem.

Table 3. Prickly Pear 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
06061500	Prickly Pear Creek near Clancy, MT	At-Site	242	566	830	1,090	1,400	2,470
		RRE wtd	243	578	865	1,150	1,520	2,710

cfs: cubic feet per second.
RRE wtd: Systematic data weighted with regional regression equation (RRE).

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 2019a). The upper 84% confidence limit calculated in the gage analysis was used by USGS to determine the 1%+ flood frequency peak flow estimates (FEMA, 2019). The Prickly Pear Creek mainstem 1%+ flood frequency peak flow estimates for the gage located on the Prickly Pear Creek mainstem is listed in Table 4.

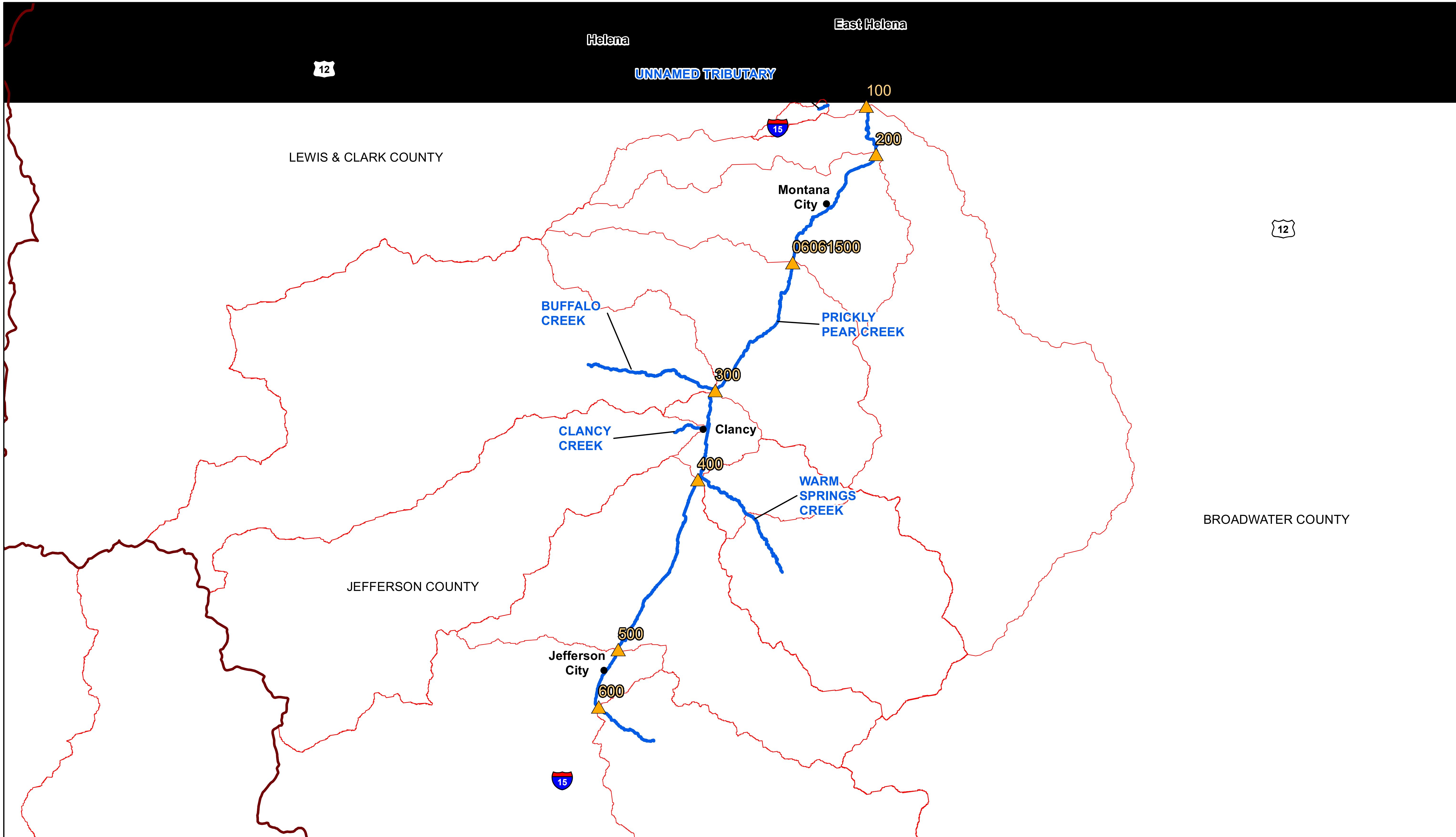
Table 4. Prickly Pear Creek Mainstem USGS Gage 1%+ Peak Flow Analysis

USGS Gage Station Number	Station Name	Drainage Area (sq. mi)	1% + AEP Peak discharge, At-Site (cfs)	1% + AEP Peak discharge, RRE wtd (cfs)
06061500	Prickly Pear Creek near Clancy, MT	192	2,390	1,930

sq. mi: square miles.
cfs: cubic feet per second.
RRE wtd: Systematic data weighted with regional regression equation (RRE).

3.1.4 Prickly Pear Creek Mainstem Flow Nodes

For the Prickly Pear Mainstem, Pioneer conducted flood frequency estimates for both gaged and ungaged sites. Peak flow estimates were calculated at seven flow nodes within the four tributaries (1 gaged site and 6 ungaged sites). The flow nodes were located at major sub-tributaries and at the downstream end of study reaches. The flow node locations and corresponding watershed areas are summarized in Table 5 and shown on Figure 2.



Legend

- Prickly Pear Creek Study Reaches
- Flow Nodes
- HUC 8 Boundaries
- HUC 12 Boundaries
- Stream

Flow Node Change: 600, 500, 400, 300, 06061500, 200, 100

[redacted]

1 Engineering Place
Helena, MT 59602

Phone: (406) 442-3050
Fax: (406) 442-7862

R:\1447\052_Mad_Jeff_Riv_Surv_PPC_Map\GIS\Exhibits\Hyd Summary Report\Figure_2.mxd

DRAWN BY: BNC
CHK'D BY: KKM
APPR. BY: KKM
DATE: 1/6/20

Prickly Pear Creek Mainstem
Flow Node Locations

Prickly Pear Creek and Tributaries Floodplain Study

PROJECT NO.
1447.052

Figure 2

Table 5. Prickly Pear Creek Mainstem Flow Nodes

Node/USGS Station ID	Location Description	River Mile Where Accumulated Flow Computed	Calculated Basin Area (sq. mi)	DA_U/DA_G
100	Reach origin	0.0	247	1.3
200	Middle Prickly Pear Creek	1.5	205	1.1
06061500	USGS Gage Prickly Pear Creek near Clancy, MT	5.1	192	-
300	Buffalo Creek	9.0	130	0.7
400	Warm Springs Creek	11.3	74	0.4
500	Jefferson City, MT	15.9	52	0.3
600	Headwaters Prickly Pear Creek	17.4	21	0.1

(sq. mi): Area in square miles.
DA_U: Drainage area at ungaged site.
DA_G: Drainage area at gaged site.

3.1.5 Prickly Pear Creek Mainstem Discharges

Pioneer conducted a peak discharge frequency analysis for the Prickly Pear Creek mainstem study reach (Pioneer 2019a). The study reach extends 19 miles from the reach origin at the Jefferson County line. This hydrologic analysis developed flood frequency estimates for both gaged and ungaged sites. Peak flow estimates were calculated at seven locations (flow nodes) within the watershed (1 gaged site and 6 ungaged sites). The ungaged sites (flow nodes) were located at HUC 12 boundaries, major tributaries, population centers, and at the end of study reaches. One stream gage, USGS gage Prickly Pear Creek near Clancy, MT (06061500) was used to estimate Annual Exceedance Probability (AEP) peak flow values for the study area. The gage is located at river mile 5.1 of the study reach.

The Prickly Pear Creek watershed in this study is considered unregulated. As documented by Pioneer, the basin parameters for the flow nodes evaluated in this study fall within the range of basin and climatic characteristics used to develop the regional regression equations. The weighted peak flow values were selected for the recommended flood discharge estimate on USGS gage 06061500 Prickly Pear Creek near Clancy, MT and used in the gage transfer method to estimate flows at ungaged nodes. The peak flow 1%+ (plus) estimates were developed for all gaged and ungaged locations using standard FEMA methodologies (FEMA, 2019).

The hydrologic analysis results provided in Table 6 and shown on Figure 3 represents the recommended discharges at each flow node location throughout the study reach. As noted by Pioneer, flow at each node was projected upstream to just below the next upstream flow node in the hydraulic model. Hydrology for Lewis and Clark County cross section BT was obtained from the Lewis and Clark County FIS report and was applied to the duplicate cross section BT, which is the basis for known water surface elevations in the hydraulic model. The hydraulic model river stations at which all flow changes were applied are included in Table 6. The hydrologic analysis conforms to the FEMA standard for enhanced level studies and was approved by FEMA in 2019.

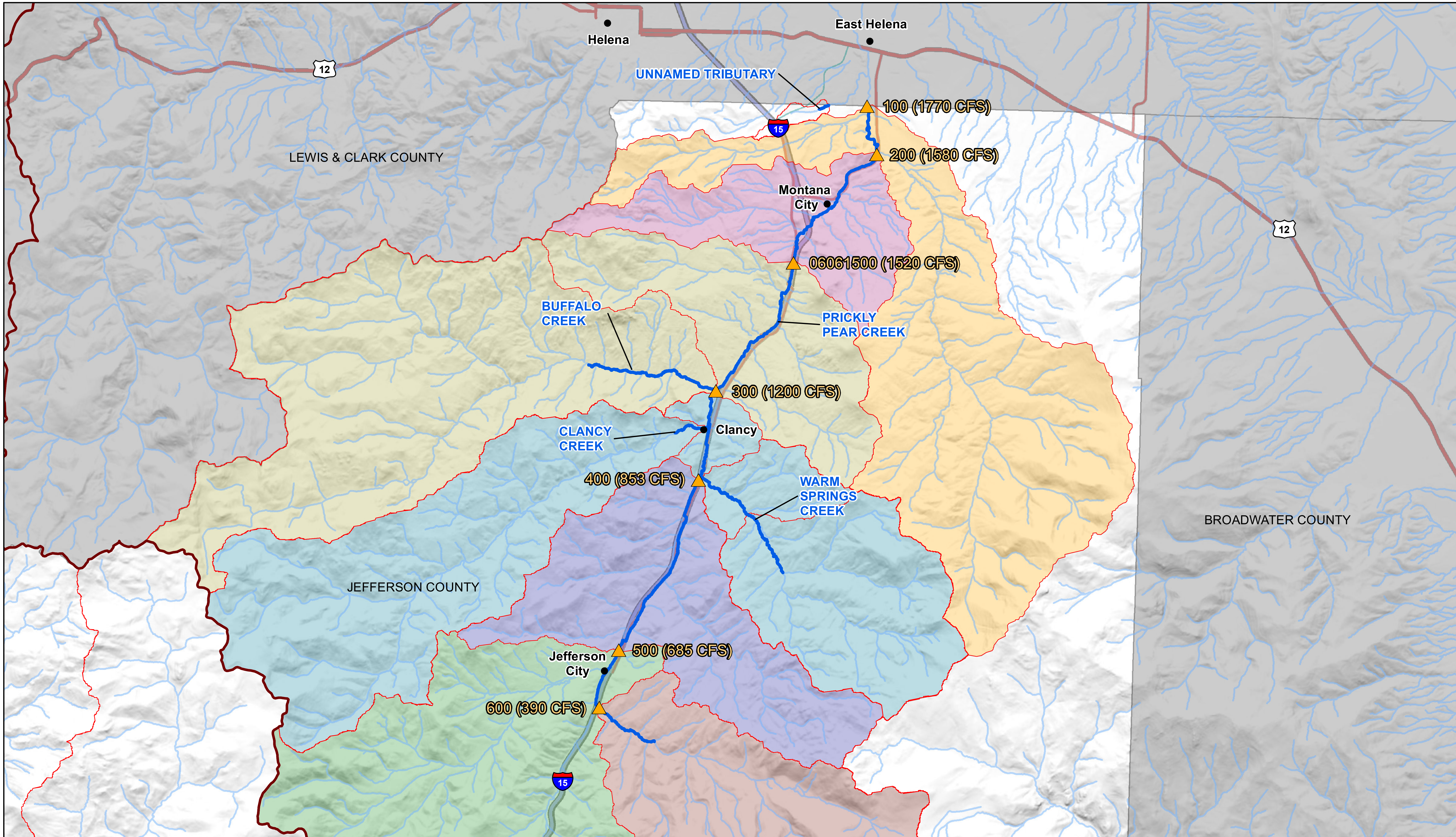
Table 6. Prickly Pear Creek Mainstem Flood Discharges

Node/USGS Station ID	Location Description	Hydraulic River Station Where Flow Applied	Estimated Discharge (cfs) 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 +
L&C Co Eff	XS BT approximately 140 feet north of county line	-136	715	1,050	1,400	1,805	3,200	2,300
100[1]	Reach origin	7,701	700	1,030	1,360	1,770	3,100	2,250
200[1]	Middle Prickly Pear Creek	26,660	607	905	1,200	1,580	2,810	2,010
06061500[2]	USGS Gage Prickly Pear Creek near Clancy, MT	46,446	578	865	1,150	1,520	2,710	1,930
300[1]	Buffalo Creek	58,638	431	662	894	1,200	2,200	1,520
400[1]	Warm Springs Creek	82,549	282	449	622	853	1,630	1,080
500[1]	Jefferson City, MT	90,346	215	351	493	685	1,350	870
600[1]	Headwaters Prickly Pear Creek	98,968	107	185	271	390	824	495

1. Analyzed with USGS Gage Transfer Method
2. Analyzed with USGS RRE Weighted Method

cfs: cubic feet per second.

Morrison Maierle



Legend

- Prickly Pear Creek Study Reaches
- Flow Nodes
- HUC 8 Boundaries
- HUC 12 Boundaries
- Stream

Flow Node Change

600, 500, 400, 300, 06061500, 200, 100

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: KKM
APPR. BY: KKM
DATE: 1/6/20

R:\1447\052_Mad_Jeff_Riv_Surv_PPC_Map\GIS\Exhibits\Hyd Summary Report\Figure_3.mxd

Prickly Pear Creek Mainstem
1% AEP Discharges

PROJECT NO.
1447.052

Prickly Pear Creek and Tributaries Floodplain Study

Figure 3

3.2 Prickly Pear Creek Tributaries

Throughout the study area, five flow nodes on the Prickly Pear Creek tributary study reaches were identified by Pioneer as having significant changes in streamflow or being at a critical location. All flow nodes are located at ungaged locations. The study tributaries in this report were based on the Jefferson County Modernization Study Area Map provided by the DNRC. The river stations were based on the Prickly Pear Creek tributaries delineated by Pioneer based on Google imagery. The Prickly Pear Creek tributary alignments begin at the confluence of Buffalo Creek, Clancy Creek, and Warm Springs Creek with Prickly Pear Creek mainstem. A fourth unnamed tributary begins at the Jefferson County line, joining with Prickly Pear Creek mainstem about one mile downstream from the study reach origin. The upstream extents of the study reaches were determined by the Montana DNRC and the Jefferson County government and approved by FEMA as the scope of the current flood study for Buffalo Creek, Clancy Creek, Prickly Pear Creek, Unnamed Tributary, and Warm Springs Creek.

3.2.1 Prickly Pear Creek Tributaries USGS Stream Gage Analysis

There are four USGS stream gages located on Prickly Pear Creek tributaries (with over ten years of record): USGS gaging stations Mitchell Gulch near East Helena, MT (06058700), Jackson Creek near East Helena, MT (06061700), Crystal Creek near East Helena, MT (06061800) and McClellan Creek near East Helena, MT (06061900). All four gages shown on Figure 1 have periods of record greater than or equal to 18 years and a summary of the gages is provided in Table 7.

Table 7. Prickly Pear Creek Tributary USGS Gages Station

USGS Gage Station Number	Station Name	Regulation Status as of 2014	Total Number of Years of Peak-Flow Records	Total Period of Record, in Water Years	2017 Status
06058700	Mitchell Gulch near East Helena, MT	U	45	1959-2003	Inactive
06061700	Jackson Creek near East Helena, MT	U	18	1961-1975, 1981, 1989-1990	Inactive
06061800	Crystal Creek near East Helena, MT	U	18	1961-1975, 1981, 1989-1990	Inactive
06061900	McClellan Creek near East Helena, MT	U	19	1960-1975, 1981, 1989-1990	Inactive

U: Unregulated stream.

3.2.2 Prickly Pear Creek Tributary USGS Station Regression Equations Analysis

The USGS performed a gage analysis and a weighted with regional Regression Equations analysis for the Prickly Pear Creek Tributary Stations (USGS 2019). Results for systematic and weighted flood frequency estimates with regional regression equations for the gage located on the Prickly Pear Creek tributaries are provided in Table 8.

Table 8. Prickly Pear Creek Tributary 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
06058700	Mitchell Gulch near East Helena, MT	At-Site	12	141	263	368	476	724
		RRE wtd	13	135	250	351	464	771
06061700	Jackson Creek near East Helena, MT	At Site	13	55	113	189	314	983
		RRE-wtd	13	52	94	134	178	290
06061800	Crystal Creek near East Helena, MT	At-Site	13	45	71	94	122	205
		RRE-wtd	13	46	74	100	132	231
06061900	McClellan Creek near East Helena, MT	At-Site	151	442	727	1,030	1,450	3,070
		RRE wtd	146	413	646	856	1,090	1,720

cfs: cubic feet per second.
RRE wtd: Systematic data weighted with regional regression equation (RRE).

3.2.3 Prickly Pear Creek Tributary USGS Station 1%+ Peak Flow Analysis

The 1%+ AEP event was calculated by the USGS (USGS 2019) per FEMA guidance documents (FEMA, 2019) to provide a confidence range that the 1% annual-chance flood frequency peak flow estimates are likely to fall within. The upper 84% confidence limit calculated in the gage analysis was used by USGS to determine the 1%+ flood frequency peak flow estimates (FEMA, 2019). The Prickly Pear Creek tributary 1%+ flood frequency peak flow estimates presented in Table 9**.**

Table 9. Prickly Pear Creek Tributary USGS 1%+ Flood Frequency Estimates

USGS Gage Station Number	Station Name	Drainage Area (sq. mi)	1% + AEP Peak discharge, At-Site (cfs)	1% + AEP Peak discharge, RRE wtd (cfs)
06058700	Mitchell Gulch near East Helena, MT	8	1,150	676
06061700	Jackson Creek near East Helena, MT	3	1,400	293
06061800	Crystal Creek near East Helena, MT	4	274	190
06061900	McClellan Creek near East Helena, MT	33	3,980	1,620

RRE wtd: Systematic data weighted with regional regression equation (RRE).
sq. mi: square miles.
cfs: cubic feet per second.

None of the four USGS stream gages listed in Table 9 are located on a study reach. Therefore, the four tributary USGS gages were not considered by Pioneer for this analysis.

3.2.4 Prickly Pear Creek Tributary Flow Change Node Locations

Pioneer completed a detailed review of the study area to identify all potential flow change locations (flow nodes) within the Prickly Pear Creek tributary study reaches (Pioneer 2019a). 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.

Pioneer noted that hydraulic models simulate flood events using steady-state conditions and the peak flow rate calculated at a flow node is projected to the next upstream flow node. Flow nodes were assigned immediately upstream of tributary junctions; this method of locating the flow nodes was employed so that the additional flow resulting from the tributary confluence was accurately reflected to the reach downstream of the confluence.

Pioneer recommended three flow nodes (Buffalo Creek, Clancy Creek, Warm Springs Creek) located just upstream of each tributary confluence with Prickly Pear Creek mainstem. One additional flow node was added at the reach origin of the Unnamed tributary to Prickly Pear Creek mainstem. A secondary flow node was located just upstream of the Badger Creek confluence on Warm Springs Creek. In total, Pioneer determined there were five flow nodes. Due to their drainage area size, and since the ungaged flow nodes do not have a GNIS hydrographic feature name, Pioneer developed a location description for each ungaged flow node.

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

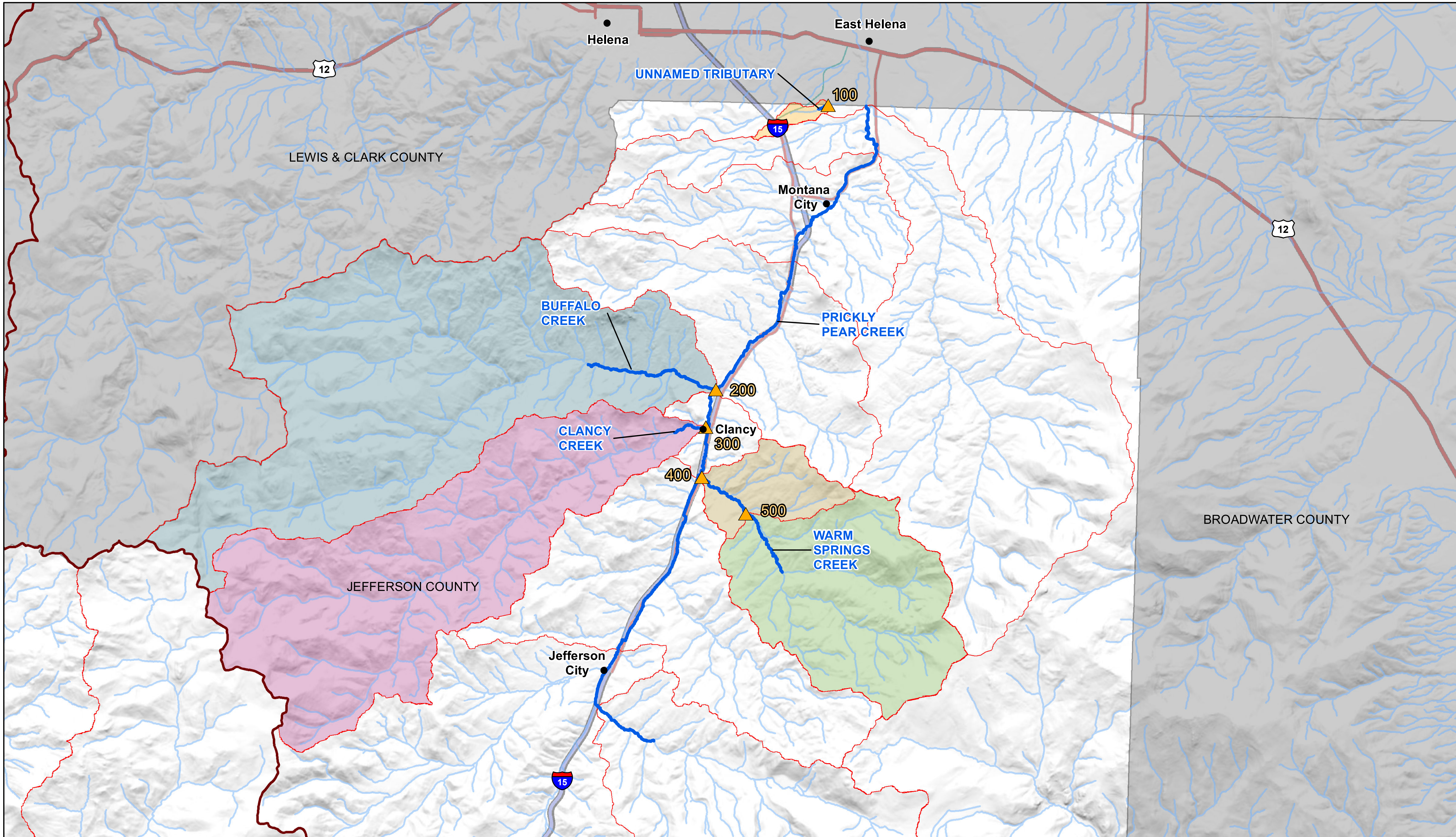
1. The ratio of the drainage areas lies between 0.6 and 1.4.
2. The arrival times of flood peaks are similar for the 2 combining watersheds.
3. The likelihood of both watersheds being covered by the storm is high.

The Prickly Pear Creek mainstem drainage area at the tributary confluences is not within the drainage ratio of 0.6 to 1.4. Pioneer noted that the study tributaries do not meet the drainage area ratio criteria. Furthermore, the study tributaries and Prickly Pear Creek mainstem are not gaged at the tributary/mainstem confluence. Pioneer noted that data to determine criteria No. 2 was not available. Pioneer determined that the tributaries do not meet the FEMA criteria for coincident peaks. Table 10 summarizes the flow nodes used in this study and Figure 4 shows the Prickly Pear Creek Tributary flow node and sub-basin locations.

Table 10. Prickly Pear Creek Tributary Flow Nodes

Node/USGS Station ID	Location Description	River Mile Where Accumulated Flow Computed	Calculated Basin Area[2] (sq. mi)	Tributary
100	Unnamed Tributary	0.0	1	Unnamed Tributary
200	Buffalo Creek	0.0	44	Buffalo Creek
300	Clancy Creek	0.1	33	Clancy Creek
400	Downstream end of Warm Springs Creek Study Reach	0.1	21	Warm Springs Creek
500	Warm Springs Creek downstream of junction with Badger Creek	1.8	17	Warm Springs Creek

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



Legend

- Prickly Pear Creek Study Reaches
- Flow Nodes
- HUC 8 Boundaries
- HUC 12 Boundaries
- Stream

Flow Change Node: 100, 200, 300, 400, 500

Morrison Maierle
engineers • surveyors • planners • scientists

1 Engineering Place
Helena, MT 59602
Phone: (406) 442-3050
Fax: (406) 442-7862

R:\1447\052_Mad_Jeff_Riv_Surv_PPC_Map\GIS\Exhibits\Hyd Summary Report\Figure_4.mxd

DRAWN BY: BNC
CHK'D BY: KKM
APPR. BY: KKM
DATE: 1/6/20

Prickly Pear Creek Tributaries
Flow Node Locations

Prickly Pear Creek and Tributaries Floodplain Study

PROJECT NO.
1447.052

Figure 4

3.2.5 Prickly Pear Creek Tributaries Discharges

To calculate peak flood discharge estimates at the ungaged flow nodes, Pioneer considered methods described by the USGS (USGS, 2018). These methods included estimating flood frequency using regional flood-frequency regression equations and estimating flood frequency on gaged streams by translating gaged data to ungaged locations (drainage-area ratio adjustment or logarithmic interpolation between 2 gaged sites). No USGS gages exist on Prickly Pear Creek tributaries. Therefore, gage-based analysis was not considered for the tributary discharges.

Pioneer used the regional regression method for all Prickly Pear Creek tributary study reaches (Pioneer 2019a). The five flow nodes are not regulated by upstream dams and the flow nodes are located within the Southwest Region watershed areas as defined by (USGS, 2015a). The regression equations use a drainage area (A) and percentage of drainage basin above 6,000 feet elevation (E_{6000}).

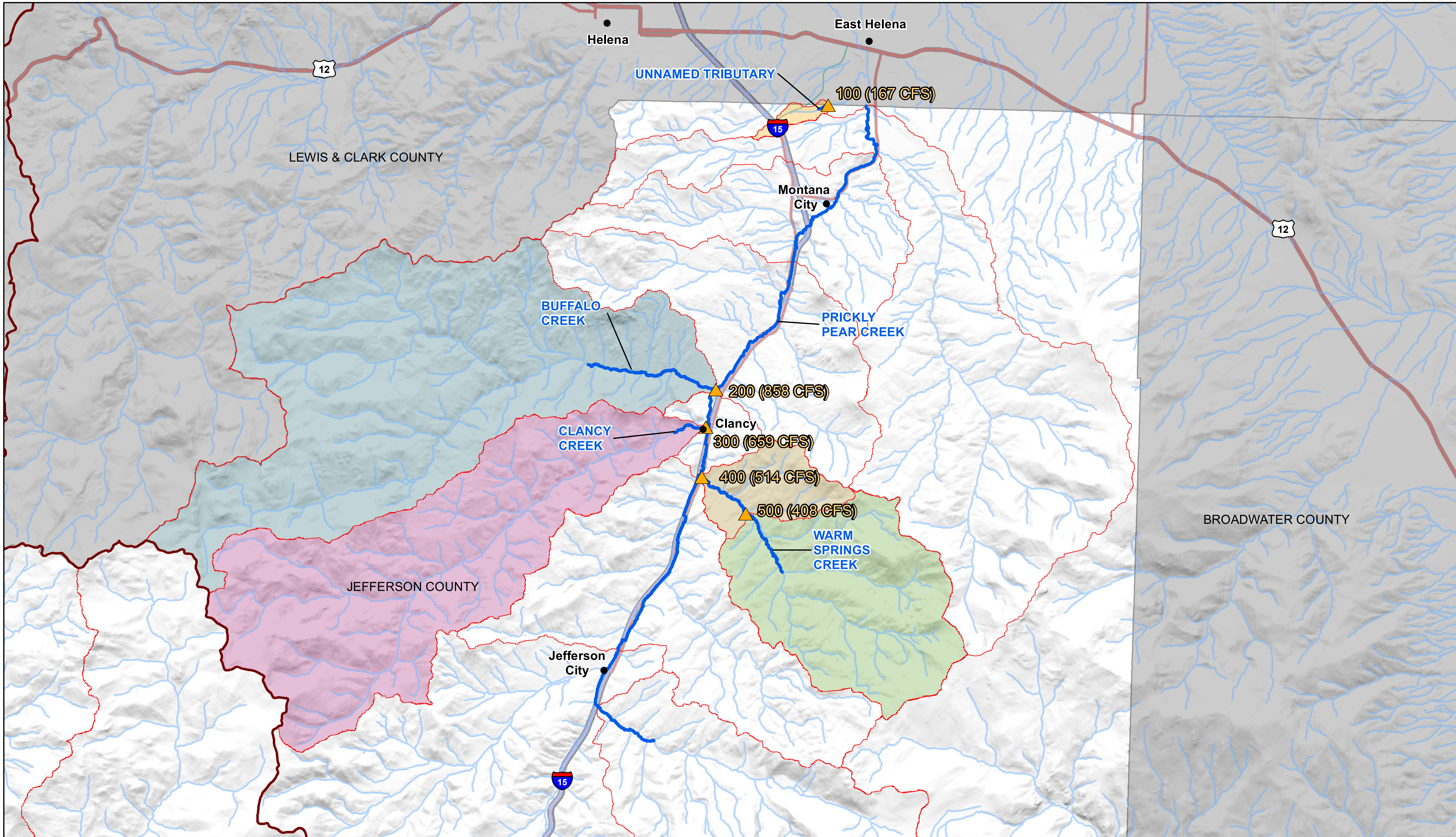
Pioneer concluded that regional regression equations were applicable to the Prickly Pear Creek tributary study reaches at all 5 flow nodes. No other method was considered in this analysis. All flow nodes were used to develop peak flow estimates for the 50, 10-, 4-, 2, 1-, 0.2% and 1%+ (plus) AEP events.

Table 11 summarizes the flood frequency discharge rates calculated in the Pioneer Hydrology Report for the Prickly Pear Creek tributary study reaches. Figure 5 shows the 1% AEP discharge for each flow node location. This hydrologic analysis conforms to FEMA standards for enhanced level studies and was approved by FEMA in 2019.

Table 11. Prickly Pear Creek Tributary Flood Discharges Using Regression Analysis

Node ID	Location Description	Hydraulic River Station Where Flow Applied	StreamStats/Southwest Regression Region Estimated Discharge (cfs)					
			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% + 100-year +
100	Unnamed Tributary	1,661	21	54	98	167	470	290
200	Buffalo Creek	20,222	350	527	680	858	1,350	1,490
300	Clancy Creek	5,676	271	407	523	659	1,040	1,150
400	Warm Springs Creek Confluence with Prickly Pear Creek	9,191	194	303	399	514	842	893
500	Warm Springs Creek at Badger Creek	19,226	158	243	319	408	659	709

cfs: cubic feet per second.



Legend

- Prickly Pear Creek Study Reaches
- Flow Nodes
- HUC 8 Boundaries
- HUC 12 Boundaries
- Stream

Flow Change Node: 100, 200, 300, 400, 500

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: KKM
APPR. BY: KKM
DATE: 1/6/20

R:\1447\052_Mad_Jeff_Riv_Surv_PPC_Map\GIS\Exhibits\Hyd Summary Report\Figure_5.mxd

Prickly Pear Creek Tributaries
1% AEP Discharges

Prickly Pear Creek and Tributaries Floodplain Study

PROJECT NO.
1447.052

Figure 5

4.0 Hydraulics

The methods and techniques used to complete the hydraulic analysis for Prickly Pear Creek and Tributaries within Jefferson County, Montana are presented in the following sections. The analysis utilized the LiDAR mapping and field hydraulic structure assessments to develop the Enhanced Level Option E, 1% AC Zone AE and 0.2% AC Zone X mapping without floodway.

4.1 Hydraulic Analysis

This flood study covers Prickly Pear Creek and selected tributaries within Jefferson County, MT. The study area, as shown on Figure 1, consists of reaches of the following five streams; Prickly Pear Creek, Unnamed Tributary, Warm Springs Creek, Buffalo Creek, and Clancy 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 one-dimensional (1D) hydraulic analysis. HEC-RAS also provides unsteady-flow analysis using model mesh with either diffusion wave or Full Momentum (St. Venant) equations for two-dimensional (2D) hydraulic analysis.

Cross sections were placed with the GeoHECRAS hydraulic computer modeling software (CivilGEO 2020) at flow distances or reach lengths generally ranging from approximately 15 to 500 feet and at structures located within the floodplain study reach. The Prickly Pear Creek hydraulic model has one channel flow length (RS 17153) exceeding 500 feet. At this location, the profile baseline is meandering, and the down valley reach lengths are less than 500 feet. The hydraulic analyses for this project are presented throughout this report and the associated deliverables in international feet units as described in the standard Montana NAD83 (2011) State Plane Datum (international feet).

Quality Control and Quality Assurance processes have been developed for Hydraulic and Floodplain Mapping tasks to ensure the global floodplain study accuracy and defensibility and the quality of the various deliverables composing the hydraulic and floodplain mapping package. Multiple quality check points occur throughout the development of the floodplain study to ensure quality is "built-in" throughout the development of the floodplain study sub-tasks. Rigorous peer review of all hydraulic analyses is completed and consensus is developed prior to presenting the floodplain study for external review and comment. The quality review components include written documentation of internal review comments and checklists. This documentation is included in Appendix E. Additionally, a QA-QC Report with additional detail about the Quality Control and Assurance processes and documentation has been included in the Supplemental_Data folder of the digital submittal package for the floodplain study.

Key hydraulic features and modeling approach details associated with each stream reach studied are discussed in the following sections.

4.1.1 Prickly Pear Creek

The Prickly Pear Creek one-dimensional (1D) hydraulic model begins from the north termination point at the boundary between Jefferson County and Lewis and Clark County and extends upstream to the south for approximately 18.7 creek-miles (Figure 6). Prickly Pear Creek was broken up into two models, a lower reach and upper reach; this improved HEC-RAS program stability, allowed for faster run times, and improved efficiency for creating flood maps and other deliverables. The lower reach is approximately 8.1 creek-miles and has 14 hydraulic structure crossings. The lower reach uses a known water surface elevation as the downstream boundary condition. The water surface elevations for cross section BT from the Lewis Clark County FIS report published in 2012 were used as the downstream boundary condition except for the 4% annual chance event and the 1%+ annual chance event. These water surfaces elevations were interpolated based on the water surfaces elevations bounding these profiles from the Lewis and Clark County floodplain study.

The upper reach is approximately 10.6 creek-miles in length and has 33 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 at river station (RS) 42,911.

4.1.2 Unnamed Tributary

The Unnamed Tributary 1D hydraulic model begins 1,080 feet below the border of Jefferson County and Lewis and Clark County and extends upstream to the southwest to approximately 0.3 creek-miles above the county boundary (Figure 6). The tributary reach has a normal depth slope boundary condition of approximately 0.021207 feet/feet. No split flow or tributary reaches to Unnamed Tributary were necessary to model this reach of stream. This Unnamed Tributary has no hydraulic structure crossings.

4.1.3 Warm Springs Creek

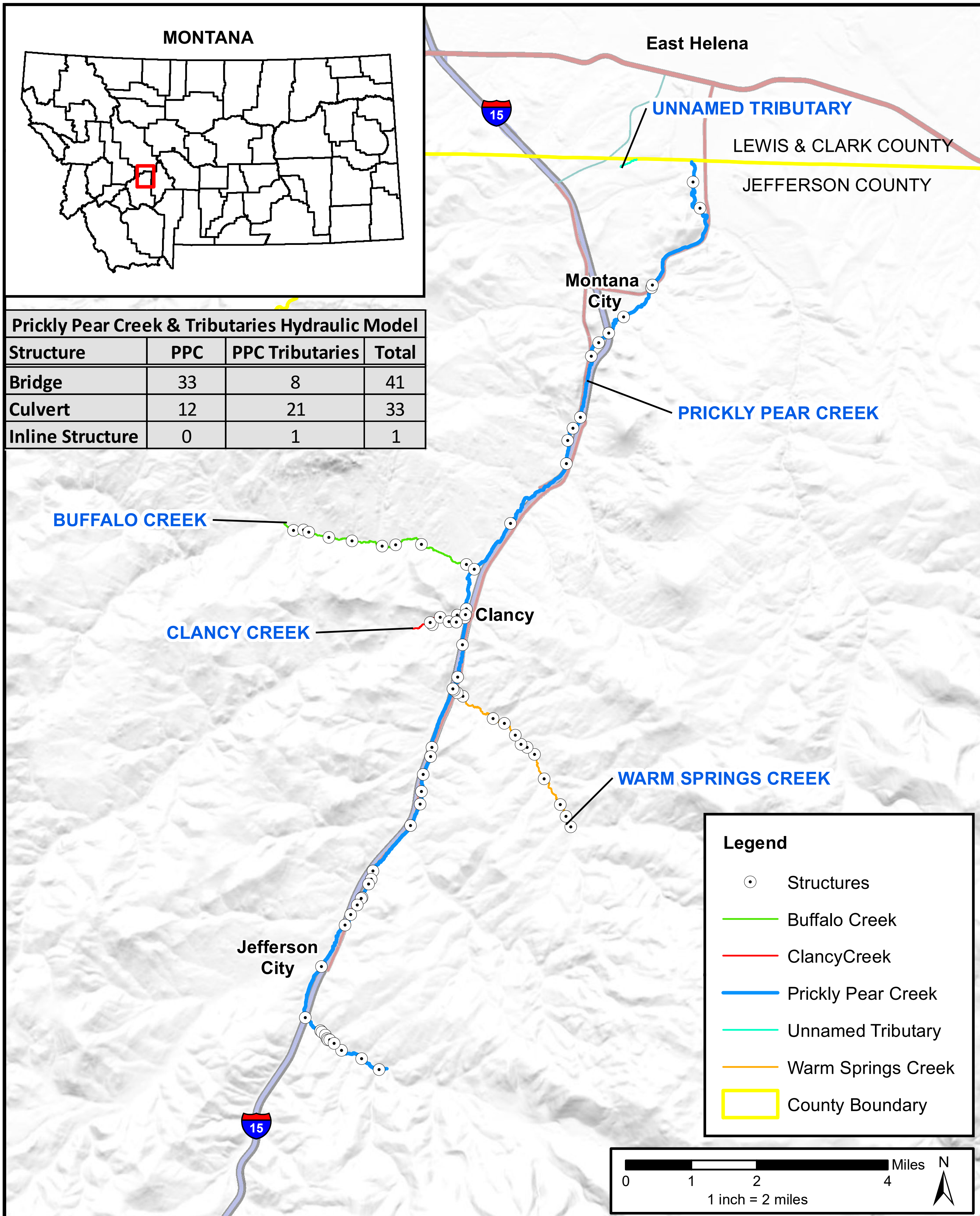
The Warm Springs Creek 1D hydraulic model begins at the confluence with the Prickly Pear Creek and extends upstream to the southwest for approximately 3.6 creek-miles (Figure 6). The tributary reach has a normal depth slope boundary condition of approximately 0.017092 feet/feet. No split flow or tributary reaches to Warm Springs Creek were necessary to model this reach of stream. This reach of Warm Springs Creek has 16 hydraulic structure crossings.

4.1.4 Buffalo Creek

The Buffalo Creek 1D hydraulic model begins at the confluence of the Prickly Pear Creek and extends upstream to the southwest for approximately 3.8 creek-miles (Figure 6). The tributary reach has a normal depth slope boundary condition of approximately 0.008245 feet/feet. No split flow or tributary reaches to Buffalo Creek were necessary to model this reach of stream. This reach of Buffalo Creek has nine hydraulic structure crossings.

4.1.5 Clancy Creek

The Clancy Creek 1D hydraulic model begins at the confluence of the Prickly Pear Creek and extends upstream to the southwest for approximately 1.1 creek-miles (Figure 6). The tributary reach has a normal depth slope boundary condition of 0.01112 feet/feet. Split flow reaches to Clancy Creek were necessary to model this stream. After evaluation alternative approaches to represent the hydraulic conditions, an approach using a 2D hydraulic model to inform the development of the 1D hydraulic model was chosen. This reach of Clancy Creek has eight hydraulic structure crossings. Lateral weirs were included in the 1D model, but they are not utilized to actively route flow in the model. Flow relationships were extracted from the 2D model and assigned to the 1D model.



Prickly Pear Creek & Tributaries Hydraulic Model			
Structure	**PPC**	**PPC Tributaries**	**Total**
Bridge	33	8	41
Culvert	12	21	33
Inline Structure	0	1	1

Morrison Maierle
engineers • surveyors • planners • scientists

1 Engineering Place
Helena, MT 59602
Phone: (406) 442-3050
Fax: (406) 442-7862

DRAWN BY: BC
CHK'D BY: LDC
APPR. BY: LDC
DATE: 6/16/2020

Jefferson Countywide - Modernization

Prickly Pear Creek & Tributaries Study Area

PROJECT NO. 1447.052

FIGURE NO. 6

R:\1447\052_Mad_Jeff_Riv_Surv_PPC_Map\GIS\Exhibits\Hyd Summary Report\Figure_6.mxd

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 LiDAR survey on the Prickly Pear Creek and Tributaries within Jefferson County for the DNRC between September 27, 2018 and September 19, 2019. The LiDAR survey included near-infrared wavelength for terrestrial topography for the Prickly Pear Creek and Tributaries. The specifications for the LiDAR 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 Jefferson County LiDAR Technical Data Report as summarized in Table 4 (QSI 2019).

Table 12. LiDAR Relative Vertical Accuracy

Parameter	Result
Sample	587 flight line surfaces
Average	0.139 feet
Median	0.139 feet
RMSE	0.155 feet
Standard Deviation	0.045 feet
95% Confidence (1.96*RMSE)	0.088 feet

The LiDAR deliverables included three-foot grid bare earth digital elevation models (DEM) for the entire length of the Prickly Pear Creek and Tributaries corridors (QSI 2019).

4.3 Field Structure Inventory

A Field Structure Inventory of the hydraulic structures for the Prickly Pear Creek and Tributaries study was performed by Pioneer Technical Services, Inc. (Pioneer 2019b). Table 13 is a summary of the structures inventoried on Prickly Pear Creek and Tributaries.

Table 13. Field Structure Inventory

ID No.	Structure Type	Tributary Reach	Roadway	River Station (feet)
B201	Bridge	Prickly Pear Creek	Private Drive	24063
R193	Railroad	Prickly Pear Creek	Railroad	1860
R194	Railroad	Prickly Pear Creek	Railroad	5208
C195	Culvert	Prickly Pear Creek	Railroad	14623
C196	Culvert	Prickly Pear Creek	Highway 518	14920
B197	Bridge	Prickly Pear Creek	McClellan Creek Road	18640
B198**	Bridge	Prickly Pear Creek	McClellan Creek Walkway	-
B199a	Bridge	Prickly Pear Creek	I-15 North & South	21146
C199	Culvert	Prickly Pear Creek	I-15 North & South	21146
C202	Culvert	Prickly Pear Creek	Highway 282 South	29484
B203	Bridge	Prickly Pear Creek	Private Walkway	30728
B204**	Bridge	Prickly Pear Creek	Private Walkway	-
C205	Culvert	Prickly Pear Creek	Sleepy Hollow Lane	32109
B206**	Bridge	Prickly Pear Creek	Private Walkway	-
B207	Bridge	Prickly Pear Creek	Haab Lane	34201
B208	Bridge	Prickly Pear Creek	Sunnyside Lane	41800
D209**	Diversion	Prickly Pear Creek		-
B210	Bridge	Prickly Pear Creek	Lump Gulch Road	46776
B211	Bridge	Prickly Pear Creek	Legal Tender Lane	50574
B212	Bridge	Prickly Pear Creek	Railroad Way	51107
B213	Bridge/ Box Culvert	Prickly Pear Creek	I-15 North & South	53679
B214	Bridge	Prickly Pear Creek	Private Drive	56653
B215	Bridge/ Box Culvert	Prickly Pear Creek	I-15 North & South	58039
C216	Culvert	Prickly Pear Creek	I-15 North & South, Highway 282	53679
B217	Bridge	Prickly Pear Creek	Private Drive	64271
B218	Bridge	Prickly Pear Creek	Private Drive	65978
B219	Bridge	Prickly Pear Creek	Private Road	67417
C220	Culvert	Prickly Pear Creek	Primrose Lane	58039
B221	Bridge	Prickly Pear Creek	Ponderosa Ranch Road	70478
B222	Bridge	Prickly Pear Creek	Private Drive	75563
C223	Culvert	Prickly Pear Creek	Dredge Rock Drive	63297
B224	Bridge	Prickly Pear Creek	Private Drive	76784
C225	Culvert	Prickly Pear Creek	Private Drive	78053
B226	Bridge	Prickly Pear Creek	Emerson Peak Road	78130
C227	Culvert	Prickly Pear Creek	Private Walkway	76344
B227.5**	Bridge	Prickly Pear Creek	Private Walkway	-
B228	Bridge	Prickly Pear Creek	Emerson Peak Road	78817
B229	Bridge	Prickly Pear Creek	Emerson Peak Road	79778
C230	Culvert	Prickly Pear Creek	I-15 North & South, Highway 282	80936
C230a**	Culvert	Prickly Pear Creek	I-15 North & South	-
C231	Culvert	Prickly Pear Creek	I-15 Interstate Access	85330

Table 13. Field Structure Inventory (Cont.)

ID No.	Structure Type	Tributary Reach	Roadway	River Station (feet)
C232	Culvert	Prickly Pear Creek	I-15 North & South	89964
B232.5	Bridge	Prickly Pear Creek	Private Walkway	91814
B233	Bridge	Prickly Pear Creek	Private Drive	91975
B233.3**	Bridge	Prickly Pear Creek	Private Walkway	-
B233.7**	Bridge	Prickly Pear Creek	Private Walkway	-
B234	Bridge	Prickly Pear Creek	Private Drive	92409
B235**	Bridge	Prickly Pear Creek	Private Walkway	-
B235.3	Bridge	Prickly Pear Creek	Private Walkway	92735
B235.7**	Bridge	Prickly Pear Creek	Private Walkway	-
B236**	Bridge	Prickly Pear Creek	Private Walkway	-
B237	Bridge	Prickly Pear Creek	Private Walkway	92919
B238	Bridge	Prickly Pear Creek	Private Drive	93052
B238.5	Bridge	Prickly Pear Creek	Private Walkway	93574
B239	Bridge	Prickly Pear Creek	Private Drive	94412
B240	Bridge	Prickly Pear Creek	Private Drive	96410
B241	Bridge	Prickly Pear Creek	Golconda Gulch	98266
C242	Culvert	Buffalo Creek	Liverpool Mine Road	914
C243	Culvert	Buffalo Creek	Halford Road	5656
C244	Culvert	Buffalo Creek	Rocky Mountain Drive	8785
B245	Bridge	Buffalo Creek	Private Drive	10140
C246	Culvert	Buffalo Creek	Private Drive	13337
B247**	Bridge	Buffalo Creek	Private Drive	-
B248	Bridge	Buffalo Creek	Private Drive	15538
C249	Culvert	Buffalo Creek	Private Drive	17462
C250	Culvert	Buffalo Creek	Private Drive	18009
C251	Culvert	Buffalo Creek	Sheep Mountain Road	19135
C252	Culvert	Clancy Creek	Private Drive	220
B252.5	Bridge	Clancy Creek	Foot Bridge	1220
B253	Bridge	Clancy Creek	North Main Street	1250
B254	Bridge	Clancy Creek	Private Walkway	1960
B255	Bridge	Clancy Creek	Private Walkway	2910
C256	Culvert	Clancy Creek	Clancy Creek Road	4010
*	Culvert	N. Main St Ditch	W. Cherry St	
C257	Culvert	Warm Springs Creek	South Highway 282	85
B258	Bridge	Warm Springs Creek	Warm Springs Creek Road	413
C259	Culvert	Warm Springs Creek	Private Drive	981
C260	Culvert	Warm Springs Creek	Sierra Lane	5244
C261	Culvert	Warm Springs Creek	Private Drive	6786
C262	Culvert	Warm Springs Creek	Lupine Lane	8357
C263	Culvert	Warm Springs Creek	Private Drive	9402
C264	Culvert	Warm Springs Creek	Private Drive	10087
C264a	Culvert	Warm Springs Creek	Private Drive	10087
C265	Culvert	Warm Springs Creek	Woodland Park Road	11042
C265a	Culvert	Warm Springs Creek	Woodland Park Road	11042

Table 13. Field Structure Inventory (Cont.)

ID No.	Structure Type	Tributary Reach	Roadway	River Station (feet)
C266	Culvert	Warm Springs Creek	Woodland Park Loop	13408
C266a	Culvert	Warm Springs Creek	Woodland Park Loop	13408
B266.5**	Bridge	Warm Springs Creek	Private Walkway	-
B267**	Bridge	Warm Springs Creek	Private Walkway	-
B268**	Bridge	Warm Springs Creek	Private Walkway	-
B269**	Bridge	Warm Springs Creek	Private Walkway	-
B270	Bridge	Warm Springs Creek	Private Drive	16773
C271	Culvert	Warm Springs Creek	Private Drive	18060
C272	Culvert	Warm Springs Creek	September Drive	19077

* Structure does not have an ID number.

** Bridge structure not modeled.

4.4 Profile Baseline

The alignment of the Prickly Pear Creek and Tributaries stream centerlines were prepared by Pioneer during the hydrologic analysis for study streams (Pioneer 2018a). 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 stream centerlines as stream distance (river stationing) in feet above the respective downstream limit. The flow change locations (flow nodes) of the Prickly Pear Creek and Tributaries were set at creek station locations as summarized in Tables 5 and 10. During the development of the hydraulic analysis, the water centerlines were refined for final hydraulic model Profile Baselines. While the lines aren't identical, the alignment and river station at the precision of one-tenth of a mile was unchanged. The Profile Baselines were used to locate cross sections and key features along the streams.

Split flow reach Profile Baselines were added during the hydraulic analysis to the Prickly Pear Creek and Clancy Creek models to include flow reaches as required to appropriately account for hydraulic flow distribution and to prepare the preliminary floodplain mapping. Key features along the stream reaches are summarized in Table 14.

Table 14. Profile Baseline Key Features

Reach	River Station (feet)	Type	Description
Buffalo Creek	0	Confluence	Confluence with Prickly Pear Creek
Buffalo Creek	20,222	Study Limit	Limit of Study, Approximately 3.8 River Miles above Confluence with Prickly Pear Creek
Clancy Creek	0	Confluence	Confluence with Prickly Pear Creek
Clancy Creek	1,364	Divergence	N. Main Street Ditch Divergence from Clancy Creek
Clancy Creek	1,181	Town	Unincorporated town of Clancy
Clancy Creek	2,050	Convergence	Clancy School 1 Convergence with Clancy Creek
Clancy Creek	2,665	Convergence	Clancy School 2 Convergence with Clancy Creek
Clancy Creek	4,131	Divergence	Clancy School 2 Divergence from Clancy Creek
Clancy Creek	5,676	Study Limit	Limit of Study, Approximately 1.1 River Miles above Confluence with Prickly Pear Creek
Clancy School 1	0	Convergence	Convergence with Clancy Creek
Clancy School 1	871	Divergence	Divergence from Clancy School 2
Clancy School 2	0	Convergence	Convergence with Clancy Creek
Clancy School 2	1,221	Divergence	Divergence from Clancy Creek
N. Main Street Ditch	0	Confluence	Confluence with Prickly Pear Creek
N. Main Street Ditch	1,622	Divergence	Divergence from Clancy Creek
Prickly Pear Creek	0	Boundary	Lewis & Clark/Jefferson County Boundary
Prickly Pear Creek	1,860	Structure Crossing	Active Railroad Crossing
Prickly Pear Creek	5,208	Structure Crossing	Active Railroad Crossing
Prickly Pear Creek	14,623	Structure Crossing	Active Railroad Crossing
Prickly Pear Creek	14,920	Structure Crossing	Highway 518
Prickly Pear Creek	21,146	Structure Crossing	Interstate 15 North & South
Prickly Pear Creek	29,484	Structure Crossing	Highway 282 South
Prickly Pear Creek	46,481	Confluence	Buffalo Creek confluence with Prickly Pear Creek
Prickly Pear Creek	51,046	Confluence	Clancy Creek confluence with Prickly Pear Creek
Prickly Pear Creek	53,679	Structure Crossing	Interstate 15 North & South
Prickly Pear Creek	57,951	Confluence	Warm Springs Creek confluence with Prickly Pear Creek
Prickly Pear Creek	58,039	Structure Crossing	Interstate 15 North & South
Prickly Pear Creek	63,297	Structure Crossing	Interstate 15 North & South, Highway 282
Prickly Pear Creek	85,330	Town	Unincorporated town of Jefferson City
Prickly Pear Creek	92,931	Local Landmark	Tizer Gardens
Prickly Pear Creek	98,968	Study Limit	Limit of Study, Approximately 18.7 River Miles above Lewis & Clark/Jefferson County Boundary
Unnamed Tributary	0	Boundary	Lewis & Clark/Jefferson County Boundary
Unnamed Tributary	1,661	Study Limit	Limit of Study, Approximately 0.3 River Miles above Lewis & Clark/Jefferson County Boundary
Warm Springs Creek	0	Confluence	Confluence with Prickly Pear Creek
Warm Springs Creek	85	Structure Crossing	Highway 282
Warm Springs Creek	9,191	Confluence	Badger Creek confluence with Warm Springs Creek
Warm Springs Creek	19,226	Study Limit	Limit of Study, Approximately 3.6 River Miles above Lewis & Clark/Jefferson County Boundary

4.5 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 2016b), 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 was taken from the effective Lewis and Clark Flood Insurance Study for Prickly Pear Creek cross section BT which is just north (≈130 feet) of the Lewis and Clark County boundary (FEMA, 2012). The 2018 LOMR for Prickly Pear Creek related to the ASARCO site stream restoration near east Helena tied to the original effective study water surface elevations below cross section BT.

The effective hydraulic model for Prickly Pear Creek in Lewis and Clark County was prepared circa 1985 and includes one cross section approximately 1,800 feet south of the county boundary. The water surface profile in the effective Lewis and Clark County FIS is lower slope than is computed for the Jefferson County flood study. Although the Jefferson County Prickly Pear Creek flood study begins at cross section BT known water surface elevations, there is a vertical discrepancy of more than one foot at the county line between the two studies. The flood study for Lewis and Clark County was completed within a year or two of a flood equivalent to the 1% AC flow, which may account for some of the difference in flood elevations. Additionally, the hydraulic modeling for Jefferson County incorporates improvements in hydraulic modeling theory, modeling computing technology, and terrain data accuracy and extents which may also be the basis for the difference. In discussion with Montana DNRC and Compass, the described hydraulic modeling approach was completed as the best alternative to present accurate flood risk while also aligning the older flood study with the new flood study across the county line.

To address the use of coincident peaks between the study tributaries and the Prickly Pear 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 Prickly Pear Creek and Tributaries do not meet the above listed criteria and, 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 all tributary reaches. The normal depth slope approximates the slope of the Hydraulic Grade Line (HGL) and was calculated by iterative model runs resulting in convergence at the HGL and boundary condition slope for the first several hundred feet of each 1D model.

A summary of the boundary conditions established for each model segment for the Prickly Pear Creek and Tributaries floodplain study in Jefferson County is provided in Table 15.

Table 15. Boundary Condition Summary

Tributary Reach	Model Segment	Boundary Condition
Unnamed Tributary	Unnamed Tributary	Normal Depth Slope = 0.021207 ft/ft
Warm Springs Creek	Warm Springs Creek	Normal Depth Slope = 0.017092 ft/ft
Buffalo Creek	Buffalo Creek	Normal Depth Slope = 0.008245 ft/ft
Clancy Creek	Clancy Creek A	Normal Depth Slope = 0.01112 ft/ft
	Clancy Creek B	Junction at Convergence with Clancy School 1
	Clancy Creek C	Junction at Convergence with Clancy School 2
	Clancy School 1	Junction at Convergence with Clancy Creek B
	Clancy School 2	Junction at Convergence with Clancy Creek C
	N. Main St Ditch	Normal Depth Slope = 0.006 ft/ft
Prickly Pear Creek	PPC_Lower	10% AC Known WSE = 3936.3 ft
		4% AC Known WSE = 3936.8 ft*
		2% AC Known WSE = 3937.3 ft
		1% AC Known WSE = 3937.6 ft
		0.2% AC Known WSE = 3938.7 ft
		1%+ AC Known WSE = 3938.0 ft*
	PPC_A	10% AC Known WSE = 4162.89 ft
		4% AC Known WSE = 4163.84 ft
		2% AC Known WSE = 4164.65 ft
		1% AC Known WSE = 4165.34 ft
		0.2% AC Known WSE = 4166.69 ft
		1%+ AC Known WSE = 4165.88 ft
	PPC_B	Junction at Convergence with PPC_Overbank
	PPC_Overbank	Junction at Convergence with PPC_B
	PPC_C	Junction at Divergence with PPC_Overbank

* Profile was not included in Lewis & Clark County FIS, therefore the WSE was interpolated.

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-percent annual-chance (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 raster elevation model development process or was influenced by water in the stream.

Low-flow channels were created on Prickly Pear Creek, Clancy Creek, and Buffalo Creek based on targeted bathymetric data collected by Pioneer Technical Services.

Review of the targeted bathymetric data versus LiDAR terrain indicated that insertion of a low-flow channel was not necessary for Warm Springs Creek. To determine the size of the low-flow channel the area between the LiDAR and the bathymetric data was calculated. For Prickly Pear Creek the low-flow channel is broken into reach segments based on where the bathymetric data was surveyed and the location of flow node changes to account for the conveyance area decreases as the flood flows decrease in the upstream direction.

4.7 Hydraulic Structures

The geometries of hydraulic structures were modeled based on data collected during the Structure Field Survey (Pioneer, 2019b). The data package included field measurements for 94 hydraulic structures located within the study limits as listed in Table 13. Each structure was assigned an identification code that included a 'B' for bridge, 'C' for culvert, or 'D' for diversion and a number generally corresponding to the order of the structures beginning at the downstream extent of the Prickly Pear Creek and Tributaries study reach and progressing upstream. The structures crossing Prickly Pear Creek and Tributaries include highway crossings along I-15, abandoned railroad track alignments, and roadway crossings along County, frontage and private roadways.

Expansion and contraction coefficients assignments at the two upstream and one downstream bridge cross sections were assigned to model bridge/culvert/diversion constrictions and were generally increased from the natural channel values 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. In some instances, the hydraulic structure expansion and contraction coefficients were increased above the typical 0.3 and 0.5 to account for severe contraction and expansion conditions zones and to yield reasonable profile relationships. As required by FEMA Guidance for One-Dimensional hydraulic modeling, approval for use of A-typical expansion and contraction coefficients has been requested and approved. The request letter and approval is included in Appendix E. These locations are included in Table 17.

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. 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 structures (no piers or obstructions within the bridge opening). 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 which 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 method 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 C_D and K Coefficients

Pier Shape	C_D	K
Triangular nose with 90° angle	1.6	0.9
Semicircular nose and tail	1.33	0.9
Circular Piers	1.2	0.9
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 DEM averaging in narrow streams or LIDAR DEM limitations for 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. A summary of culvert structure hydraulic model settings is provided in Table 19.

The following sections describe the unique conditions for hydraulic structure crossings for Prickly Pear Creek and each tributary reach studied. All other hydraulic structures were modeled in accordance with standard engineering practices, HEC-RAS guidance, and FEMA Guidance and Standards.

Photographs 1 thru 5 illustrate the different types of roadway hydraulic conveyance structures that were modeled for the Prickly Pear 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.

4.7.1 Prickly Pear Creek

Prickly Pear Creek has 47 modeled hydraulic structure crossings. 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.

The structure crossing I-15 North & South at RS 53,679 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 structure crossing I-15 North & South at station 56,653 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 I-15 North & South at station 80,963 is an 11 feet by 16 feet corrugated steel pipe arch. The chart and scale were chosen to best represent the dimensions of the culvert, since the HEC-RAS culvert tables for this culvert type do not include culvert dimensions as large as the in-place culvert.

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

4.7.2 Unnamed Tributary

Unnamed Tributary has no hydraulic structure crossings.

4.7.3 Warm Springs Creek

Warm Springs Creek has sixteen hydraulic structure crossings included in the hydraulic model. A few small pedestrian bridges were determined to be insignificant because it is likely that they would float away or be destroyed during the regulatory flood. The sixteen crossing structures and modeling data for Warm Springs Creek are summarized in Tables 17, 18 and 19.

4.7.4 Buffalo Creek

Buffalo Creek has nine hydraulic structure crossings included in the hydraulic model. One pedestrian bridge was determined to be insignificant because it is likely that it would float away or be destroyed during the regulatory flood. The bridge crossing structures and modeling data for Buffalo Creek are summarized in Tables 17, 18 and 19.

4.7.5 Clancy Creek

Clancy Creek has eight hydraulic structure crossings consisting of three pedestrian bridges, four culverts, and an inline weir. The North Main Street Clancy Creek crossing (RS 1,250. B253) was identified as a bridge in the field structure inventory. However, review of the structure indicated that it could be represented as an embedded reinforced concrete box culvert or a three-sided concrete culvert. This crossing is undersized for the 1% AEP flows, overtops on the left overbank, and caused a minor flow split to the north. A 2D hydraulic model was developed to inform the regulatory 1D model. Current HEC-RAS model logic provides for modeling of culverts, but not bridges. The crossing was modeled as a culvert based on engineering judgement after review of the available structure data and to provide consistency between the 2D and 1D hydraulic model analyses.

The inline weir option was utilized to represent the overtopping of Clancy Creek Road for the Clancy School 2 split flow path. The inline weir option was required since the culvert analysis for the main stem crossing was truncated at the match line between the Clancy

Creek main stem flow path and the Clancy School 2 split flow path to meet 1D hydraulic modeling logic. The weir coefficient was varied to yield 1D water surface elevations and the relationship of water surface elevations between the split flow reaches upstream of Clancy Creek Road that were consistent with the 2D model results. The bridge and culvert crossing structures and modeling data for Clancy Creek are summarized in Tables 17, 18, and 19.

Table 17. Summary of Bridge Structures

ID No.	Roadway	Tributary Reach	River Station (feet)	Spans	Total Span (feet)	Deck Width (feet)	Pier Widths (feet)	Appendix C Photo Page #
B245	Private Drive	Buffalo Creek	10,140	1	24.4	16	-	198
B248	Private Drive	Buffalo Creek	15,538	1	15	11.8	-	206
B252.5	Foot Bridge	Clancy Creek	1,220	1	16.5	3.1	-	222
B253	North Main Street	Clancy Creek	1,250	1	10.8	23.8	-	226
B254	Private Walkway	Clancy Creek	1,960	1	19.6	5	-	229
B255	Private Walkway	Clancy Creek	2,910	1	20.8	5.4	-	233
R193	Railroad	Prickly Pear Creek	1,860	5	106	12	1.0, 1.0, 1.0, 8.0	1
R194	Railroad	Prickly Pear Creek	5,208	2	96.4	21.1	5.5	4
B197	McClellan Creek Road	Prickly Pear Creek	18,640	1	23	26	-	14
B199a	I-15 North & South	Prickly Pear Creek	21,146	5	225	40.4	3	21
B200	Stoney Brook Drive	Prickly Pear Creek	22,518	1	41.3	22.1	-	27
B201	Private Drive	Prickly Pear Creek	24,063	1	54	16.4	-	31
B203	Private Walkway	Prickly Pear Creek	30,728	1	28	7	-	37
B207	Haab Lane	Prickly Pear Creek	34,201	1	52	29	-	48
B208	Sunnyside Lane	Prickly Pear Creek	41,800	1	26.4	16	-	52
B210	Lump Gulch Road	Prickly Pear Creek	46,776	1	36.8	26	-	58
B211	Legal Tender Lane	Prickly Pear Creek	50,574	1	20	24.6	-	61
B212	Railroad Way	Prickly Pear Creek	51,107	1	19.9	21.5	-	64
B213	I-15 North & South	Prickly Pear Creek	*	1	20.7	22	-	67
B214	Private Drive	Prickly Pear Creek	56,653	1	43.3	12	-	71
B215	I-15 North & South	Prickly Pear Creek	*	1	20.8	22.6	-	75
B217	Private Drive	Prickly Pear Creek	64,271	1	16	71.7	-	81
B218	Private Drive	Prickly Pear Creek	65,978	1	10.3	16.1	-	84
B219	Primrose Lane	Prickly Pear Creek	67,417	1	22.8	16.2	-	87
B221	Ponderosa Ranch Road	Prickly Pear Creek	70,478	1	19	22.2	-	93
B222	Private Drive	Prickly Pear Creek	75,563	1	20.8	11.9	-	96
B224	Private Drive	Prickly Pear Creek	76,784	1	14.3	18.9	-	102
B226	Emerson Peak Road	Prickly Pear Creek	78,130	1	22.4	12.7	-	108

Table 17. Summary of Bridge Structures (Cont.)

ID No.	Roadway	Tributary Reach	River Station (feet)	Spans	Total Span (feet)	Deck Width (feet)	Pier Widths (feet)	Appendix C Photo Page #
B228	Emerson Peak Road	Prickly Pear Creek	78,817	1	24.1	12	-	116
B229	Emerson Peak Road	Prickly Pear Creek	79,778	1	52.1	12.3	-	120
B232.5	Private Walkway	Prickly Pear Creek	91,814	6	47.6	20	1.0, 1.0, 1.0, 6.0, 2.0	136
B233	Private Drive	Prickly Pear Creek	91,975	2	23.3	12.2	0.5	142
B234	Private Drive	Prickly Pear Creek	92,409	1	16.8	14.2	-	151
B235.3	Private Walkway	Prickly Pear Creek	92,735	1	13.8	4.1	-	158
B237	Private Walkway	Prickly Pear Creek	92,919	1	20.2	6	-	167
B238	Private Drive	Prickly Pear Creek	93,052	1	22.3	12.4	-	170
B238.5	Private Walkway	Prickly Pear Creek	93,574	3	31.2	4	0.7, 0.7	174
B239	Private Drive	Prickly Pear Creek	94,412	1	29.5	14.4	-	178
B240	Private Drive	Prickly Pear Creek	96,410	1	24.3	18.6	-	181
B241	Golconda Gulch	Prickly Pear Creek	98,266	1	17.9	16	-	185
B245	Private Drive	Buffalo Creek	10,140	1	26	16	-	198
B248	Private Drive	Buffalo Creek	15,538	1	20.3	11.8	-	206
B258	Warm Springs Creek Road	Warm Springs Creek	413	1	18.6	24.7	-	243
B270	Private Drive	Warm Springs Creek	16,773	1	16	14	-	290

* Bridge structure modeled as box culvert.

Table 18. Summary of Bridge Model Settings

ID No.	Roadway	Tributary Reach	River Station (feet)	Contraction Coefficient	Expansion Coefficient	Low Flow Method	High Flow Method
B245	Private Drive	Buffalo Creek	10,140	0.3	0.5	Energy	Pressure/Weir
B248	Private Drive	Buffalo Creek	15,538	0.3	0.5	Energy	Pressure/Weir
B252.5	Foot Bridge	Clancy Creek	1,220	0.3	0.5	Energy	Energy Only
B253	North Main Street	Clancy Creek	1,250	0.3	0.5	Energy	Energy Only
B254	Private Walkway	Clancy Creek	1,960	0.3	0.5	Energy, Momentum	Pressure/Weir
B255	Private Walkway	Clancy Creek	2,910	0.3	0.5	Energy, Momentum	Pressure/Weir
R193	Railroad	Prickly Pear Creek	1,860	0.3	0.5	Energy	Energy Only
R194	Railroad	Prickly Pear Creek	5,208	0.3	0.5	Energy, Momentum, Yarnell	Energy Only
B197	McClellan Creek Road	Prickly Pear Creek	18,640	0.3	0.5	Energy	Energy Only
B199a	I-15 North & South	Prickly Pear Creek	21,146	0.3	0.5	Energy, Momentum, Yarnell	Energy Only
B200	Stoney Brook Drive	Prickly Pear Creek	22,518	0.3	0.5	Energy	Pressure/Weir
B201	Private Drive	Prickly Pear Creek	24,063	0.3	0.5	Energy	Energy Only
B203	Private Walkway	Prickly Pear Creek	30,728	0.3	0.5	Energy	Energy Only
B207	Haab Lane	Prickly Pear Creek	34,201	0.3	0.5	Energy	Pressure/Weir
B208	Sunnyside Lane	Prickly Pear Creek	41,800	0.3	0.5	Energy	Pressure/Weir
B210	Lump Gulch Road	Prickly Pear Creek	46,776	0.3	0.5	Energy	Pressure/Weir
B211	Legal Tender Lane	Prickly Pear Creek	50,574	0.3	0.5	Energy	Pressure/Weir
B212	Railroad Way	Prickly Pear Creek	51,107	0.3	0.5	Energy	Pressure/Weir
B213	I-15 North & South	Prickly Pear Creek	*	0.3	0.5	Modeled as culvert	
B214	Private Drive	Prickly Pear Creek	56,653	0.3	0.5	Energy	Pressure/Weir
B215	I-15 North & South	Prickly Pear Creek	*	0.3	0.5	Modeled as culvert	
B217	Private Drive	Prickly Pear Creek	64,271	0.3	0.5	Energy	Pressure/Weir
B218	Private Drive	Prickly Pear Creek	65,978	0.3	0.5	Energy	Pressure/Weir
B219	Private Road	Prickly Pear Creek	67,417	0.3	0.5	Energy	Energy Only
B221	Ponderosa Ranch Road	Prickly Pear Creek	70,478	0.3	0.5	Energy	Pressure/Weir

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

ID No.	Roadway	Tributary Reach	River Station (feet)	Contraction Coefficient	Expansion Coefficient	Low Flow Method	High Flow Method
B222	Private Drive	Prickly Pear Creek	75,563	0.3	0.5	Energy	Pressure/Weir
B224	Private Drive	Prickly Pear Creek	76,784	0.7	0.9	Energy	Pressure/Weir
B226	Emerson Peak Road	Prickly Pear Creek	78,130	0.3	0.5	Energy	Pressure/Weir
B228	Emerson Peak Road	Prickly Pear Creek	78,817	0.3	0.5	Energy	Pressure/Weir
B229	Emerson Peak Road	Prickly Pear Creek	79,778	0.3	0.5	Energy	Pressure/Weir
B232.5	Private Walkway	Prickly Pear Creek	91,814	0.3	0.5	Energy, Momentum, Yarnell	Pressure/Weir
B234	Private Drive	Prickly Pear Creek	92,409	0.3	0.5	Energy	Energy Only
B235.3	Private Walkway	Prickly Pear Creek	92,735	0.3	0.5	Energy	Energy Only
B237	Private Walkway	Prickly Pear Creek	92,919	0.3	0.5	Energy	Energy Only
B238	Private Drive	Prickly Pear Creek	93,052	0.3	0.5	Energy	Pressure/Weir
B238.5	Private Walkway	Prickly Pear Creek	93,574	0.3	0.5	Energy, Momentum, Yarnell	Energy Only
B239	Private Drive	Prickly Pear Creek	94,412	0.3	0.5	Energy	Pressure/Weir
B240	Private Drive	Prickly Pear Creek	96,410	0.3	0.5	Energy	Pressure/Weir
B241	Golconda Gulch	Prickly Pear Creek	98,266	0.3	0.5	Energy	Pressure/Weir
B258	Warm Springs Creek Road	Warm Springs Creek	413	0.3	0.5	Energy	Pressure/Weir
B270	Private Drive	Warm Springs Creek	16,773	0.3	0.5	Energy	Pressure/Weir

* Bridge structure modeled as a culvert.
** Bridge structure pier foundations modeled in topography of cross sections.

Table 19: Summary of Culvert Crossings

ID No.	Roadway	Tributary Reach	River Station (feet)	Culvert Length (feet)	Culvert Type	Culvert Shape	Culvert Size (feet)	Appendix C Photo Page #
C195	Railroad	Prickly Pear Creek	14,623	147, 147	CSP, CSP	Circular, Circular	11.0, 11.0	7
C196	Highway 518	Prickly Pear Creek	14,920	126, 126	CSP, CSP	Circular, Circular	10.5, 10.5	10
C199	I-15 North & South	Prickly Pear Creek	21,146	291, 291	CSP, CSP	Circular, Circular	11.0, 11.0	21
C202	Highway 282 South	Prickly Pear Creek	29,484	50, 50	CSPA, CSPA	Arch, Arch	8.1 x 12.8, 8.1 x 12.8	34
C205	Sleepy Hollow Lane	Prickly Pear Creek	32,109	36.3	CSPA	Arch, Open Bottom	6.1 x 22	44
B213	I-15 North & South	Prickly Pear Creek	53,679	120.7	RCB	Box	9.5x20.7	67
B215	I-15 North & South	Prickly Pear Creek	56,653	128.84	RCB	Box	10x21	75
C216	I-15 North & South, Highway 282	Prickly Pear Creek	58,039	252.6	CSP	Circular	16.0	78
C220	Primrose Lane	Prickly Pear Creek	68,531	36.2	CSP	Circular	8.0	90
C223	Dredge Rock Drive	Prickly Pear Creek	76,344	29.6	CSP	Circular	9.5	99
C225	Private Drive	Prickly Pear Creek	78,053	20.3	CSPA	Arch	7.0 x 8.5	105
C227	Private Walkway	Prickly Pear Creek	76,344	-	-	-	-	111
C230	I-15 North & South, Highway 282	Prickly Pear Creek	78,053	267.5	CSPA	Arch	11.0 x 16.0	124
C230a	I-15 North & South	Prickly Pear Creek	80,936	237	CSP	Circular	8.0	127
C231	I-15 Interstate Access	Prickly Pear Creek	85,330	140.1	CSP	Circular	12.0	130
C232	I-15 North & South	Prickly Pear Creek	89,964	217, 100	RCB, RCP	Box, Circular	12.0 x 14.0, 3.0	133
C242	Liverpool Mine Road	Buffalo Creek	914	30	CSPA	Arch	4.9 x 6.7	188
C243	Halford Road	Buffalo Creek	5,656	43	CSPA	Arch	5.6 x 7.9	191
C244	Rocky Mountain Drive	Buffalo Creek	8,785	50, 45	CSPA, CSPA	Arch, Arch	5.9 x 6.8, 3.2 x 4.7	194
C246	Private Drive	Buffalo Creek	13,337	20.3	CSPA	Arch	6.3 x 9.3	202
C249	Private Drive	Buffalo Creek	17,462	29.8	CSP	Circular	6.5	210
C250	Private Drive	Buffalo Creek	18,009	41	CSP	Circular	5.0	213
C251	Sheep Mountain Road	Buffalo Creek	19,135	32	CSP	Circular	6.0	216
C252	Private Drive	Clancy Creek	220	30.2	CSPA	Arch	4.6 x 6.1	219
C256	Clancy Creek Road	Clancy Creek	4,010	50	CSPA	Arch	4.9 x 6.7	237

Table 19: Summary of Culvert Crossings (Cont.)

ID No.	Roadway	Tributary Reach	River Station (feet)	Culvert Length (feet)	Culvert Type	Culvert Shape	Culvert Size (feet)	Appendix C Photo Page #
	West Cherry St	N Main St Ditch	1,120	52	CMP	Circular	1.5	
C257	South Highway 282	Warm Springs Creek	85	30, 30	RCB, RCB	Box, Box	5.0 x 6.0, 5.0 x 6.0	240
C259	Private Drive	Warm Springs Creek	981	30.4, 28.5	RCP, RCP	Circular, Circular	2.5, 4.0	246
C260	Sierra Lane	Warm Springs Creek	5,244	60.7	CSP	Circular	6.5	249
C261	Private Drive	Warm Springs Creek	6,786	38.8	CSP	Circular	5.0	252
C262	Lupine Lane	Warm Springs Creek	8,357	80	CSP	Circular	6.0	255
C263	Private Drive	Warm Springs Creek	9,402	34, 34	CSP, CSP	Circular, Circular	4.0, 2.0	258
C264	Private Drive	Warm Springs Creek	10,087	35	CSP	Circular	5.0	261
C264a	Private Drive	Warm Springs Creek	10,087	29.8	HDPE	Circular	2.0	261
C265	Woodland Park Road	Warm Springs Creek	11,042	29.5	CSP	Circular	6.0	266
C265a	Woodland Park Road	Warm Springs Creek	11,042	32.3	CSP	Circular	4.0	266
C266	Woodland Park Loop	Warm Springs Creek	13,408	49.4	CSPA	Arch	4.9 x 6.8	271
C266a	Woodland Park Loop	Warm Springs Creek	13,408	38	CSPA	Arch	2.8 x 4.1	271
C271	Private Drive	Warm Springs Creek	18,060	31.5	SMSI	Circular	6.3	293

Culvert Types:
CSPA – Corrugated Steel Pipe Arch,
CSP – Corrugated Steel Pipe
RCP – Reinforced Concrete Pipe,
RCPA – Reinforced Concrete Pipe Arch
RCB – Reinforced Concrete Box
SMSI – Smooth Steel/Iron Pipe

Photograph 1: Prickly Pear Creek – Railroad at RS 5,208 (B194)

Photograph 2: Prickly Pear Creek – Highway 282 South at RS 29,484 (C202)

Photograph 3: Warm Springs Creek – South Highway 282 RS 85 (C257)

Photograph 4: Buffalo Creek – Private Drive at RS 15,538 (B248)

Photograph 5: Clancy Creek – Foot Bridge at RS 1,220 (B252.5)

4.8 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 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 20. 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 20. Manning's 'n' Values

Roughness Area Land Class Type	Manning's 'n' Value Range	Initial Value	Description
Main Channel	0.028 – 0.09	0.050	Gravel, cobbles, well-rounded boulders and bedrock sections.
Pasture	0.036 – 0.142	0.063	Grasses, alfalfa, intermixed with weeds.
Willows	0.051 – 0.148	0.080	Willows with stems of herbaceous vegetation.
Urban-Developed	0.042 – 0.143	0.078	Herbaceous & woody vegetation with manmade structures.
Forest	0.052 − 0.129	0.075	Vegetation is primarily trees and shrubs.

A unique Manning's roughness value of 0.5 was used to represent the zero-flow boundary of the Clancy School for both the 2D and 1D modeling for Clancy Creek. Manning's roughness values for the 2D model development are discussed in more detail in Section 4.10.2 below. The Manning's roughness spatial polygon file required for the 2D model was the basis of Manning's roughness assignment in the Clancy Creek 1D model. Minor adjustments to the roughness values and locations were incorporated into the 1D modeling to yield acceptable results and reasonable profiles in the final model.

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 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 railroad and roadway 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 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 occasionally throughout the hydraulic models. The typical purpose of the blocked obstruction was to fill in the channel of a tributary stream for the Prickly Pear main stem model or to fill in the channel of Prickly Pear Creek for the tributary models when the inclusion of the channel either resulted in unreasonable increases in conveyance area or excluding the channel was needed to develop reasonable flood profile relationships. A unique purpose for the blocked obstruction was representation of the Clancy School building in the Clancy Creek model. The blocked obstruction was utilized in concert with high roughness in the 1D model to simulate the walls of the school building and provide cross section constraints where the bare earth terrain precluded cross section development with end points above the 0.2% AEP water surface elevation. When assigned, the blocked obstruction feature was documented in each model node description as described for the ineffective areas

4.10 Split Flow Modeling

During the hydraulic analysis, split flow reaches were identified on Prickly Pear Creek and Clancy Creek. The Prickly Pear Creek split flow reach was less complex and modeled using1D modeling techniques. The Clancy Creek split flow areas displayed more complex flow patterns and a 2D model was prepared to inform development of the final 1D hydraulic model.

4.10.1 Prickly Pear Creek Split Flow

The Prickly Pear Creek split flow was caused by overbank flooding on the right overbank along natural ground below RS 72,389. The main creek channel and overbank flow path are separated by natural high ground and the ground slope along the main stem of the creek and split flow path have unequal ground slopes, 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 flow split location. The automatic junction optimization routine in HEC-RAS was used to calculate the split flows to each reach. Flood flows were routed down each flow split until the floodplains converged near Prickly Pear Creek RS 70,800. The flow split discharges are summarized in Table 21.

Table 21. Prickly Pear Creek Split Flow Flood Discharges

Location Description	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 +
Prickly Pear Creek above Split Flow location	82549	282	449	622	853	1,630	1,080
Prickly Pear Creek after Split Flow location	72280	282	399	466	530	671	578
Prickly Pear Creek Overbank	1608	0	50	156	323	959	502
Prickly Pear Creek below confluence with Overbank Flow	82549	282	449	622	853	1,630	1,080

4.10.2 Clancy Creek Split Flow 2D Model Development

There are two primary flow splits from the main stem of Clancy Creek. The upper Clancy Creek split flow was caused by insufficient capacity of the culvert under Clancy Creek Road at RS 4,010. This structure was named C256 in the structure inventory by Pioneer. Flood flows overtop Clancy Creek Road on the right overbank and discharge to the Clancy School area. This flood flow path has a secondary flow split at the Clancy School building and flooding is routed back to Prickly Pear Creek on both the north and south sides of the school (Figure 7).

The lower flow split was caused by insufficient capacity of the culvert for North Main Street at RS 1,250. This structure was named B253 in the structure inventory by Pioneer. Flood flows overtop North Main Street on the left overbank and a portion of the overtopping flow is routed north along the roadside ditch for North Main Street. The North Main Street flood flow path does not converge with Clancy Creek. It discharges to the Prickly Pear Creek floodplain at Legal Tender Lane, approximately 460 feet downstream of the mouth of Clancy Creek. As noted above, the flooding patterns for the split flow reaches were complex, and a 2D hydraulic model was prepared to inform development of the 1D hydraulic model.

2D Model Hydrology and Flow Files

The hydrology input was provided as described above from the Hydrology Report completed by Pioneer. Clancy Creek is a relatively short reach and had a single flow rate for the flooding source. Unsteady flow files were prepared for each of the six flood profiles to provide flow change routing needed for the 1D hydraulic model development. The duration of the unsteady flow files was varied in initial model runs to determine a duration that approximated “steady-state” conditions. A warmup period was included in the model plans to wet the model domain prior to beginning the model simulation. The unsteady flow data for each event are provided in Table 22.

Table 22. Unsteady Flow Data for Modeled "Steady-State" Flood Profiles

Date	Time	Simulation Time	10% Flow	4% Flow	2% Flow	1% Flow	0.2% Flow	1%+ Flow
02-04-2020	8:00	0	257	387	497	590	988	1,093
02-04-2020	9:00	1	271	407	514	659	1,040	1,150
02-04-2020	10:00	2	271	407	514	659	1,040	1,150
02-04-2020	11:00	3	271	407	514	659	1,040	1,150
02-04-2020	12:00	4	271	407	514	659	1,040	1,150

The initial time step flow was set at approximately 90-95% of the design flow for each event as iterative model runs demonstrated improved stability when a minor ramp up in flow was specified for the unsteady flow file.

Topographic Data

The terrain data for the 2D model was prepared from the LiDAR terrain collected by Quantum Spatial Inc. under contract with the Montana DNRC (QSI, 2019). The terrain data used for the 2D model was modified to include a low-flow channel at an appropriate elevation required to accurately model the culvert crossings at Clancy Creek Road and North Main Street. The low-flow channel was developed primarily from the targeted bathymetric data which demonstrated that the low-flow channel could be approximated as a rectangular section 12 feet wide and 1.9 feet deep. The typical low-flow channel was adjusted immediately adjacent to the structure crossings to align with the field structure assessment data.

The Clancy School building was scrubbed from the topographic terrain data prepared for floodplain modeling use in accordance with standard practice for bare earth terrain preparation. The Clancy School building is a large structure and obstructs shallow sheet flow type flooding moving from west to east. Since the ground surface did not represent the obstruction created by the building, the building footprint was modeled using a very high roughness value to simulate a zero flow area in the model mesh.

The Horizontal topographic data component was prepared in Montana State Plane coordinate system in units of International Feet in the North American Datum of 1983 (2011). The Vertical topographic data component was prepared in units of US feet referenced to the North American Vertical Datum of 1988.

Model Geometry Development

The 2D hydraulic model was prepared using HEC-RAS v5.0.7. The software GeoHECRAS was used to prepare the hydraulic modeling to take advantage of the improved ability to set up the model mesh which increased model accuracy and preparation efficiency. The 2D model was developed and tuned for the 1% AEP flood flow, which is the regulatory flood used for floodplain administration. The additional FEMA flood profiles were computed to determine split flow rates throughout the model domain, but the geometry was not adjusted or tuned to address minor nuances specific to the non-regulatory flood flow rates.

The basic model mesh was developed using the “Adaptive Mesh” tool in GeoHECRAS. This tool is based on algorithms that evaluate the terrain and proximity to user input mesh elements such as break lines. This tool will prepare a mesh with model cell sizes that increase with distance from user mesh elements and have relatively small terrain variation, reducing the total mesh cells and associated model calculation time. Development of the model mesh was an iterative process, with mesh complexity added for high ground that divided flow paths, primary flow channels, and anthropologic features (e.g. roads, school building). The model mesh development process also included iteration of model flow files building to a “steady-state” final model variable set that demonstrates “steady-state” conditions without unnecessarily long model simulation time. The model was initially developed using the more stable Diffusion Wave equation set and was migrated to the more accurate (but can be more susceptible to instability) Full Momentum equations.

The final model mesh included cell sizes varying from 10x12 feet along roadway and high ground break lines up to roughly 90 feet in width and length in floodplain areas away from flood controlling or directing features such as embankments, roads, hydraulic structures, etc. An element size of approximately 10 feet, parallel to the controlling terrain, was selected for the final model as that cell size yielded stable model calculations. Additionally, many of the residential roads are 20-25 feet wide, and the 10-foot cell spacing fit the embankment terrain variation well. Larger mesh cell sizes, ranging from 20 to 50 feet were used along primary flow path centerlines.

The Clancy Creek floodplain through the area of interest is generally composed of a confined channel with limited flooding in the overbanks. The overflow into the Clancy School area is characterized by smoothly varying terrain (e.g. football field and parking lot) with distinct terrain breaks at transitions from developed areas to either more natural ground or an adjacent developed area. Break lines were used throughout the model domain to increase model density along flow transition areas as necessary to appropriately model flow moving between primary flow paths.

Boundary Conditions

An unsteady flow boundary condition was inserted at the upstream end of the Clancy Creek reach, approximately 1,400 feet upstream (west) of the first flow split at Clancy Creek Road. Flood flow rates were applied to the model mesh at the upstream boundary location for each of the flood profiles noted above. A normal depth downstream boundary condition was inserted at the bottom of the model mesh approximately 200 feet downstream of Legal Tender Lane. The downstream boundary condition was within the Prickly Pear Creek floodplain approximately 700 feet downstream of the mouth of Clancy Creek and separated approximately 1,250 feet as the crow flies from the North Main Street flow split location. The ground slope of 0.0102 feet/feet of the Prickly Pear Creek floodplain below the Legal Tender Lane bridge was applied as the normal depth boundary condition value. Recommended standard engineering practice for 2D hydraulic modeling is to place boundary conditions at least two to three floodplain widths away from the model areas of interest to avoid inadvertently affecting model results with boundary condition assumptions or affects of the model mesh. The floodplain width for the upper reach of Clancy Creek is typically less than 100 feet. The floodplain width for the lower portion of Clancy Creek approaches 450 feet in width. The boundary conditions meet the recommended separation from the areas of interest for the 2D model.

Surface Roughness (Manning's)

A landcover and roughness values were developed for the Clancy Creek area using the same method and rationale applied for roughness development for the 1D hydraulic modeling throughout the Prickly Pear Creek and Tributaries study reaches. In accordance with recent 2D modeling recommendations by the Federal Highway Administration, the roughness values prepared for the 1D modeling were not adjusted for the 2D modeling approach (FHWA 2019). Roughness polygons were generally large areas assigned based on land use and vegetation.

The lawn/pasture-meadow areas of the model were assigned a roughness of 0.06. The riparian areas were assigned a roughness of 0.075. The residential and commercial developed areas were assigned a roughness of 0.075 as well. The forest areas in the upper portion of the model were assigned a roughness of 0.07. The low-flow channel area of Clancy Creek was assigned a roughness of 0.046. As noted above, Clancy School significantly influences the flood flow paths in the upper split flow area. A roughness value of 0.5 was assigned to a polygon representing the footprint of the Clancy School building to simulate a zero-flow area since the building was removed from the LiDAR data during bare-earth terrain development.

Lateral Flow/Flow Split

Lateral flow split routing was defined by assigning break lines along ground topography separating flow paths to align cell faces with the topography controlling flow. Standard 2D modeling calculation between model mesh elements was used rather than the 2D Connection model feature. This approach allows the model to calculate the flow split relationship without requiring the modeler to estimate a weir coefficient for the flow over irregular topography.

Clancy Creek Road and North Main Street Culverts

The 2D Connection model feature was used to model the road crossings at Clancy Creek Road and North Main Street. The 2D Connection features allowed inclusion of the culvert openings through the embankment in the 2D modeling analysis. The 2D Connection feature was truncated to the general vicinity of the culvert. The culverts were inserted into the embankment based on the information provided in the structure assessment completed by Pioneer (Pioneer 2019). See Section 4.7 above for details and discussion of the culverts at these road crossing locations. Overtopping weir coefficients were set to the typical 1D hydraulic model value of 2.6. Break lines were used to align mesh elements with the roadway centerline and roadway overtopping along the remainder of the roadway was computed in the normal 2D computation environment between mesh elements.

Model Plan Variables and Sensitivity Analyses

The time step was varied through model development as complexity was increased to included 2D Connection nodes and mesh element refinement along flow controlling features.

The selected model time step is two seconds. The two-second time step generally results in Courant Numbers less than one throughout the model domain. Review of recent literature indicates that the Courant Number limitations are less applicable for Unsteady models used to approximate Steady-State conditions, as changes in the amount of flow and associated velocities and water surface elevations do not occur in a stable model. Additionally, sensitivity analysis for time steps as low as 0.5 seconds, which yields Courant Numbers below 1 throughout the entire modeling domain, indicated that model results of interest (flow split to Clancy School and spatially averaged water surface elevations) were not affected at the selected two-second time step. The two-second time step was selected to minimize run times, facilitate sensitivity analyses, and to minimize time required for analysis review.

Several variables were adjusted from the HEC-RAS default settings. The default settings for a HEC-RAS 2D model are generally set to provide model stability for initial model development. These variables should be adjusted for each model to fit the characteristics of the area being studied. The three variables relating to weir submergence damping were increased to the median value of 2.0 to resolve model instabilities related to very shallow weir overtopping along portions of North Main Street.

The final model was prepared using the Full Momentum equations with a theta value of 0.6, which yields the most accurate results while increasing the potential for model instability. Several model runs were required during development of the 2D model geometry to allow for adjustment of the computational mesh required to address problem areas and to produce the minimum theta value. Sensitivity analysis of theta values and use of the Diffusion Wave computational approach yielded minor improvements to the minimum theta value. Since the model was stable with the minimum theta value and model run times were acceptable, the Full Momentum equation set with the 0.6 theta was carried forward for final model preparation.

The Eddy Viscosity coefficient can be described as a variable with similar effects as the contraction and expansion coefficients in a one-dimensional model. Typically, a higher value for the Eddy Viscosity coefficient increases accuracy in numerical model results for backwater eddy flows, velocities in areas of flow contraction and expansion, and water surface elevations in areas of contraction and expansion. While the Clancy Creek topography terrain could be characterized as moderately variable on a micro topography scale, the terrain changes across the valley are relatively gradual.

The modeled water surface elevations and split flow rates were insensitive to increasing the Eddy Viscosity coefficient in areas of contraction and expansion adjacent to the flow split control features on Clancy Creek Road and North Main Street. Increasing the Eddy Coefficient increased model run time and numerical instability resulting in computational errors in higher velocity mesh elements. Since the flow split computed by the model was insensitive (less than 1% change in split rates) to the increased Eddy Viscosity coefficient, a value of 0.0 was carried into final model development.

Surface roughness, (Manning's Values) were also tested for model sensitivity. A change of ± 20% in the Manning's roughness values were evaluated. The model was relatively insensitive to the global roughness changes with flow rate to the Clancy School split flow area across Clancy Creek Road varying less than 10 cfs for each alternative. Therefore, the initial roughness values were carried into final model development.

2D Modeling Results Summary

The 2D model was run for a duration of four hours. Constant flow, representing "steady-state" conditions was achieved approximately halfway through the four-hour model simulation time at the downstream flow boundary.

The 2D modeling demonstrated the shallow sheet flow style flooding in the Clancy School upper split flow area and provided clarity for primary flow paths for creation of the 1D hydraulic model. As shown in Figure 7 below, the split flow originates with overtopping of Clancy Creek Road south of the main Clancy Creek Channel. More than one-half the flow from the Clancy Creek flooding source cannot be conveyed by the culvert and is routed to the Clancy School split flow path (Table 23 & Figure 9).

Figure 7. Clancy Creek Upper Flow Split – 2D Model Flow Patterns

As shown in Figure 7, most of the flood flow in the Clancy School flood area is conveyed east to the school ball fields through a topographic depression in the southwest corner of the Clancy School ball fields. Shallow flooding typically less than one foot in depth is routed across the ball fields in the east by north east direction with an initial flood flow return to the main channel of Clancy Creek near the midpoint of the football field encircled by the track. The bulk of the shallow flooding is divided by the Clancy School and routed to Clancy Creek either along the topographic depression immediately north of the school or through the parking lot south of the school and across the playground area where it discharges back to Clancy Creek.

As described above, the topographic elevation data was scrubbed to an approximate bare earth model elevation at the Clancy School. The terrain data indicates that the walls of the school could be at risk of flood water elevations around one foot in depth at the western end of the campus. The topography slopes down to the Clancy Creek floodplain around the building to both the north and south. Site survey would be required to determine the flood risk relationship between the flood water surface elevations and the finished floor elevation of Clancy School.

The lower flood flow split is smaller in magnitude, with most of the flow overtopping North Main Street returning to Clancy Creek within approximately 250 feet. Approximately 3% of the 1% AEP flow is routed in the North Main Street western roadside ditch and does not return to Clancy Creek.

Figure 8. Clancy Creek Lower Flow Split – 2D Model Flow Patterns

While the flood flow rate to the North Main Street alignment is relatively small, it does represent a flood risk for the residences along North Main Street and for the structures along Legal Tender Lane, which is approximately 1,000 feet north of the split flow divergence shown in Figure 8 (see Figure 9 or Clancy Creek work maps).

4.10.3 Clancy Creek Split Flow – 1D Model Development

As mentioned above, the purpose of the 2D model is to provide clarity on the split flow flood flow rates and to demonstrate flood flow patterns. These two inputs allow efficient development of 1D modeling since flood flow rates can be directly assigned in the model. Additionally, 1D model cross sections can be constructed that are perpendicular to the flood flows and confirm that the 1D constraint of a single flood elevation across a cross section is appropriate by orienting cross sections parallel to 2D model water surface elevation contours.

Evaluation of the 2D hydraulic model indicated three split flow reaches were required to capture the complexity of the split flow flood patterns (Figure 9). The upper split flow reach is named Clancy School 2. The Clancy School 2 split flow path routes flow from the divergence from Clancy Creek west of Clancy Creek Road across the Clancy School ball fields to a convergence with Clancy Creek immediately north of the Clancy School. As noted above, flow diverges from the Clancy School ball fields area at the western end of the Clancy School building. The Clancy School 1 split flow path routes flow from the western end of the Clancy School south through the parking lot then through the playground area immediately east of Clancy School where it converges with the Clancy Creek floodplain approximately 200 feet east of the school building. The lower split flow reach is named North Main Street Ditch. This split flow path routes flow along the western roadside ditch of North Main Street for approximately 800 feet prior to overtopping North Main Street. After overtopping North Main Street, flow is routed to the southern side of Legal Tender Lane prior to discharging to Prickly Pear Creek.

Cross sections for the 1D hydraulic model were aligned perpendicularly to the general flood flow direction indicated by the 2D modeling. In some cases, complexity was added to the cross section to better align with both flow patterns and the water surface elevation contours indicated in the 2D model. Cross sections were generally placed to yield coincident end points between the separate flood reaches. This is a standard modeling practice utilized for 1D model development to assist in accurate flow tracking, flow assignment/calculation, and lateral weir placement. A low-flow channel was inserted into the 1D cross sections to represent the flow area indicated by comparing the targeted bathymetric section with the terrain data. The low-flow channel was approximated as a rectangular area 12 feet wide by 1.9 feet deep. The low-flow channel was altered to fit field inventory structure measurements as needed for cross sections bounding hydraulic structures.

Hydraulic structures were modeled as described in Section 4.7 above. The inline weir hydraulic structure feature was selected to represent Clancy Creek Road for the Clancy School 2 split flow path. The weir coefficient was adjusted to yield water surface elevations and elevation relationships between the Clancy Creek and Clancy School 2 flow paths above Clancy Creek Road as was calculated in the 2D model results for the 1% AEP flood profile.

Flow rates for the split flow flooding within the Clancy Creek reach were extracted from the 2D model using profile lines. The profile lines were aligned with cross sections. The flow logic included measurement of flood flow rates at cross sections associated with the split flow path. The flood flow in the split flow path was subtracted from the associated cross section in the flood source reach to ensure conservation of flow throughout the model domain. Within the portion of the model where the Clancy Creek, Clancy School 2, and Clancy School 1 reaches simultaneously convey the combined flood flows, minor adjustments (< 5 cfs) to flow rate results from the 2D model were made to maintain conservation of flow. The flow value indicated by the 2D model was assigned to the cross section as a flow change in the 1D hydraulic modeling flow file.

Lateral weirs were inserted in the 1D hydraulic model at the lateral flow divergence and convergence locations for the 1% AEP profile. Lateral weirs were also placed at locations where cross section end points were insufficient to contain the 0.2% AEP flood profile to meet FEMA modeling requirements and standard engineering practice. The 1D hydraulic model does not actively optimize the flow rate across the lateral weirs separating the split flow reaches.

Junction nodes were utilized at convergence of split flow reaches with Clancy Creek. Flow lengths across the junction were adjusted to represent the centerline flow path of flood flows rather than the profile baseline alignment distance as appropriate. The Energy Equation was selected as the junction computation mode.

The cross sections on Clancy Creek and Clancy School 1 forming the upstream bounding cross sections for the junction node were placed with coincident endpoints and at appropriate distances from the downstream cross section to yield equal water surface elevations at the 1% AEP flood. These cross sections allowed computation of reasonable flood profile relationships for all profiles. At the common end point for each cross section, the cross section ground elevation does not meet the typical 1D modeling requirement for cross section end points to be above the 0.2% water surface elevation.

As described above, the flow rates were extracted from the 2D model and hard-coded within each stream reach in the steady flow data for the 1D model. The water budget for the split flow is provided in Table 23 for all profiles. The split flow relationships are illustrated for the 1% AEP profile in the flow diagram shown on Figure 9.

As noted above in the 2D model development discussion, a roughness value of 0.5 was assigned at the location of the Clancy School to represent the zero-flow boundary of the school building. In the 1D model, both the roughness value of 0.5 and the blocked obstruction feature were utilized to represent the school building walls. The increased roughness value was set just outside the blocked obstruction to eliminate the frictionless boundary of the blocked obstruction. Due to the unusual nature of the flooding around the school, cross sections do not meet the requirement for cross sections end points above the 0.2% AEP water surface elevation. The required elevation and flow bounding were provided with the blocked obstruction feature at the approximate location of the cross section intersection with the school walls.

The 2D model indicates flow overtopping North Main Street in excess of the conveyance capacity of the North Main Street Ditch is routed through the developed area east of North Main Street (Figure 8). This flow complexity is not duplicated in the 1D hydraulic model, since the cross sectional conveyance area of the floodplain immediately below (east) of North Main Street has sufficient capacity to route flood flows without flooding in the residential area shown in the 2D modeling. Therefore, all flow overtopping North Main Street was applied to cross section 1,181 (Figure 9), which is slightly more conservative for final floodplain development within the main stem reach of Clancy Creek. The flood risk in the developed area east of North Main Street from the Clancy Creek Floodplain to the intersection between North Main Street and West Cherry Street is captured with a shallow flooding map area (Zone AO). Based on 2D model results, a shallow flooding depth of one foot or less is recommended for the flood mapping in this shallow flooding area.

Table 23. Clancy Creek Split Flow Data Summary

Clancy Creek Split Flow Data Summary

Plan: Clancy Creek MultipleProfile

Recurrance Interval		Clancy Creek River Station													
		5676	4064	4046	3971	3827	3644	3509	3194	2986	2558	2017	1268	1181	119*
Flow Rate (cfs)	10% AC	271	248	180	177	175	175	175	197	205	232	271	261	262	262
	4% AC	407	350	214	203	193	193	195	246	269	337	407	388	392	393
	2% AC	523	434	250	232	213	213	219	296	336	434	523	499	504	506
	1% AC	659	520	278	248	218	219	233	348	413	550	659	627	637	640
	0.2% AC	1040	737	371	312	258	267	294	519	647	876	1,040	987	1,008	1,015
	1%+ AC	1150	794	400	331	273	284	315	575	719	972	1,150	1,090	1,115	1,123

* Clancy Creek flows reduced from source flooding flow by amount routed to Prickly Pear Creek along North Main St split flow

Recurrance Interval		North Main Street Ditch River Station							
		1622	1458	1369	1153*	307**	241**	181**	119
Flow Rate (cfs)	10% AC	0.001	10	9	9	7	5	2	1
	4% AC	0.001	19	15	14	11	8	3	1
	2% AC	0.001	24	19	17	12	9	3	1
	1% AC	0.001	32	22	19	14	10	4	1
	0.2% AC	0.001	53	32	25	17	13	5	2
	1%+ AC	0.001	60	35	27	19	14	5	2

* Flow downstream of RS 1,153 discharges to Prickly Pear Creek floodplain below confluence of Clancy Creek

** Δ flow from upstream RS discarded from modeling to Prickly Pear floodplain north of Legal Tender Lane

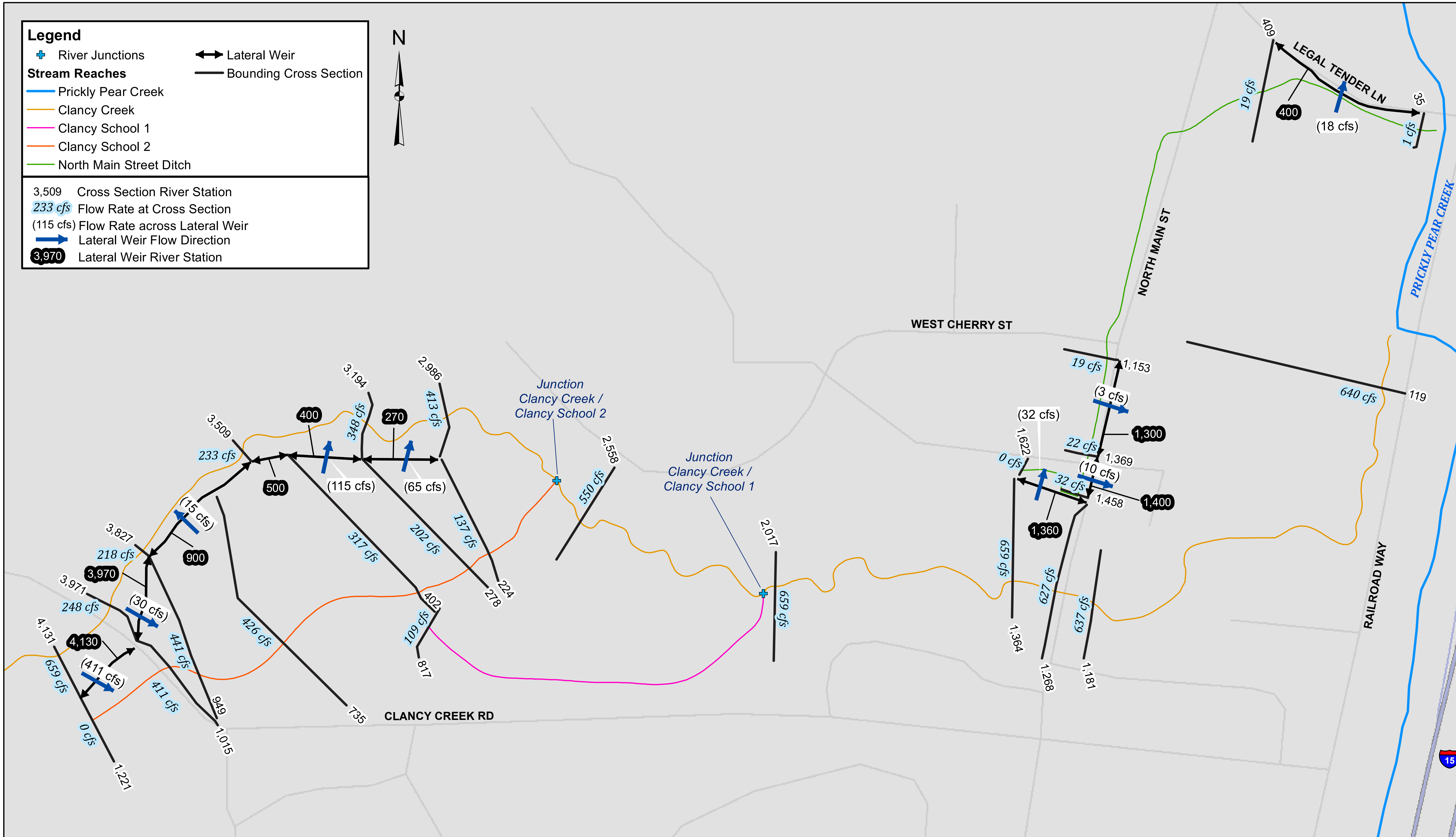
Recurrance Interval		Clancy School R 1 RS
		871
Flow Rate (cfs)	10% AC	39
	4% AC	70
	2% AC	89
	1% AC	109
	0.2% AC	164
	1%+ AC	178

Recurrance Interval		Clancy School Reach 2 River Station									
		1221	1117	1062	1015	949	868	735	402	278	224
Flow Rate (cfs)	10% AC	0.001	23	91	94	96	96	96	57	35	27
	4% AC	0.001	57	193	204	214	214	212	142	91	68
	2% AC	0.001	89	273	291	310	310	304	215	138	98
	1% AC	0.001	139	381	411	441	440	426	317	202	137
	0.2% AC	0.001	303	669	728	782	773	746	582	357	229
	1%+ AC	0.001	356	750	819	877	866	835	657	397	253

Lateral Weir Flow Data Summary Table

Recurrance Interval		Clancy Creek RS			Clancy School 2 RS			North Main Street Ditch RS		
		4130	3970	1360	900	400	270	1400	1300	400
Flow Rate (cfs)	10% AC	94	2	10	0	22	8	1	0	8
	4% AC	204	10	19	2	51	23	4	1	13
	2% AC	291	19	24	6	77	40	5	2	16
	1% AC	411	30	32	15	115	65	10	3	18
	0.2% AC	728	54	53	36	225	128	21	7	23
	1%+ AC	819	58	60	42	260	144	25	8	25

Note: Conservation of flow was confirmed at the downstream boundary of all Lateral Weir nodes where cross section end points aligned between reaches.



1 inch = 200 feet

0 200 400 800 Feet

Morrison Maierle
engineers • surveyors • planners • scientists

1 Engineering Place
Helena, MT 59602

Phone: (406) 442-3050
Fax: (406) 442-7862

R:\1447\052_Mad_Jeff_Riv_Surv_PPC_Map\GIS\Exhibits\Hyd Summary Report\Figure_9.mxd

DRAWN BY: BNC
CHK'D BY: LDC
APPR. BY: LDC
DATE: 6/4/20

Prickly Pear Creek Tributaries
1% AEP Discharges

Clancy Creek Flow Diagram Map

PROJECT NO.
1447.052

Figure 9

The flood flows conveyed in the North Main Street Ditch reach north of West Cherry Street do not return the Clancy Creek floodplain. Therefore, the flood flow values for Clancy Creek below the crossing of North Main Street are less than the flood source values provided for the Clancy Creek reach.

The terrain south of Legal Tender Lane is very flat, allowing access to the Legal Tender Bar and Grill parking areas from the road. The flood flows conveyed by the North Main Street Ditch flow path overtop Legal Tender Lane opposite the Legal Tender Bar and Grill over approximately 300 feet of roadway. This condition is represented by a lateral weir from North Main Street Ditch RS 35 to 409. Flows leaving the model domain across Legal Tender Lane enter the Prickly Pear Creek floodplain and were discarded from the hydraulic model.

4.10.4 Worst Case Scenario Discussion

Worst case scenario evaluation may be pursued in floodplain modeling to capture flood risk along alternate flow paths if the feature causing a flow split were to fail or be altered in a way to change the flow rate along separate flow paths. Worst case scenario evaluation is typically conducted when the feature causing or influencing a flow split is anthropogenic (levee, road embankment, irrigation diversion, etc.). For the split flow along Prickly Pear Creek, the flow split occurs along a natural overbank high ground separated flow path. The split flow approach represents the likely worst case scenario.

As discussed above, there are two primary split flow paths along the Clancy Creek study reach. Clancy Creek Road crosses the floodplain roughly perpendicularly to flood flow upstream of the Clancy School area, causing the upper flow split. The culvert under Clancy Road is too small to pass flood flows and flow overtops the roadway along the right overbank into the Clancy School area. As shown in Figure 9, the Clancy Creek primary channel is too small to pass all flood flows downstream of Clancy Creek as well, and a small component (30 cfs) of flow moves from the Clancy Creek main channel to the Clancy School area immediately downstream of Clancy Creek Road. Since the overbank flow to Clancy School would occur even if the Clancy Creek Road embankment and culvert were removed from the hydraulic model, the split flow to Clancy School reasonably represents the worst case flooding along both flood reaches. The secondary split flow around the Clancy School building is not influenced by hydraulic structures or other embankments. The flow split around the school reasonably represents the worst case flooding for that area.

The lower flow split is caused by the North Main Street road embankment. Flow overtopping North Main Street but not flowing along the northern roadway ditch was added back into the model immediately downstream of the roadway instead of tracking it along the shallow flooding flow path through the developed area east of the roadway. This approach captured the worst case flood flow rate in the Clancy Creek main channel segment downstream of North Main Street. The flow diverted to the North Main Street ditch flow path is minor. Adding the 20 cfs to the main channel of Clancy Creek would not influence flood risk elevations by more than the significant digit rounding (0.1 feet) for reporting flood risk. Therefore, the split flow analysis computed along the two reaches in this area reasonably represents the worst case flooding along these flow paths.

4.11 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 aligns 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 has a steep gradient or where a flow regime change could occur. In accordance with FEMA guidance and engineering standard practice for floodplain studies, these models have been completed using sub-critical calculation routines in HEC-RAS.

Profile smoothing is required where minor numerical modeling 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, and modeling variables are 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. The 1%+ AC crosses below the 1% AC profile at RS 71,119. After attempting to resolve the cross section using standard engineering practice, it was left as is because the profiles due not cross when reported at the precision required by FEMA Guidance and Standards. Therefore, profiles do not cross when presented in the profile panels for the study.

Table 24. 1% AC Profile Smoothing River Stations

Tributary Reach	River Station (feet)	Reason for Profile Smoothing
Prickly Pear Creek	18640	Drawdown within structure
Prickly Pear Creek	24063	Drawdown within structure
Prickly Pear Creek	58039	Drawdown within structure
Prickly Pear Creek	67417	Drawdown within structure

4.12 Model Calibration

Stream gage data at USGS gage 06061500 Prickly Pear Creek near Clancy, Montana was used to compare the HEC-RAS model for the Prickly Pear Creek analysis. Reference marks for the USGS gage were surveyed in May 2019 by Pioneer Technical Services, Inc., (Pioneer, 2018c). Water surface elevations were calculated for the highest available flow records based on the USGS gage height records and the 2019 Pioneer survey in NAVD88 datum. The Prickly Pear Creek model water surface was within 0.12 feet for the peak flow rate of 1,200-cfs recorded on June 19, 1975. The modeling results for Prickly Pear Creek are reasonably calibrated for the purposes of a floodplain study.

Table 25. Prickly Pear Creek Calibration Results

Event Year	Gage Height (FT)	Peak Streamflow (CFS)	Gage Elevation (FT)	Model Elevation (FT)	Difference (Model-Gage)
1975	6.56	1200	4077.01	4077.13	0.12
2011	5.37	1030	4075.82	4076.68	0.86
1981	8.82	2300	4079.27	4079.63	0.36

This was the only gage calibration data available for the Prickly Pear Creek and Tributaries flood study. The other four tributary reaches were generally similar in land use and geomorphic setting to Prickly Pear Creek. Therefore, the modeling parameters selected for Prickly Pear 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 1975, 1981, and 2011 floods. The floodplain mapping generally appeared to be consistent with the available flooding photos/imagery and floodplain extent interpretation.

4.13 Floodways

Floodways for the Jefferson County Modernization Prickly Pear Creek and Tributaries floodplain study were not included in accordance with the FEMA/Montana DNRC Mapping Activity Statement (MAS) 2018-02 scope of work.

The hydraulic model for Prickly Pear Creek lower reach includes a floodway plan with encroachment stations at Lewis and Clark County cross section BT and at Jefferson

County cross section A to reflect the floodway analysis and delineation included in the Lewis and Clark County FIS. The floodway encroachment width at Lewis and Clark County cross section BT was set the same as the floodway width reported in the Lewis and Clark effective FIS floodway data table. The floodway encroachment width at Jefferson County cross section A was set based on the effective Lewis and Clark County mapped floodway width. The modeled floodway width meets the modeled to mapped width requirement to be within 5% of the Jefferson County FIRM panel scale of 1,000:1. Discussion of map presentation of the floodway is included in section 5.2.

4.14 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 Prickly Pear 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 IN:200 FT and 1 IN:10 FT respectively for Unnamed Tributary, Prickly Pear Creek, Prickly Pear Creek Overbank, and Buffalo Creek. Horizontal and vertical scales were selected at 1 IN:100 FT and 1 IN:5 FT respectively for Warm Springs Creek, Clancy Creek, Clancy School 1, and Clancy School 2. The selected scale for North Main Street Ditch was 1 IN:100 FT Horizontal and 1 IN:2 FT vertical. The horizontal and vertical scales were selected to provide profile panels where all six flood profiles could be distinguished while limiting the total number of profile panels.

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. North Main St. Ditch profile panels 16P-17P). 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 five primary stream reaches and the associated split flow reaches are provided in Appendix B.

Drawdowns (hydraulic jumps) occur for non-regulatory 1%+ and 0.2% AC profiles at Prickly Pear Creek RS 46,747 46,776, which are the downstream face and immediately downstream of the Lump Gulch Road. This location of the model was very sensitive to modeling variable changes. The model was tuned to reasonably represent the 1% AC regulatory flood event. These drawdowns remain in the hydraulic simulation, but they were smoothed to reasonable profile relationships in the profile panels.

A drawdown (hydraulic jump) occurs for the non-regulatory 0.2% AC flood profile at Prickly Pear Creek RS 58,039 just upstream of an I-15 North and South hydraulic structure crossing. This location of the model was very sensitive to modeling variable changes. The model was tuned to reasonably represent the 1% AC regulatory flood event. The drawdown remains in the hydraulic simulation, but it was smoothed to a reasonable profile relationship in the profile panel.

At Prickly Pear Creek RS 65,678 – 65,999, just upstream of a small Private Road bridge, the 1%+ AC profile crosses below the 1% AC profile by 0.02 feet. This location of the model was very sensitive to variable changes. The model was tuned to reasonably represent the 1% AC regulatory flood event. When the simulated water surface elevations for the two profiles are rounded to the FEMA mandated precision of 1/10th foot, the reported water surface elevations are equal, and the profiles do not cross. The minor crossing profile remains in the hydraulic simulation but does not appear on the profile panels due to the precision at which data is reported for a FEMA floodplain study.

4.15 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. The cHECk-RAS software was programmed for HEC-RAS v4.1.0. Several messages in cHECk-RAS appear to be related to the loss of 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 Prickly Pear 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 D 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 Digital Elevation Model with a separate Digital Elevation Model (DEM) representing the water surface elevations of the 1% and 0.2% annual-chance events. The results of the hydraulic modelling and topographic data were 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 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 were removed from the work maps for clarity due to the dense placement required for the numerical model. Node names were 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% annual-chance water surface profile and less than one-half acre in size were not delineated. 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)
Warm Springs Creek	14131	4472
Prickly Pear Creek	66895	4352
Prickly Pear Creek	66340	4348
Prickly Pear Creek	74543	4423
Prickly Pear Creek	76626	4451
Prickly Pear Creek	80722	4484
Prickly Pear Creek	80472	4493

Table 26. Backwater Elevation Summary (Cont.)

Tributary Reach	River Station (feet)	1% AC (WSE)
Prickly Pear Creek	80256	4489
Prickly Pear Creek	80058	4488
Prickly Pear Creek	79842	4486
Prickly Pear Creek	79648	4483
Prickly Pear Creek	79468	4482
Prickly Pear Creek	79279	4478
Prickly Pear Creek	79199	4476
Prickly Pear Creek	79035	4474

There are two locations along Prickly Pear Creek where it was determined that flooding should be mapped to provide the communities with the increased risk in these areas even though the model does not show water in the area. The first area is from RS 53,488 to 58,167. At cross section 58,167 Prickly Pear Creek makes a 90-degree bend and flows under the interstate, however the 0.2% AC profile overtops the roadway berm resulting in a small flow down the west side of I-15 until it reaches cross section 53,488 and recombines with the mainstem of Prickly Pear Creek.

The second area is from RS 78,906 to 81,173. At cross section 81,173 Prickly Pear Creek makes a 90-degree bend and flows under the interstate, however, the 0.2% AC profile overtops the berm resulting in a small flow down the west side of I-15 until it reaches cross section 78,906 where the terrain becomes pinched and water is unable to flow downstream. A culvert located near RS 79,586 has the potential to connect the flows on the east and west side of I-15. Therefore, the west side of I-15 was mapped with BFEs that matched the corresponding cross sections on the east side of I-15. This area is included in the Backwater Elevation Summary Table 26 above.

5.2 Map Tie-in Locations

The Prickly Pear Creek and Tributaries study ties in on the downstream end to the effective mapping for Lewis and Clark County. The FIRM panel scales between the Lewis and Clark County effective FIRM map and the FIRM scale approved Jefferson County basemap are different. The effective scale for Lewis and Clark County is 1 IN = 500 FT and the approved scale for Jefferson County was 1 IN = 1,000 FT. The mapping tie-in tolerance of 50 feet was determined by using 5 percent of Jefferson County scale. The floodplain mapping products included with this submittal fully exceed the effective mapped stream lengths for this area of Jefferson County and will replace all effective Zone A floodplain mapping for Prickly Pear Creek and Unnamed Tributary.

Montana DNRC prefers floodplain mapping tie-in at jurisdictional boundaries to be “snapped” to the adjacent effective floodplain mapping. The effective floodplain mapping in Lewis and Clark County was delineated based on USGS 24k contour mapping and visual observations and is not based on a hydraulic model cross section at the county line. The terrain data collected for the Jefferson County flood study project does not align well with the effective Lewis and Clark County floodplain mapping. The floodplain mapping prepared for Jefferson County was adjusted to the full extents allowed within the FEMA Standard to complete new mapping which maintains mapped and modeled widths as the greater of 5% of the FIRM panel scale or 5% of the modeled width. The floodplain mapping proposed for Jefferson County does not “snap” to the effective floodplain mapping for Lewis and Clark County, but it does tie in within 50 feet for all mapped flood zones.

A supplemental floodplain mapping delineation spanning approximately 130 feet between the Lewis and Clark County cross section BT and the county line was prepared to represent the best available information for flood risk. The supplemental flood hazard mapping does “snap” to both the effective floodplain mapping for Lewis and Clark County at cross section BT and to the Jefferson County floodplain mapping at the county line. The updated portion of the floodplain mapping lies within Lewis and Clark County.

5.3 Floodplain Boundary Smoothing

Floodplain Boundary Smoothing was completed as part of the Floodplain Mapping task. It 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 September of 2018. Floodplain smoothing will be 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 Prickly Pear Creek and Tributaries study reaches, final regulatory mapped widths were expanded to a minimum of 30 feet (3% of the FIRM panel scale). Most of the 0.2% AC floodplain was a very narrow fringe along the regulatory floodplain and was 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 were 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 were documented in the review checklists as part of the Floodplain Mapping task scope of work.

5.4 Floodplain Islands and Disconnected Ponding

Floodplain islands are occasionally included in the floodplain mapping. Typically, these areas were relatively large, blocky areas of natural high ground that was 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.

On Clancy Creek, there were areas along the Clancy School split flow paths that are above the computed water surface elevation in the 1D hydraulic model (e.g. Clancy School building footprint, ball fields). These areas were mapped into the floodplain as the shallow flooding through the area would be dynamic during a flood event and the 1D cross sections do not necessarily capture all the nuances of minor braided flood flow paths indicated in the 2D modeling. Additionally, the Clancy School footprint is represented as a scrubbed building in the bare-earth terrain. Finished floor elevations for the school are unknown and the hydraulic modeling indicates approximately a foot of inundation which could present a risk to the structure. Mapping of the entire area within the floodplain is recommended due to the potential for inundation. Pursuit of a Letter of Map Amendment to remove the school structure from the special flood hazard area based on structure specific elevation information could be evaluated by the community.

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 occurred 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. Prickly Pear Creek RS 79,000 to 81,000).

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 during the Floodplain Mapping task as requested by the DNRC. CSLF spatial files will be provided in the Supplemental Data folder of the digital submission of the Floodplain Mapping task.

5.6 Letters of Map Change

A review was made of the Letters of Map Change (LOMC) along the Prickly Pear 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. No LOMC along the Prickly Pear Creek and Tributaries study reaches were found in a search of FEMA records.

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 are deleted from the floodplain boundary at study termination where the boundary was perpendicular to the flood flow direction. When an initial FBS Audit results in a pass rate greater than the required 85% threshold, the 38-foot radius horizontal tolerance additional check is not required. FBS Audit summary reports were included in Appendices and test point shapefiles were 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%, 1plus, & 0.2% AC) as part of the Floodplain Mapping Task. 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 were 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%-plus, and 0.2% annual-chance water surface elevations were created using FEMA's RASPLOT software (FEMA 2015). Additional information, edits and formatting were made using AutoCAD. 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 FIS Report folder under the Task Documentation folder of the digital submission.

7.0 References

1. CivilGEO Engineering Software, (CivilGEO). *GeoHECRAS,* Copyright ©, 2020.
2. Environmental Systems Research Institute (ESRI). *ArcGIS Desktop: Release 10.7,* June 2019.
3. Federal Emergency Management Agency (FEMA). *cHECk-RAS, Version 2.0.1*, 2013.
4. Federal Emergency Management Agency (FEMA). *RASPLOT, Version 3.0*, April 2015.
5. Federal Emergency Management Agency (FEMA). *Flood Insurance Study, Lewis and Clark County, Montana and Incorporated Areas*, September 2012.
6. Federal Emergency Management Agency (FEMA). *Guidance for Flood Risk Analysis and Mapping, Flood Profiles,* November 2016a.
7. Federal Emergency Management Agency (FEMA). *Guidance for Flood Risk Analysis and Mapping, General Hydraulics Considerations,* November 2016b.
8. Federal Emergency Management Agency (FEMA). *Guidance for Riverine Flooding Analyses and Mapping, Hydraulics: One-Dimensional Analysis,* November 2016c.
9. Federal Emergency Management Agency (FEMA). *Guidance for Riverine Flooding Analyses and Mapping, Hydraulics: Two-Dimensional Analysis,* November 2016d.
10. Federal Emergency Management Agency (FEMA). *State of Montana DNRC Cooperating Technical Partners (CTP) Flood Risk Project Mapping Activity Statement (MAS): MAS No. 2018-02 (Jefferson Countywide – Modernization)*, July 17, 2018.
11. Federal Highway Administration (FHWA). *Two-Dimensional Hydraulic Modeling for Highways in the River Environment*, October 2019.
12. Kleinschmidt Group Inc., *The RAS Solution*. *The Place for HEC-RAS Modelers*, Copyright ©, Kleinschmidt Group Inc., 2020.
13. Montana Department of Natural Resources and Conservation (DNRC). *2014 Model Regulations*, February 20, 2014.
14. Pioneer Technical Services, Inc. (Pioneer). *Jefferson County Map Modernization Project Jefferson County, Montana, Hydrologic Analysis Report,* October 31, 2019a.
15. Pioneer Technical Services, Inc. (Pioneer). *Jefferson Countywide Modernization Field Reconnaissance and Hydraulic Structure Assessment,* May 30, 2019b, Revised May 2020.
16. Pioneer Technical Services, Inc. (Pioneer). *Jefferson Countywide Modernization Structure and Bathymetric Survey Report*, May 30, 2019c.
17. Quantum Spatial, Inc. (QSI). *Jefferson County, Montana LiDAR, LiDAR Technical Data Report,* October 11, 2019.
18. United States Army Corps of Engineers (USACE). *HEC-RAS 5.0.7,* March 2019a.
19. United States Army Corps of Engineers (USACE). *HEC-RAS 2D Modeling User's Manual, Version 5.0*, February 2016a.

20. United States Army Corps of Engineers (USACE). *HEC-RAS Hydraulic Reference Manual, Version 5.0*, February 2016b.
21. United States Army Corps of Engineers (USACE). *HEC-RAS Release Notes, Version 5.0.7*, March 2019.
22. United States Army Corps of Engineers (USACE). *HEC-RAS User's Manual, Version 5.0*, February 2016c.
23. United States Department of Agriculture (USDA). *National Agricultural Imagery Program (NIAP)*, aerial photographs 2017.
24. United States Department of Agriculture (USDA), United States Forest Service (USFS). *USFS General Technical Report RMRS-GTR-323, Photographic Guidance for Selecting Flow Resistance Coefficients in High-Gradient Channels (S ≥ 0.02)*, July 2014.
25. United States Geologic Survey (USGS). *Adjusted peak-flow frequency estimates for selected streamflow-gaging stations in or near Montana based on data through water year 2011: U.S. Geological Survey (USGS) Scientific Investigations Report (SIR) 2015-5019-D,* V. 1.1 February 2018.
26. United States Geologic Survey (USGS). *Guide for selecting Manning's roughness coefficients for natural channels and flood plains, Water-Supply Paper 2339,* March 1982.
27. United States Geologic Survey (USGS). *Determination of roughness coefficients for streams in Colorado, Water Resources Investigation Report 85-4004,* 1985
28. United States Geologic Survey (USGS). *Methods for estimating peak-flow frequencies at ungaged sites in Montana based on data through water year 2011, Scientific Investigations Report (SIR) 2015-5019-F*, V. 1.1 February 2018.
29. United States Geologic Survey (USGS). *Methods for peak-flow frequency analysis and reporting for streamgages in or near Montana Based on data through water year 2015: U.S. Geological Survey (USGS) Scientific Investigations Report (SIR) 2018-5046*, 2018.
30. United States Geologic Survey (USGS). *Peak-flow frequency analysis for 11 selected streamgages in Jefferson County, Montana, based on data through water year 2017: U.S. Geological Survey data release, https://doi.org/10.5066/P9TK3KFE*, 2019.