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Clark Fork River Floodplain Study – Phase I

Clark Fork River Hydrologic Analysis

Montana DNRC

July 26, 2017

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Clark Fork River Hydrologic Analysis

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July 26, 2017

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

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EXECUTIVE SUMMARY

Flood flow frequency calculations were conducted for a 55-mile reach of the mainstem Clark Fork River. The study reach extends from the Mineral\Missoula County border, 1 mile east of Alberton, Montana, to the Mineral\Sanders County border, approximately 8 miles northeast of St. Regis, Montana. Information gathered from this analysis will be used for future floodplain studies and mapping projects.

The hydrology of the basin is primarily snowmelt driven, although significant flows can result from precipitation events. Land use in the Clark Fork River basin is primarily agricultural with irrigated farming and ranching operations.

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

Clark Fork River basin elevations within the study area range from over 7,600 feet in the mountains to approximately 2,570 feet at St. Regis. The watershed terrain varies from a high alpine environment at the river's headwaters to narrow, inter-mountain valleys in the main reach. The hydrology of the basin is primarily snowmelt driven.

The primary cause of flooding on the Clark Fork River is spring snowmelt and ice jams (according to historical records). There are historical records from several U.S. Geological Survey (USGS) stream gages on the river that date back to 1908, which document basin flood history.

Past flood studies for the mainstem of the Clark Fork River within Mineral County are limited. Within the mainstem Clark Fork River basin, there is no Federal Emergency Management Agency (FEMA) Flood Insurance Studies for Mineral County. The USGS *Methods for Estimating Flood Frequency at Ungaged Sites in Montana Based on Data through Water Year 2011* report (Sando et al., 2015a) was an important flood study, which included flood frequency analyses for the Clark Fork River.

For this hydrologic analysis, flood flow frequency analysis was conducted to develop peak flow discharge estimates for the 50-, 10-, 4-, 2-, 1-, and 0.2-percent annual chance events. The 1%+ (plus) annual chance event was also calculated. Peak flow estimates were calculated at 15 locations (flow nodes) within the watershed (4 gaged sites and 11 ungaged sites). Estimates at the active gaged sites were conducted using Bulletin #17C methodologies (USGS, 2016). At the

ungaged and inactive gaged sites, peak flow estimates were calculated using the Two Site Logarithmic Interpolation method and the Drainage Area Gage Transfer method. These methods conform to standard engineering practice.

In the Clark Fork River watershed, the flood flow frequency estimates from this study for the active USGS gages produced peak discharge estimates that are higher than the estimates from previous the USGS studies.

The hydrologic analysis documented in this report conforms to FEMA standards for detailed/enhanced level studies, and the recommended flows of this analysis are deemed reliable and suitable for future floodplain studies and hydraulic analyses.

1 INTRODUCTION

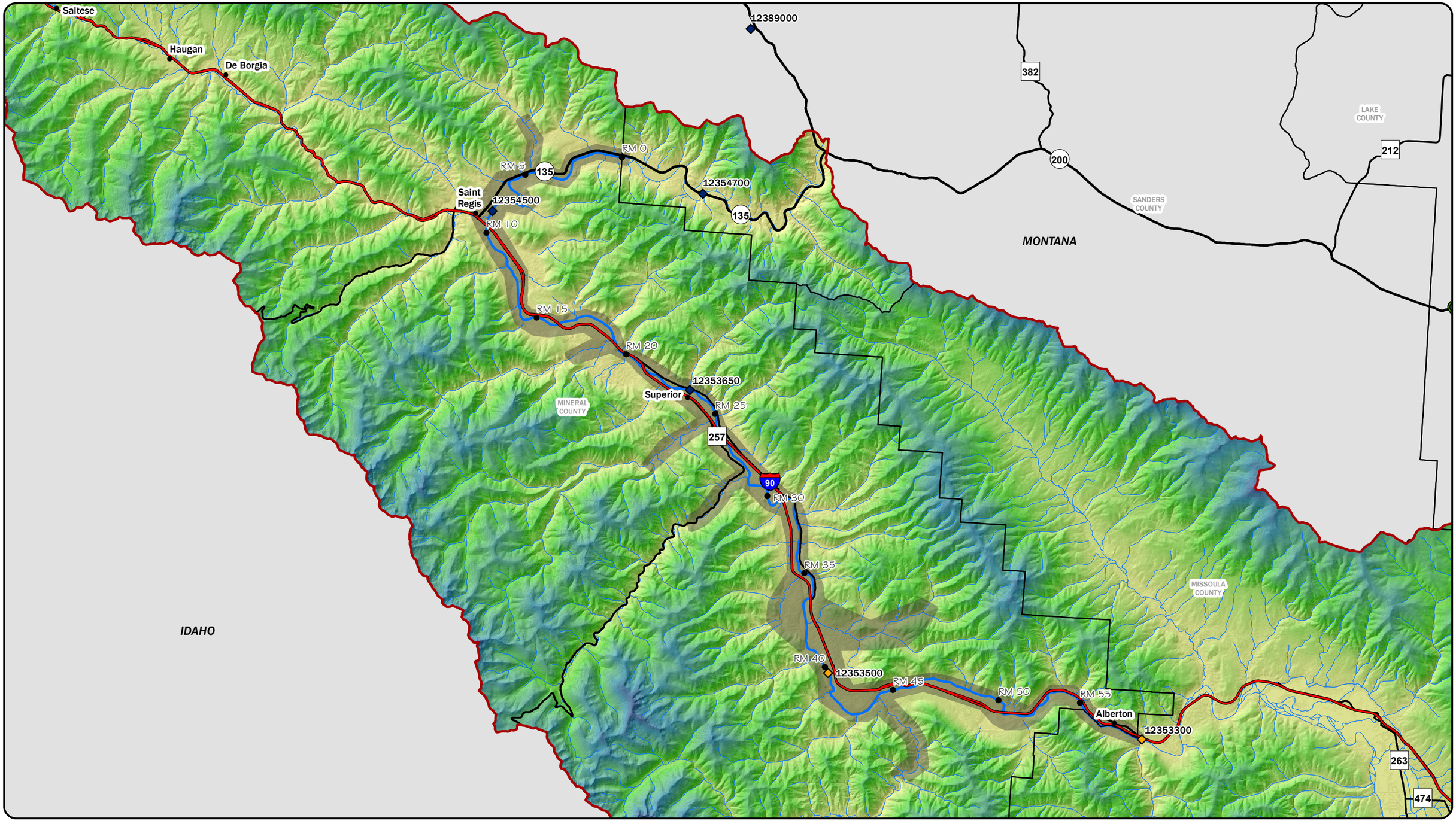
As part of the Clark Fork River Floodplain Study activities, the Montana Department of Natural Resources and Conservation (DNRC) contracted Pioneer Technical Services, Inc. (Pioneer) to complete a comprehensive peak flow hydrologic analysis for the mainstem Clark Fork River study reach. Pioneer conducted flood flow frequency calculations for a 55-mile reach of the mainstem Clark Fork River. The study does not include other tributaries. The Clark Fork River study reach extends from the river intersection with the Sanders/Mineral County line northwest of St. Regis upstream to the river intersection with the Missoula/Mineral County line east of Alberton. This study area watershed encompasses approximately 1,217 square miles. Information gathered from this analysis will be used for both detailed/enhanced level and limited detail level hydraulic analyses and floodplain mapping. Figure 1 shows the project study reach.

1.1 Background Information

The FEMA administers the National Flood Insurance Program (NFIP). As part of this program, FEMA supports flood hazard studies and prepares flood hazard maps and related documents. Most of the mainstem Clark Fork River in Mineral County is sparsely populated with a predominantly rural environment. The existing floodplain mapping for the mainstem Clark Fork River in the study area includes Approximate Zone A, and these mapping studies typically date back to the early 1970s and do not include any floodway information.

Approximate Zone A flood maps are developed using approximate methodologies and are not based on detailed hydraulic analysis. This level of flood mapping is often used in rural areas with low populations. Base Flood Elevations (BFEs) or flood depths are not identified in Approximate Zone A mapping (a BFE is the computed elevation to which floodwater is estimated to rise during the base flood). As a result, areas designated with Zone A flood mapping are difficult for local communities to manage and administer.

Detailed and Limited Detail mapping are similar in that both use standard hydrologic and hydraulic modeling methods to estimate BFEs and flood inundation areas. Both require the same topographic accuracy. However, Limited Detail mapping does not include floodway delineation, may not include a 500-year floodplain delineation, and may allow some flexibility in the acquisition and modeling of bathymetric and structure survey data.



LEGEND

- RIVER MILES
- ACTIVE USGS GAGE
- INACTIVE USGS GAGE
- TOWNS
- NHS INTERSTATE
- NHS NON-INTERSTATE
- PRIMARY
- SECONDARY
- CLARK FORK RIVER STUDY REACH
- HUC 8 BOUNDARIES
- MONTANA COUNTY BOUNDARIES
- STUDY AREA

N

DISPLAYED AS:
PROJECTION/ZONE: MONTANA STATE PLANE
DATUM: NAD 1983
UNITS: INT'L FEET
SOURCE: PIONEER, MSL, USGS

0 2 4 8
Miles

FIGURE 1

CLARK FORK RIVER STUDY AREA

PIONEER TECHNICAL SERVICES, INC.

DATE: 6/1/2017

Path: G:\DNRC\Mineral -Beaverhead County\Mineral County\CAD-GIS\GIS\CLKFK-GI-HYD-001-17.mxd

The DNRC, in partnership with FEMA, Mineral County, and other stakeholders, initiated work to produce new floodplain studies along a reach of the Clark Fork River in Mineral County. The Clark Fork River Floodplain Study will provide the groundwork for completing floodplain mapping projects along the mainstem Clark Fork River. This report documents the hydrologic analysis methodology and results completed along the mainstem Clark Fork River. The analysis includes calculation of peak discharge estimates for the 50-, 10-, 4-, 2-, 1-, and 0.2-percent annual chance events at key flow change locations (such as significant tributary confluences, stream gages, and population centers) along the study reach. This hydrologic analysis includes calculation of the 1% + (plus) annual chance discharge estimates. It also conforms to FEMA standards for detailed/enhanced level studies (FEMA, 2016a and FEMA, 2016b).

As part of this hydrologic analysis, the DNRC partnered with the USGS, under a non-formal agreement, to perform updated flood frequency analysis of all the stream gages along the mainstem Clark Fork River through Water Year 2016. Pioneer used the USGS flood frequency analysis for the gaged locations to develop peak discharge estimates at the selected ungaged flow change locations.

1.2 Basin Description

The Clark Fork River is a major tributary to the Pend Oreille River and upper headwaters of the Columbia River located west of the continental divide in western Montana. The river is formed by the confluence of Silver Bow Creek and Warm Springs Creek. The river tributaries originate in the Deerlodge National Forest near the continental divide. The watershed is formed by the Bitterroot Mountains to the west, Deer Lodge Mountains to the east, and the Pintler and Highland Ranges to the south. The mainstem Clark Fork River begins at Warm Springs, Montana, and flows north for approximately 20 miles through the Deer Lodge Valley before tuning west. The Blackfoot and Bitterroot Rivers join the Clark Fork River near Missoula. Approximately 213 miles downstream of Missoula, the Clark Fork River terminates at Lake Pend Oreille. The entire Clark Fork watershed area encompasses approximately 22,905 square miles. The study watershed basin area from the Missoula County border to the Sanders County border is approximately 1,217 square miles.

The Clark Fork River basin elevations within the study area range from approximately 7,600 feet in the mountains to approximately 2,570 feet at St. Regis. The overall basin elevations range from over 10,000 feet at the continental divide to 2,060 feet near the confluence with Pend Oreille Lake (USACE, 1967). The terrain varies from a high alpine environment in its headwaters to a heavily cultivated landscape in the Deer Lodge valley with expansive irrigated pasture lands, bracketed by rolling foothills. The hydrology of the basin is primarily snowmelt driven.

Land use in the Clark Fork River basin is primarily agricultural with irrigated farming and ranching operations. Most of the intensely farmed land is located in the Deer Lodge Valley within the Clark Fork River floodplain.

1.3 Flood History

The primary cause of flooding on the Clark Fork River is spring snowmelt and ice jams (according to historical records). The greatest flood on the Clark Fork, during the past 100 years, occurred in June 1908 at Missoula. Newspapers pointed out that it was far greater than any flood known to the oldest residents at that time. In early June the ground was already saturated from weeks of hard rain when temperatures dropped and several inches of snow covered the area. As temperatures warmed, the drenched earth began to flood, sending torrents into the river. The flood peaked at 4.5 feet above major flood stage, forcing residents to flee and railroads to shut down—even the mines in Butte, Montana, closed.

There are historical records from several USGS stream gages on the river that document flooding history. The USGS stream gages below Missoula, at Alberton, at Tarkio, and at St. Regis, are representative of the mainstem Clark Fork flood history below Missoula, at Alberton, at Tarkio, and at St. Regis, respectively. The St. Regis USGS Gage (12354500) has the longest, continuous flow record (1929-2016) with additional records from 1911 through 1923. The annual peak flow record for the St. Regis gage is shown in Figure 2. Peak flow recurrence intervals shown in Figure 2 are based on previously published flood frequency analysis through Water Year 1998 (Water-Resources Investigations Report [WRIR] 03-4308, 2004) (Parrett and Johnson, 2004).

Figure 2 shows that the peak flood of record at St. Regis occurred in 1948 and again in 1997 with a flow of 68,900 cubic feet per second (cfs), exceeding the 10% chance annual flow of 57,000 cfs. The third highest flood on record occurred in 1972 with a flow of 63,900 cfs. In the 101-year period of record at the St. Regis gage, the 10-year flow has been exceeded 8 times.

Figure 2 Clark Fork River at St. Regis (12354500)

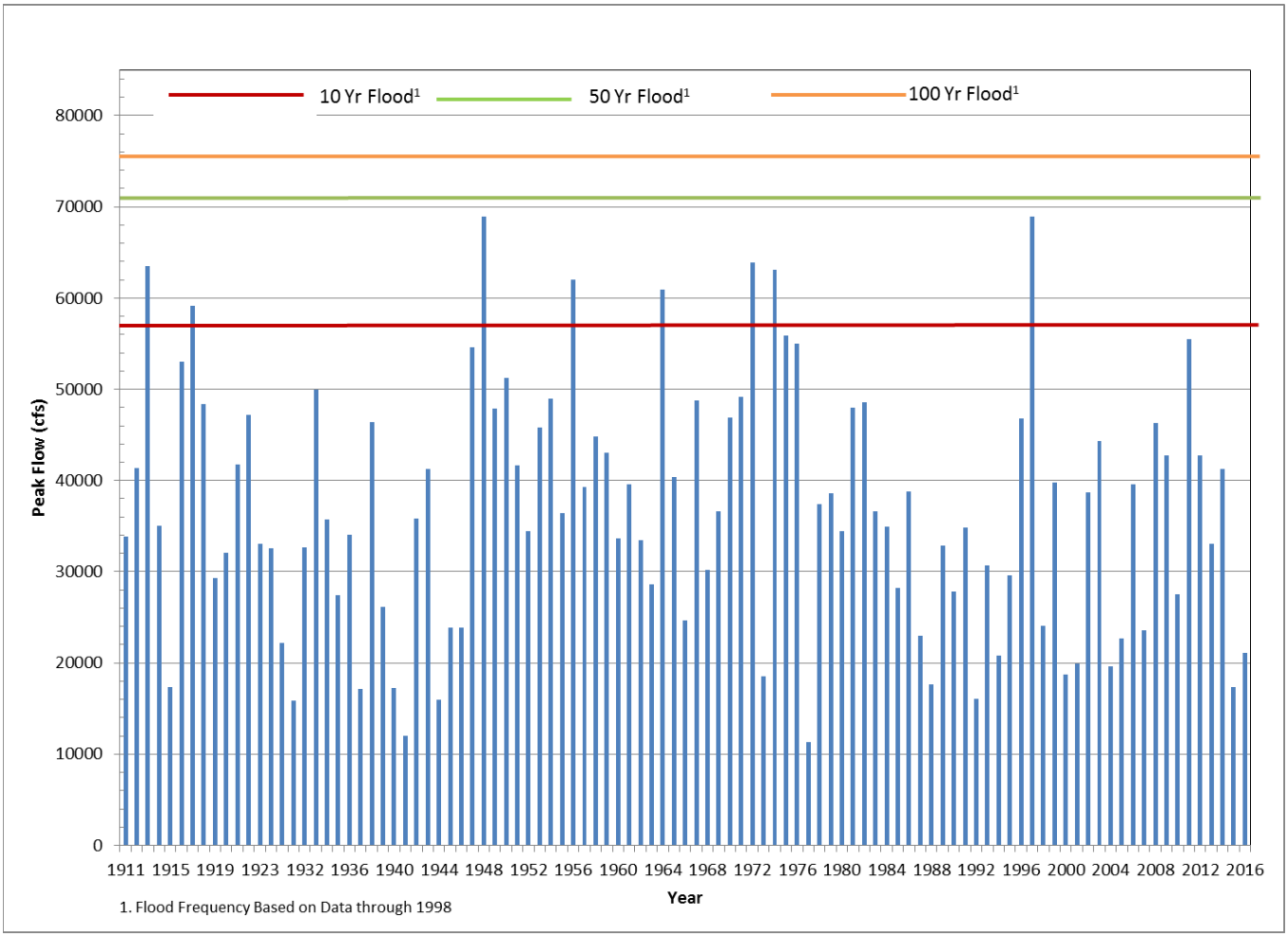


Figure 3 shows the continuous peak flow record from 1930 to 2016 for the Clark Fork River gage below Missoula (USGS 12353000). Peak flow recurrence intervals shown in Figure 3 are based on previously published flood frequency analysis from WRIR 03-4308 (Parrett and Johnson, 2004).

The flood of record below Missoula occurred in 1997 with a flow of 55,100 cfs exceeding the 10% chance annual flow of 45,200 cfs. The second highest flood on record occurred in 1948 with a flow of 52,800 cfs. In the 87-year period of record at the St. Regis gage, the 10-year flow has been exceeded 8 times.

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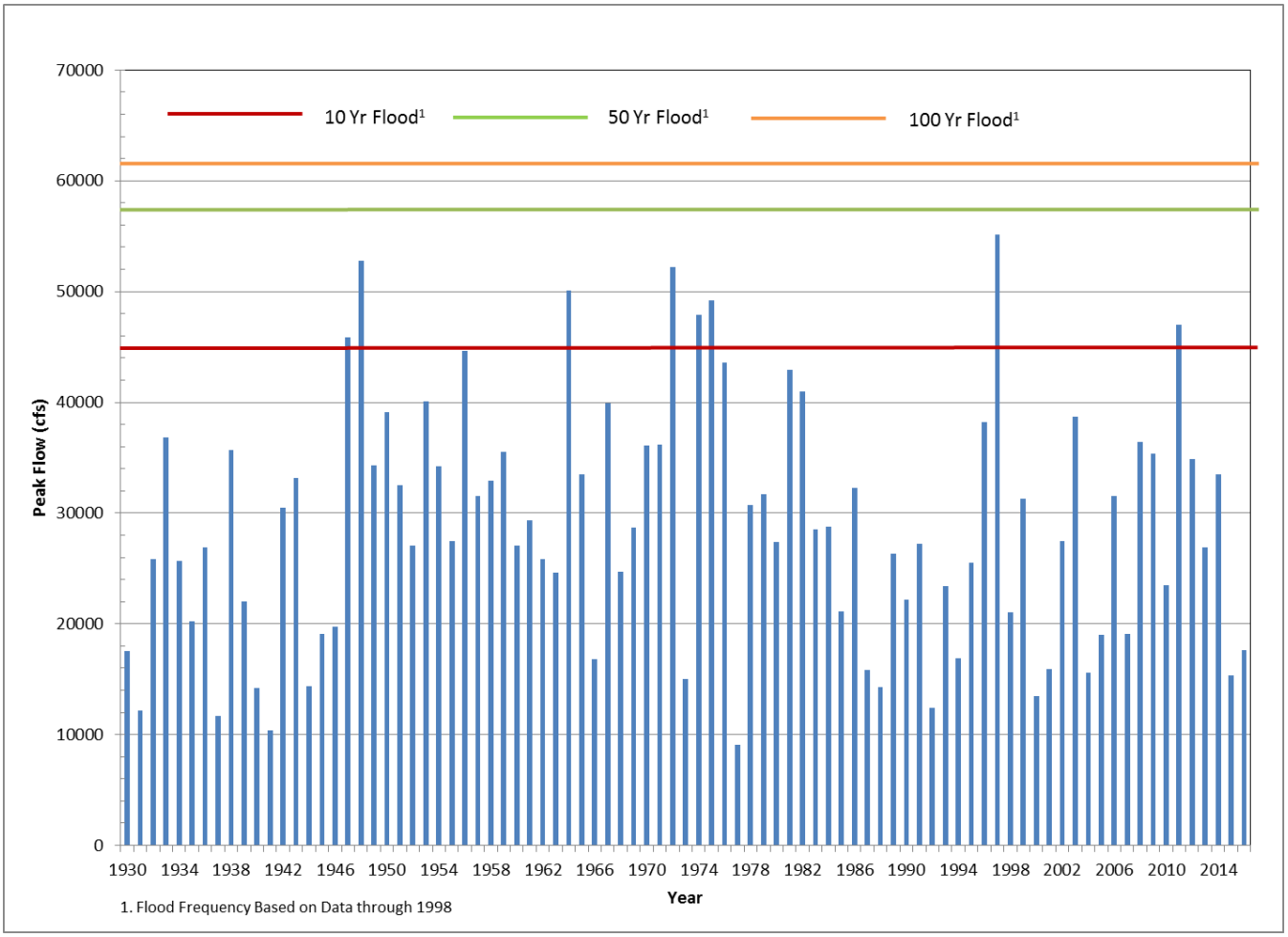
Figure 3 Clark Fork River below Missoula (12353000)



2 PAST STUDIES AND EXISTING FLOOD DATA

Past flood studies for the mainstem of the Clark Fork River within Mineral County are limited. Studies relevant to this hydrologic study are those that include peak flow frequency analyses. There are no FEMA Flood Insurance Studies within the mainstem Clark Fork River basin in Mineral County. Table 1 shows a summary of the mainstem Clark Fork River Floodplain Mapping.

Table 1 Mainstem Clark Fork River Floodplain Mapping Summary

County	Map Panel Summary					Study Details			
	Community	# of FIRM Panels	# of FBFM Panels	FIRM Panel Effective Date	FIS Date	Stream	Approx (mi)	Detailed (mi)	Total (mi)
Mineral	Mineral Co.	9	0	7/6/2015	none	Clark Fork	55	NA	NA

Source: FEMA Map Service Center

FIRM: Flood Insurance Rate Map. FIS: Flood Insurance Studies. FBFM: Flood Boundary and Floodway Map

mi: Miles measured along channel alignment

The USGS WRIR 03-4308 (Parrett and Johnson, 2004) and Scientific Investigations Report (SIR) 2015-5019-C (Sando et al., 2015b) document the flood frequency analysis on several gages along the mainstem Clark Fork River. These studies and investigations are discussed in more detail in the following sections.

2.1 Water-Resources Investigations Report 03-4308

The USGS WRIR 03-4308 developed annual peak discharges with recurrence intervals of 2, 5, 10, 25, 50, 100, 200, and 500 years (*T*-year floods) for 660 gaged sites in Montana and in adjacent areas of Idaho, Wyoming, and Canada, based on data through Water Year 1998 (Parrett and Johnson, 2004). The flood-frequency information was used in regression analyses to develop equations relating *T*-year floods to various basin and climatic characteristics, active-channel width, and bankfull width. The equations can be used to estimate flood frequency at ungaged sites. Flood-frequency data typically were determined by fitting a log-Pearson Type III probability distribution using methods described by the Interagency Advisory Committee on Water Data (IACWD), Bulletin #17B (IACWD, 1982).

Table 2 provides the WRIR 03-4308 peak discharge summary for the USGS gages on the Clark Fork River. Table 2 shows that, in general, peak flows increase with an increase in drainage area and return interval.

Table 2 WRIR 03-4308 Clark Fork River Peak Discharge Summary

USGS Station Number	USGS Station Name	Drainage Area (sq mi)	Years of Record	Peak Discharge (cfs) , indicated return interval (years) (cfs)						
				5	10	25	50	100	200	500
12354500	Clark Fork River at St. Regis, MT	10,709	83	49,500	57,000	65,300	70,700	75,600	80,000	85,200
12353000	Clark Fork River below Missoula, MT	9,003	69	38,900	45,200	52,400	57,300	61,700	65,900	70,900

Based on systematic data through 1998. sq mi: square mile. cfs: cubic feet per second.

2.2 Scientific Investigations Report 2015-5019

The USGS SIR 2015-5019-C updated annual peak discharges with annual exceedance probabilities (AEPs) of 66.7, 50, 42.9, 20, 10, 4, 2, 1, 0.5, and 0.2 percent (return intervals of 1.5, 2, 2.33, 5, 10, 25, 50, 100, 200, and 500 years, respectively) for 725 gaged sites in or near Montana, based on data through Water Year 2011 (Sando et al., 2015b). Flood-frequency data typically were determined by fitting a log-Pearson Type III probability distribution using methods described by the IACWD, Bulletin #17B (IACWD, 1982). The study was part of a larger study to develop an online StreamStats application for Montana, in conjunction with computing streamflow characteristics at gage stations, and estimate peak flow flood frequency at ungaged sites. Table 3 provides the SIR 2015-5019-C discharge summary for the Clark Fork River gages.

The USGS SIR 2015-5019-F (Sando et al., 2015a) selected 537 gaging stations from the gage study. The 537 gaging stations were segregated based on the following criteria: contributing drainage area less than about 2,750 square miles, peak-flow records unaffected by major regulation, small redundancy with nearby stations, and representation of peak-flow frequencies at sites within Montana. All the gaging stations on the Clark Fork River within Mineral County were excluded from the dataset because the contributing basin drainage area for these gages was greater than 2,750 square miles. The study used regression analyses to develop equations relating AEP flows to various basin and climatic characteristics. The relationships developed for this study resulted in lower mean standard errors of prediction than previous regression analyses.

Table 3 SIR-2015-5019-C Clark Fork River Peak Discharge Summary

USGS Station Number	USGS Station Name	Drainage Area (sq mi)	Years of Record	Peak Discharge (cfs) , indicated return interval (years) (cfs)						
				5	10	25	50	100	200	500
12354500	Clark Fork River at St. Regis, MT	10,728	96	48,700	56,200	64,600	70,200	75,200	79,800	85,400
12353000	Clark Fork River below Missoula, MT	9,017	82	38,300	44,600	51,900	56,800	61,400	65,600	70,900

Based on systematic data through 2011. sq mi: square mile. cfs: cubic feet per second.

2.3 Additional Previous Studies

Additional related previous studies conducted along the Clark Fork River within Mineral County involve water management, fisheries management, or sediment management:

- *Water Resources Data, Montana, Water Year 2005, Volume 2. Yellowstone and Upper Columbia River Basins and Ground-Water Levels,* US Department of the Interior, US Geological Survey (Berkas et al., 2006).
- *Summary of Surface-Water-Quality Data Collected for the Northern Rockies Intermontane Basins National Water-Quality Assessment Program in the Clark Fork-Pend Oreille and Spokane River Basins, Montana, Idaho, and Washington, Water Years 1999-2001, Open File Report 02-472*, US Department of the Interior, US Geological Survey (Beckwith, 2003).
- *Clark Fork River Study, Montana* (S&A/TIB) (EPA, 1973).

3 Hydrologic Analyses and Results

The purpose of the hydrologic analyses conducted as part of this project is to develop peak flow discharge estimates for the 50-, 10-, 4-, 2-, 1-, and 0.2-percent AEP events at key flow change locations (such as at significant tributaries confluences, stream gages, and population centers) along the study reach. The analysis is organized into two sections:

1. USGS Stream Gage Analysis.
2. Ungaged Flow Node Analysis.

Throughout the study area, 15 locations (flow nodes) on the Clark Fork River were identified as having significant changes in streamflow or being at a critical location. Out of the 15 flow nodes on the Clark Fork, 2 are located at active USGS stream gage sites, 2 are located at discontinued USGS stream gage sites, and 11 are located between or downstream of stream gages (ungaged sites). The river stationing used in this report was based on the Clark Fork River study alignment provided by the DNRC. The Clark Fork River study alignment begins at the border of Mineral and Sanders counties. The upstream extent of this study reach ends at the border of Mineral and Missoula counties at River Mile 55. The most upstream flow node is located at the Clark Fork River below the Missoula gaging station (USGS Station 12353000) approximately 28.6 river miles upstream from the study reach extent.

3.1 USGS Stream Gage Analysis

The USGS has historically maintained 4 stream gages along the Clark Fork River study reach. The USGS gaging station 12353000 Clark Fork River below Missoula, Montana, is upstream of the study reach but was used in the analysis. The oldest records date back to 1911 at USGS gaging station 12354500 Clark Fork River at St. Regis, with the period of record continuing from 1929 until present. Currently, there are 2 (of the 4 gages along the study reach) USGS gaging stations being maintained on the mainstem Clark Fork River, however USGS gaging station 12353650

Clark Fork River at Superior only records water temperature and was not used in this analysis. Figure 1 shows the study reach and the locations of the USGS gaging stations along the study reach. The St. Regis gage has the longest congruent period of record extending from 1929 to 2016 (88 years). Table 4 lists a summary of all the USGS stream gages used in this analysis (active and inactive) along the mainstem Clark Fork River.

In 2014 the USGS updated the regional regression equations used to estimate flood frequency at ungaged sites in Montana using stream gage data through 2011. As part of this effort, the USGS conducted flood frequency analysis on the Clark Fork River. In conjunction with the hydrologic analysis and the regression equation update, the USGS collaborated with DNRC to conduct a flood frequency analysis for the mainstem Clark Fork River using gage data through 2016. This longer period of record should produce more accurate peak discharge estimates than those based on a shorter period of record. Results of the USGS flood frequency analysis based on data through 2016 were employed in this hydrologic analysis.

This section summarizes the Clark Fork River flood frequency work conducted by the USGS. A detailed description and supporting information for the USGS flood frequency analysis is provided in Appendix A. The flood frequency analyses were performed following Bulletin #17C methods (USGS, 2016). Systematic flood frequency calculations were completed for 2 of the gages (Appendix A, Table 2) shown in Table 4, using data through 2016.

Figure 4 plots the systematic flood frequency results as a function of drainage. Figure 4 indicates peak discharges increase with increasing drainage area, as typically expected. Figure 5 tabulates the results of the flood frequency estimates.

Table 4 Clark Fork River USGS Gage Summary

Station number	Station name	Drainage[1] Area (square miles)	Period of Systematic Record[2]	Number of Annual Peaks[2]	River Station (miles)
12354500	Clark Fork at St. Regis, MT	10,728.00	1911-1923, 1929-2016	101	9.0
12353500*	Clark Fork at Tarkio, MT	9,882.00	1944-1949	0	40.3
12353300*	Clark Fork at Alberton, MT	9,272.00	1958-1963	0	N/A
12353000	Clark Fork below Missoula, MT	9,017.00	1930-2016	87	N/A

1. Source: National Watershed Information System (NWIS)
2. Data from USGS flood frequency analysis (Appendix A, Table B.1)

* Denotes inactive gage location

Figure 4 USGS Flood Frequency Estimates Systematic Record 1911 through 2016

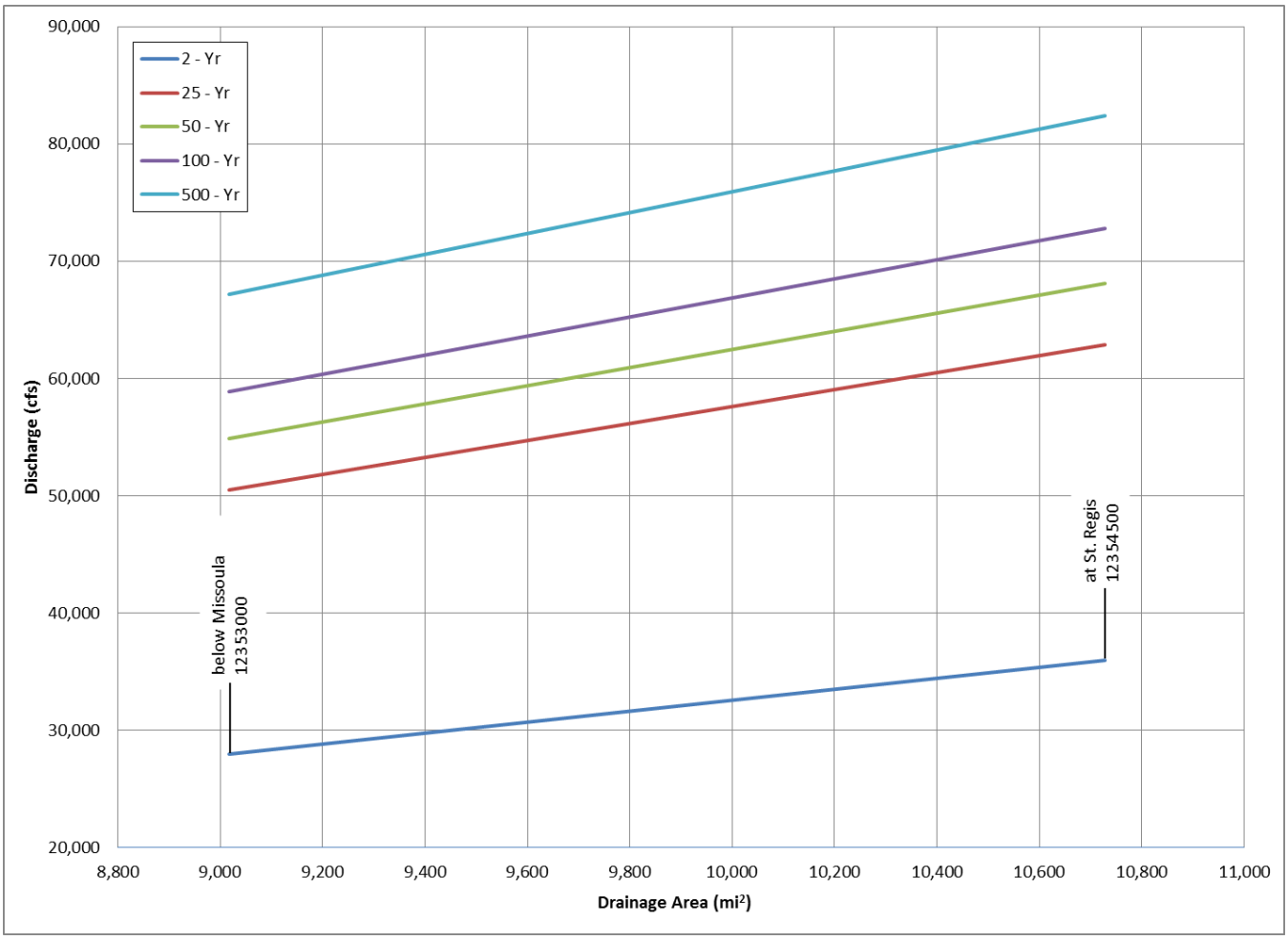


Table 5 Gage Flood Frequency Estimates Using Systematic Record

Station Number	Station name	Analysis Period of Record	Peak discharge, (cfs), for indicated exceedance probability (%)								
			66.67	50	20	10	4	2	1	0.5	0.2
			Peak discharge (cfs), for indicated return interval (years)								
			1.5	2	5	10	25	50	100	200	500
12354500	Clark Fork at St. Regis, MT	1911–23; 1929–2016	30,500	36,000	48,200	55,100	62,900	68,100	72,800	77,200	82,400
12353000	Clark Fork below Missoula, MT	1930–2016	23,500	28,000	38,100	43,900	50,500	54,900	58,900	62,700	67,200

cfs: cubic feet per second

To address the non-congruent periods of record, the MOVE.3 (Maintenance of Variance Extension, Type 3) was used to extend the historical gage records. The MOVE.3 method correlates streamflow at a short-term gaging station with a longer-term index gaging station using a base 10 logarithmic transformation. The Move.3 method can be used for record extension when a linear relationship exists between the logarithms of the same-year peak discharges at the target station and a nearby index station. A base period of 1899-1908, 1911-23, and 1929-2016 was selected for the record extension. Regulation occurs in a basin when flood flows are altered by reservoir operations or other water resource control structures (such as diversion dams). In this flood frequency analysis, gages were defined as regulated when greater than 20% of the basin lies upstream from reservoirs. The USGS in consultation with DNRC determined that the regulation on the Clark Fork River was not significant enough to affect peak flows.

Annual peak estimates from the MOVE.3 analysis were determined to be generally reasonable and consistent with recorded upstream and downstream peaks. Table 6 summarizes the Clark Fork River gage analysis flood frequency estimates using the extended record. Figure 5 plots the extended record analysis results.

Flood frequency peak flow estimates using the extended record data set establish a congruent period of record for the mainstem Clark Fork River stream gages. Using the extended record data set will minimize the potential error associated with non-congruent periods of record. For these reasons, flood flow frequency estimates using the 2016 extended record data set were selected to represent the annual chance flood potential at the Clark Fork River gaged locations.

Table 7 compares flood frequency estimates between the 2011 SIR 2015-5019-C analysis (Sando et al., 2015b) and this study's 2016 extended record analysis. Figure 6 USGS Flood Frequency Estimates Comparison 2011 and 2016compares selected recurrence intervals from Table 7 for the two Clark Fork River gages. The 2016 flood frequency flows are higher than the 2011 estimated flows. The SIR 2015-5019-C flood frequency estimates are a systematic analysis based on the entire period of record using methods described in Bulletin #17B (IACWD, 1982). The 2016 flood frequency analysis is based on the extended period of record 1899 to 2016 using methods described in Bulletin #17C (USGS, 2016); therefore, some differences between the 2011 and 2016 peak flow estimates can be attributed to the different period of records used in the analysis and the different calculation methods used.

Table 6 Gage Flood Frequency Estimates Using Extended Record

Station Number	Station name	Analysis Period of Record	Peak discharge, (cfs), for indicated exceedance probability (%)								
			66.67	50	20	10	4	2	1	0.5	0.2
			Peak discharge (cfs), for indicated return interval (years)								
			1.5	2	5	10	25	50	100	200	500
12354500	Clark Fork at St. Regis, MT	1899–1908; 1911–23; 1929–2016	30,300	36,600	50,700	59,000	68,400	74,700	80,500	85,900	92,500
12353000	Clark Fork below Missoula, MT	1899–1908; 1911–23; 1929–2016	24,200	29,100	40,200	46,900	54,700	60,000	64,900	69,500	75,300

cfs: cubic feet per second

Figure 5 USGS Flood Frequency Estimates Extended Record (1899-2016)

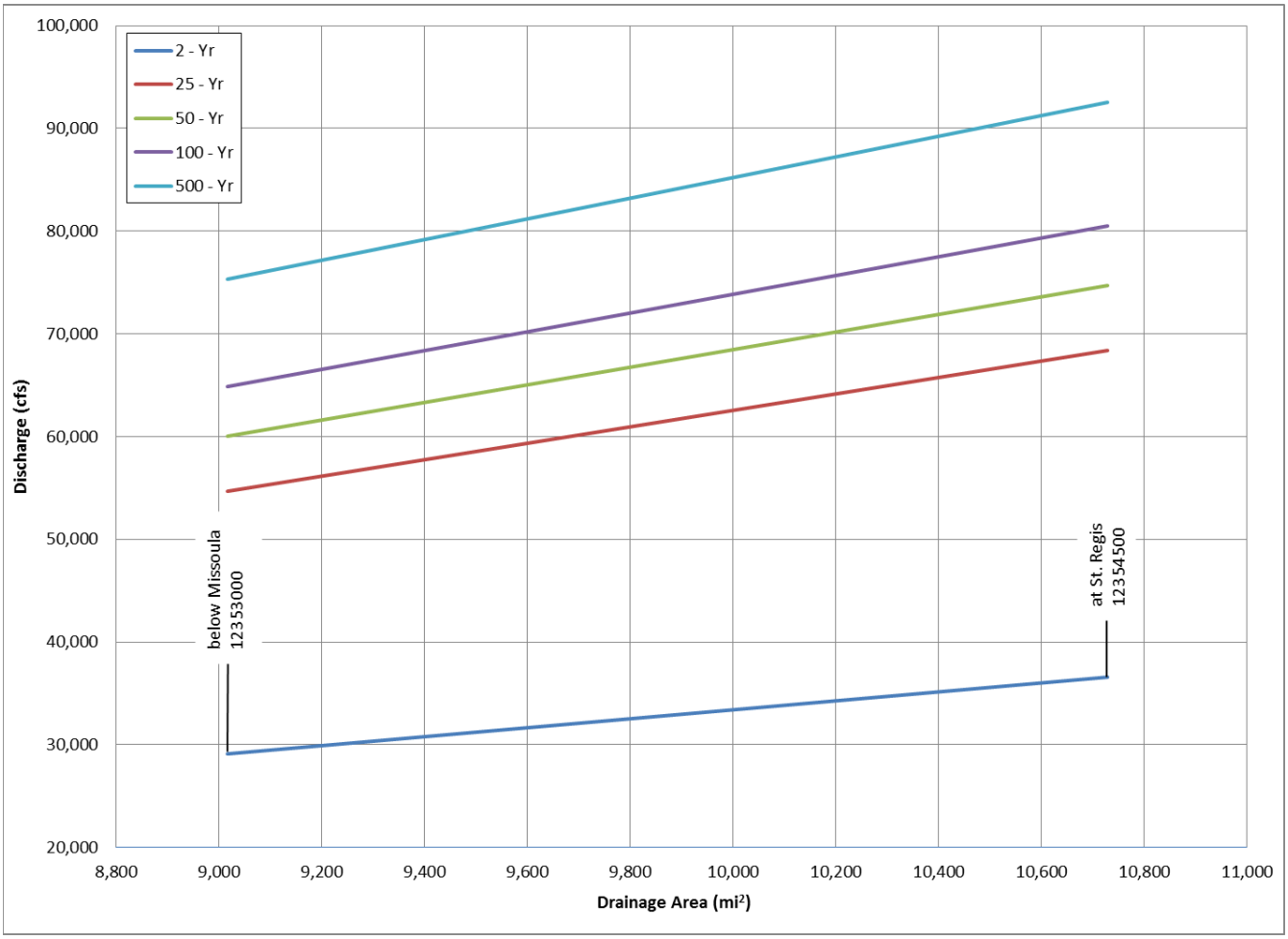
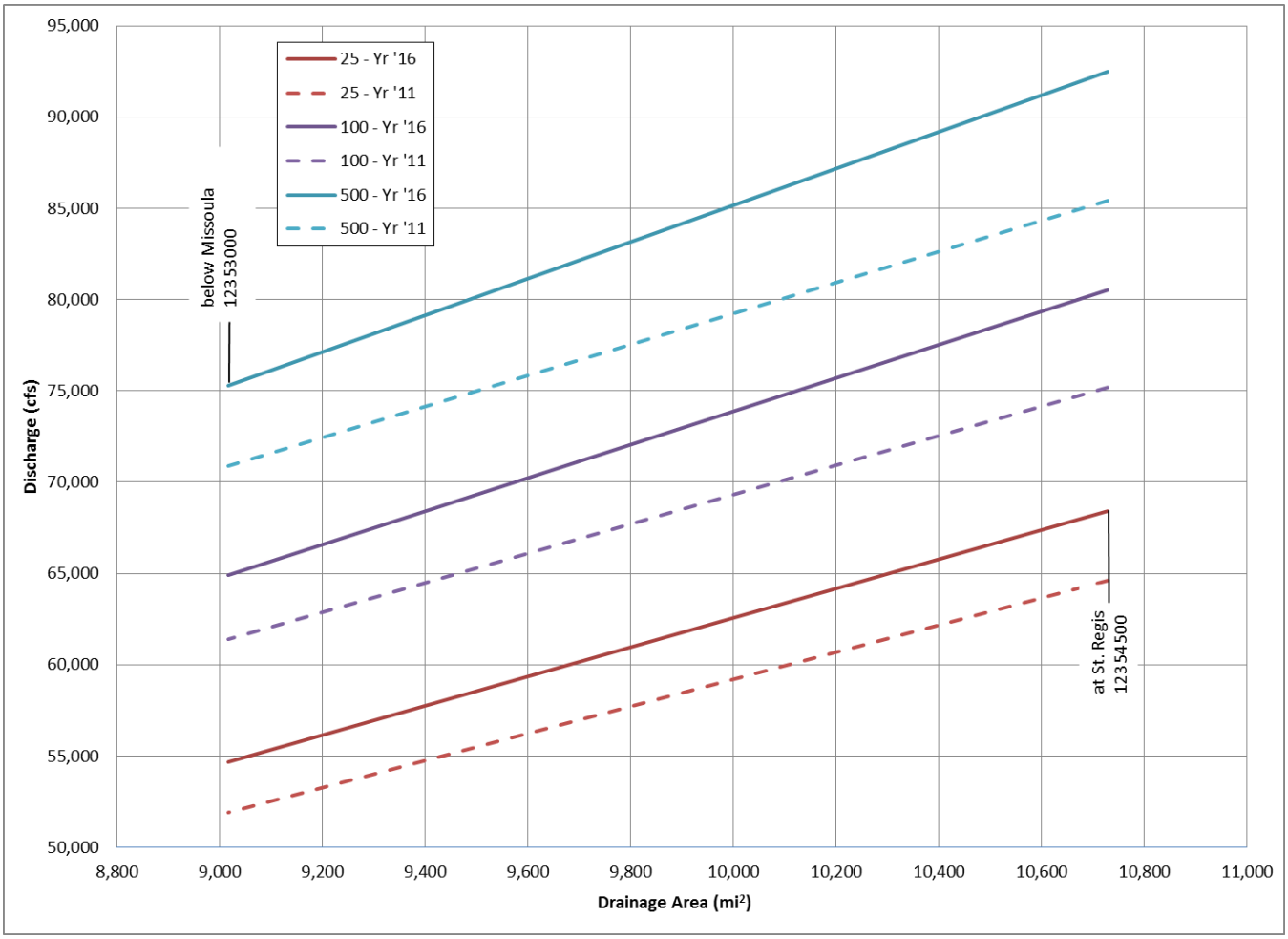


Table 7 USGS Flood Frequency Estimate Comparison 2011 and 2016

Station Number	Station Name	Peak Discharge, for Return Interval (years) (cfs)													
		5		10		25		50		100		200		500	
		2011	2016	2011	2016	2011	2016	2011	2016	2011	2016	2011	2016	2011	2016
12354500	Clark Fork at St. Regis, MT	48,700	50,700	56,200	59,000	64,600	68,400	70,200	74,700	75,200	80,500	79,800	85,900	85,400	92,500
12353000	Clark Fork below Missoula, MT	38,300	40,200	44,600	46,900	51,900	54,700	56,800	60,000	61,400	64,900	65,600	69,500	70,900	75,300

cfs: cubic feet per second

Figure 6 USGS Flood Frequency Estimates Comparison 2011 and 2016



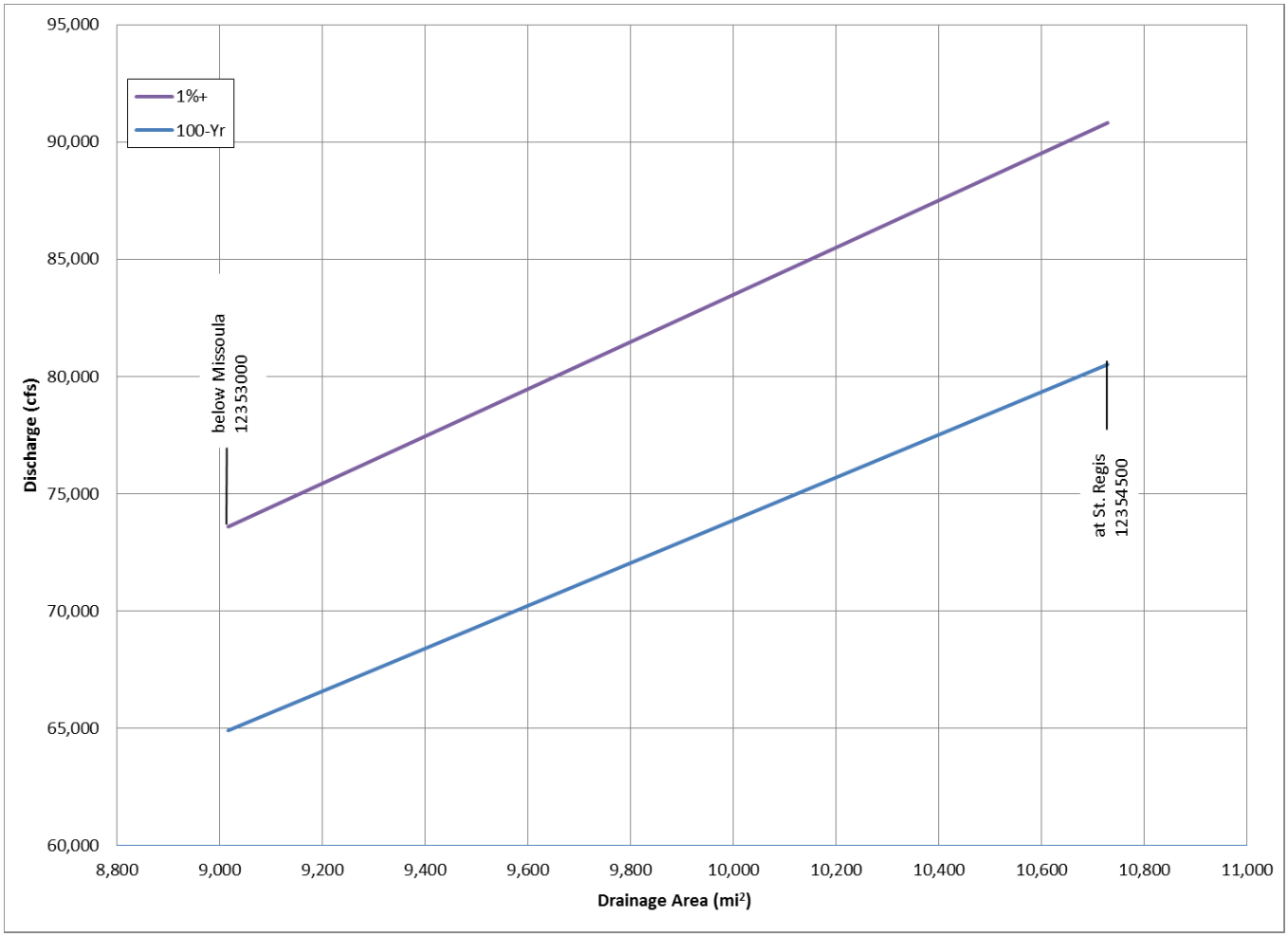
3.1.1 1% + Peak Flow Estimates

The 1%+ percent AEP event was calculated to provide a confidence range that the 1% flood frequency peak flow estimates are likely to fall within. The flood-frequency estimate equations include an "average standard error of prediction" or "average standard error of estimate" percentage that was used to define the statistical 68% confidence interval (plus or minus [+/-] one standard deviation). The resulting upper 84% confidence limit (+ 1 standard deviation) was used to determine the 1% flood frequency peak flow estimates. The Clark Fork River 1%+ flood frequency peak flow estimates are based on the extended record 1% estimates presented in Table 8 and graphically shown in Figure 7.

Table 8 USGS 1%+ Flood Frequency Estimates 2016

Station Number	Station Name	1% + Annual Exceedance Probably Peak discharge, (cfs)
12354500	Clark Fork River at St. Regis, MT	90,800
12353000	Clark Fork River below Missoula, MT	73,600

Figure 7 USGS 1%+ Flood Frequency Estimates 2016



3.2 Flow Change Node Locations

Future flood studies will use hydraulic models that are composed of geometric data and streamflow data. To accurately model the Clark Fork River, the locations of major tributary confluences and other flow change locations must be identified. The results of this hydrologic analysis will be used as the streamflow data input at the tributary confluences within the hydraulic model. A detailed review of the study area was performed to identify all potential flow change locations (flow nodes) within the mainstem Clark Fork River. At each flow node, a drainage basin area was delineated and streamflow values were calculated for the various recurrence interval floods. Generally, the hydraulic models simulate flood events using steady-state conditions, and, therefore, the peak flow rate calculated at a flow node is projected to the next upstream flow node. This method was followed for the hydrologic analysis calculations. Flow nodes were assigned immediately upstream of major tributaries; 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.

To identify significant flow change locations (flow nodes), Hydrologic Unit Code (HUC) 12-digit watershed boundaries were used to initially locate the flow nodes. The HUC 12-digit watershed boundaries represent the smallest USGS-delineated watershed areas available in geographic information system (GIS) format. Using ArcGIS (an Esri GIS mapping software), flow nodes were located just upstream of the HUC 12 boundary intersection with the Clark Fork River mainstem.

This study used the nearest Geographic Naming Information System (GNIS) hydrographic feature name for the ungaged flow node names. In some cases these features (typically tributary streams) flow into the mainstem Clark Fork River just downstream of the flow node. For hydrographic features that do not have a GNIS name, the river mile where the node is located was used as the node name.

To avoid excessive flow changes between HUC 12 boundary nodes, additional flow nodes were located immediately downstream of towns, at the end of study reaches, at county borders, or where intermediate tributaries within the HUC 12 boundaries intersected the mainstem. One flow node was added downstream of Superior, Montana. These town nodes and intermediate nodes are identified in Table 9.

The USGS National Watershed Information System (NWIS) watershed area data are GIS-calculated watershed areas using the National Hydrography Dataset Plus Version2 (NHDPlusV2) that integrates the National Elevation Dataset (NED) and the Watershed Boundary Dataset. The NHDPlus V2 NED uses 30-meter resolution digital elevation models (DEMs). Esri processed NHDPlus V2.1 and NED 30-meter DEMs to support the Esri Watershed tool. The Esri hydroconditioning process differs from the NHDPlus V2.1 process so the resulting watershed delineations do not always exactly match the USGS delineations. Differences between the USGS NWIS reported values and the Esri processed values of the percent of area covered by forest can also be attributed to the different processes used to estimate those values.

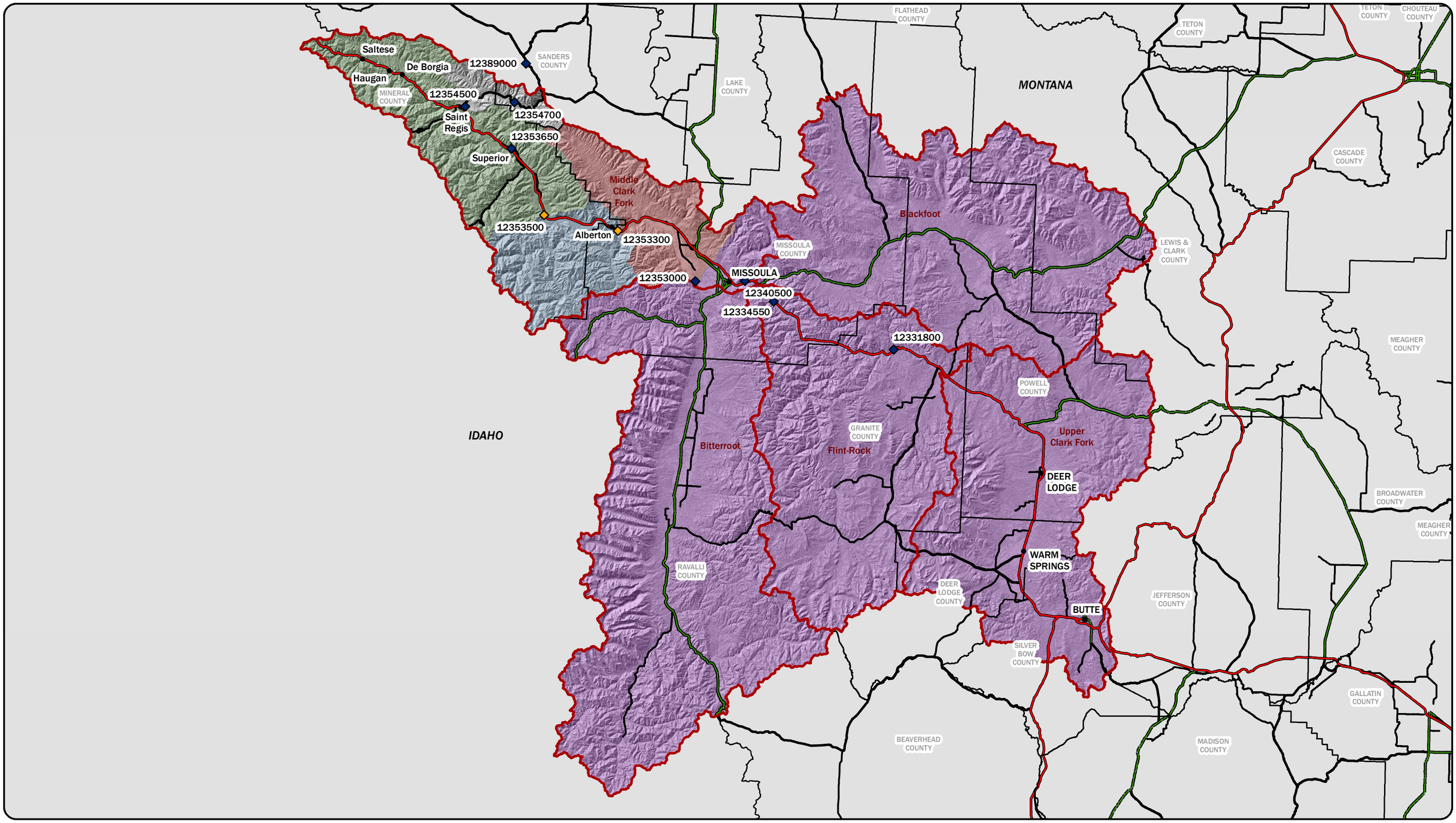
As an accuracy check, the USGS gaging station watershed areas calculated using the Watershed tool or HUC-12 polygons were compared to the USGS NWIS (http://waterdata.usgs.gov/nwis) published gaging station areas. Figure 8 shows the USGS gaging stations analyzed and the correlating GIS model-generated watershed areas within the study area. Table 9 shows the results of this comparison. Based on the 4 gaging stations analyzed, the Esri GIS model calculated watershed areas that were within 1% of the USGS NWIS published areas except for the Clark Fork River at Alberton (12353300) gage (Appendix A). This gage was only active from 1958 to 1963 and the watershed boundary was likely delineated manually. The gage watershed areas calculated using the Watershed tool or HUC-12 polygons were determined to be more accurate and were used for this analysis, resulting in an area increase of 2.06%.

A total of 15 flow nodes were identified throughout the study reach, including 4 gaged locations and 11 ungaged locations. Table 10 is a summary of all flow nodes and the associated watershed areas. Figure 9 maps the flow node locations and corresponding watershed areas from Table 10.

Table 9 Flow Node and USGS Gage Station Information Used in Hydrologic Analyses

Node/USGS Station ID	Location Description	County	River Station[2] (mi)	GIS Incremental Basin Area (mi^2)	GIS Cumulative Basin Area (mi^2)
100	Mineral County Boundary	Mineral	0.0	0.00	10776.83
200	Tamarack Creek	Mineral	4.6	47.14	10729.70
12354500	**Clark Fork at St. Regis, MT**	**Mineral**	**9.0**	**15.50**	**10714.20**
300	St. Regis River	Mineral	9.4	364.97	10349.22
400	Showey Gulch	Mineral	19.8	109.26	10239.96
500[1]	Thompson Creek	Mineral	22.5	20.24	10219.73
600	Cedar Creek	Mineral	25.3	106.38	10113.34
700	Lower Trout Creek	Mineral	28.6	80.21	10033.13
800	Dry Creek	Mineral	33.5	60.82	9972.31
900	Nemote Creek	Mineral	37.8	61.50	9910.80
12353500	**Clark Fork at Tarkio, MT**	**Mineral**	**40.3**	**21.95**	**9888.86**
1000	Lower Fish Creek	Mineral	43.8	282.33	9606.53
1100	Sawmill Creek	Mineral	54.0	37.52	9569.01
12353300	**Clark Fork at Alberton, MT**	**Missoula**	**NA**	**105.80**	**9463.21**
12353000	**Clark Fork below Missoula, MT**	**Missoula**	**NA**	**456.41**	**9006.80**

1. Denotes an additional flow node change downstream of a town reach or intermediate tributary not associated with HUC-12 boundary
2. River miles start at the downstream extent of each study reach (mi: miles)



LEGEND

- ACTIVE USGS GAGE
- INACTIVE USGS GAGE
- HUC 8 BOUNDARIES
- TOWNS
- MONTANA COUNTY BOUNDARIES
- NHS INTERSTATE
- NHS NON-INTERSTATE
- PRIMARY
- SECONDARY

USGS BASINS

- 12353300
- 12353500
- 12353000
- 12354500

N

DISPLAYED AS:
PROJECTION/ZONE: MONTANA STATE PLANE
DATUM: NAD 1983
UNITS: INT'L FEET
SOURCE: PIONEER, MSL, USGS

0 8.5 17 34
Miles

FIGURE 8

CLARK FORK RIVER
USGS WATERSHEDS

PIONEER TECHNICAL SERVICES, INC.

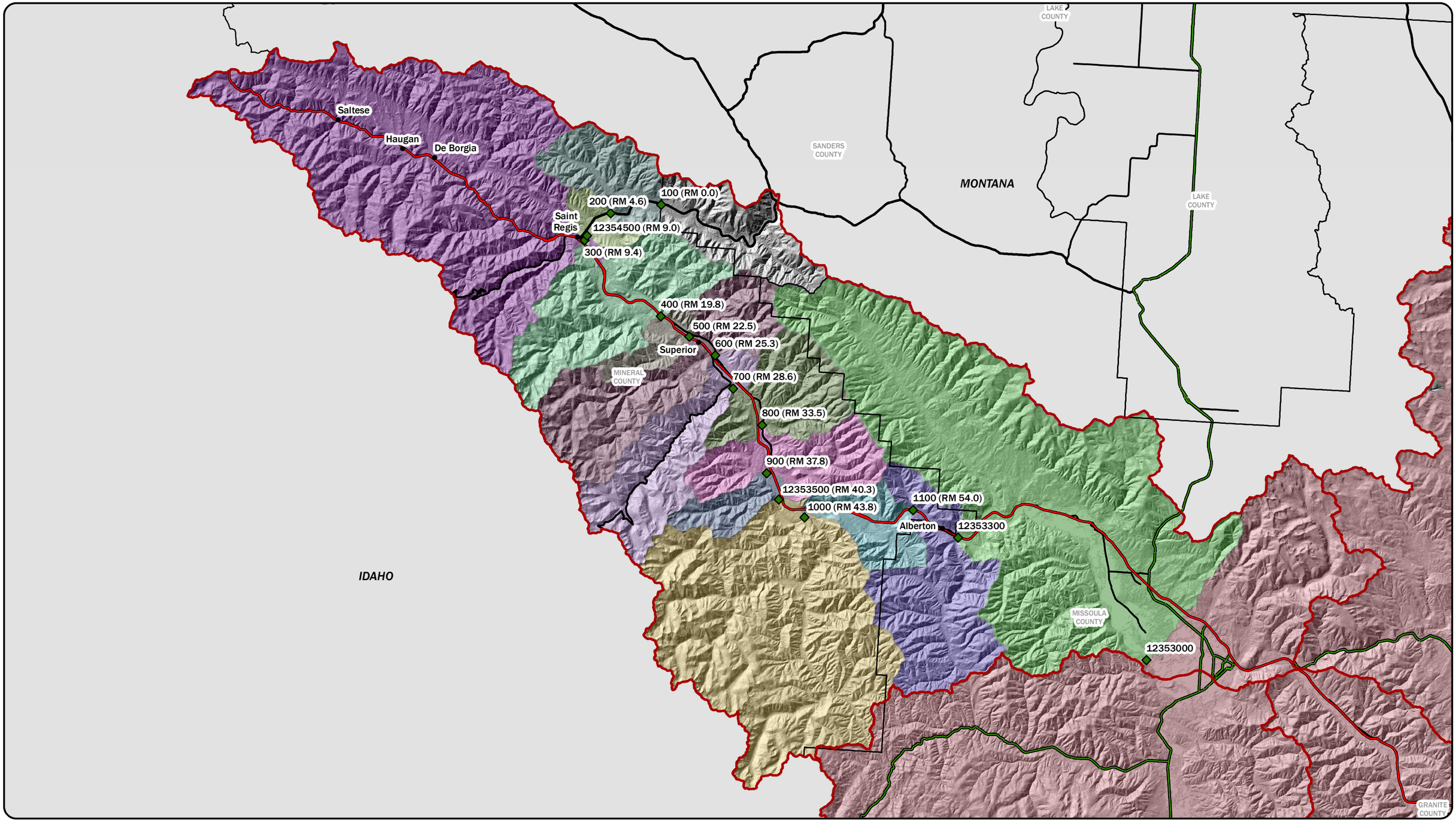
DATE: 5/2/2017

Path: G:\DNRC\Mineral -Beaverhead County\Mineral County\CAD-GIS\GIS\CLKFK-GI-HYD-002-17.mxd

Table 10 **USGS and GIS Model Watershed Comparison**

USGS Gage Station	Station Name	USGS Published Basin Area[1] (mi^2)	Proposed Basin Area[2] (mi^2)	Percent Change	Relative Accuracy of Areas
12354500	Clark Fork at St. Regis, MT	10,728	10,714	0.13%	99.9%
12353650	Clark Fork at St. Superior, MT	10,210	10,203	0.07%	99.9%
12353500	Clark Fork at Tarkio, MT	9,882	9,889	-0.07%	99.9%
12353300	Clark Fork at Alberton, MT	9,272	9,463	-2.06%	97.9%
12353000	Clark Fork below Missoula, MT	9,017	9,007	0.11%	99.9%

1. Source: National Watershed Information System (NWIS)
2. Cumulative basin areas (watershed areas) used for hydrological analysis.



LEGEND

- FLOW NODE (RIVER MILE)
- HUC 8 BOUNDARIES
- TOWNS
- MONTANA COUNTY BOUNDARIES
- NHS INTERSTATE
- NHS NON-INTERSTATE
- PRIMARY
- SECONDARY

FLOW CHANGE NODE: 12353000, 12353300, 1100, 1000, 12353500, 900, 800, 700, 600, 500, 400, 300, 12354500, 200, 100

N

DISPLAYED AS:
PROJECTION/ZONE: MONTANA STATE PLANE
DATUM: NAD 1983
UNITS: INT'L FEET
SOURCE: PIONEER, MSL, USGS

0 3.5 7 14
Miles

FIGURE 9

PIONEER TECHNICAL SERVICES, INC.

DELINEATED SUB BASIN AREAS AND FLOW NODE LOCATIONS

DATE: 5/2/2017

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3.3 Gage Transfer to Ungaged Sites

To calculate peak flood discharge estimates at the ungaged flow nodes, Pioneer considered methods described in USGS SIR 2015-5109-F (Sando et al., 2015a). These methods included estimating flood frequency using regional flood-frequency relations (regression analysis) and estimating flood frequency on gaged streams by translating gaged data to ungaged locations (Drainage Area Gage Transfer and logarithmic interpolation between two gaged sites).

The hydrologic regions defined in SIR 2015-5019-F (Sando et al., 2015a) indicate the Clark Fork River flows through the west region. All the mainstem Clark Fork River flow nodes are classified as unaffected by major regulation. The SIR 2015-5019-F report indicates that using the regional regression equations on regulated streams might not be reliable and is not recommended. Additionally, the SIR 2015-5019-F report states that regression equations are possibly not reliable for an ungaged site that is outside the range of values used to develop the equations. The ungaged Clark Fork River flow node drainage areas are not within the range of values used to develop the west region regressions equations. Therefore, the regional regression equations were determined to be not applicable to the ungaged sites on the mainstem Clark Fork River.

Numerous USGS gaging stations are located on the mainstem Clark Fork River and all the ungaged Clark Fork River flow nodes are located between two gaging stations. The USGS gaging stations downstream of the study reach are affected by major regulation, and those gages were not used to estimate flows at ungaged flow nodes. The USGS gages 12354500 and 12353300 (Clark Fork at Tarkio and Alberton, respectively) each have only 6 years of records and did not record peak flows; consequently these gages were not used to estimate flows at the ungaged flow nodes. The two site logarithmic interpolation method was used to estimate peak flows at ungaged flow nodes on the Clark Fork River between the St. Regis and Missoula gages.

There are two ungaged flow nodes on the Clark Fork River that are located downstream of the St. Regis gage site. The two site logarithmic interpolation method is not applicable to these two flow nodes. These ungaged flow node drainage areas meet the SIR 2015-5019-F guidance criteria for the Drainage Area Gage Transfer method (i.e., are within the ratio of 1.5 to 0.5 of the gage drainage area) (Sando et al., 2015a). Therefore, the Drainage Area Gage Transfer method was used to calculate peak flow frequency estimates at these ungaged flow nodes on the Clark Fork River Study reach.

3.3.1 Two Site Logarithmic Interpolation Method

Pioneer used the log interpolation method presented in SIR 2015-5019-F (Sando et al., 2015a) for analysis on ungaged sites between two gaged sites. In this method, the logarithm of the flood-frequency discharge estimates at the ungaged site is linearly interpolated based on discharge estimates and drainage basin areas of the upstream and downstream gaged sites. This method is presented in the equation below from SIR 2015-5019-F:

$$\log Q_{AEP,U} = \log \mathrm{Q}_{AEP,G1} + \frac{\log \mathrm{Q}_{AEP,G2} - \log \mathrm{Q}_{AEP,G1}}{\log \mathrm{DA}_{G2} - \log \mathrm{DA}_{G1}} (\log \mathrm{DA}_U - \log \mathrm{DA}_{G1})$$

where

log	is the base 10 logarithm
$Q_{AEP,U}$	is the AEP-percent peak flow at the ungaged site, in cfs
$Q_{AEP,G1}$	is the AEP-percent peak flow at the upstream gaged site, in cfs
$Q_{AEP,G2}$	is the AEP-percent peak flow at the downstream gaged site, in cfs
DA_{G2}	is the drainage area at the downstream gaged site, in square miles
DA_{G1}	is the drainage area at the upstream gaged site, in square miles
DA_U	is the drainage area at the ungaged site, in square miles

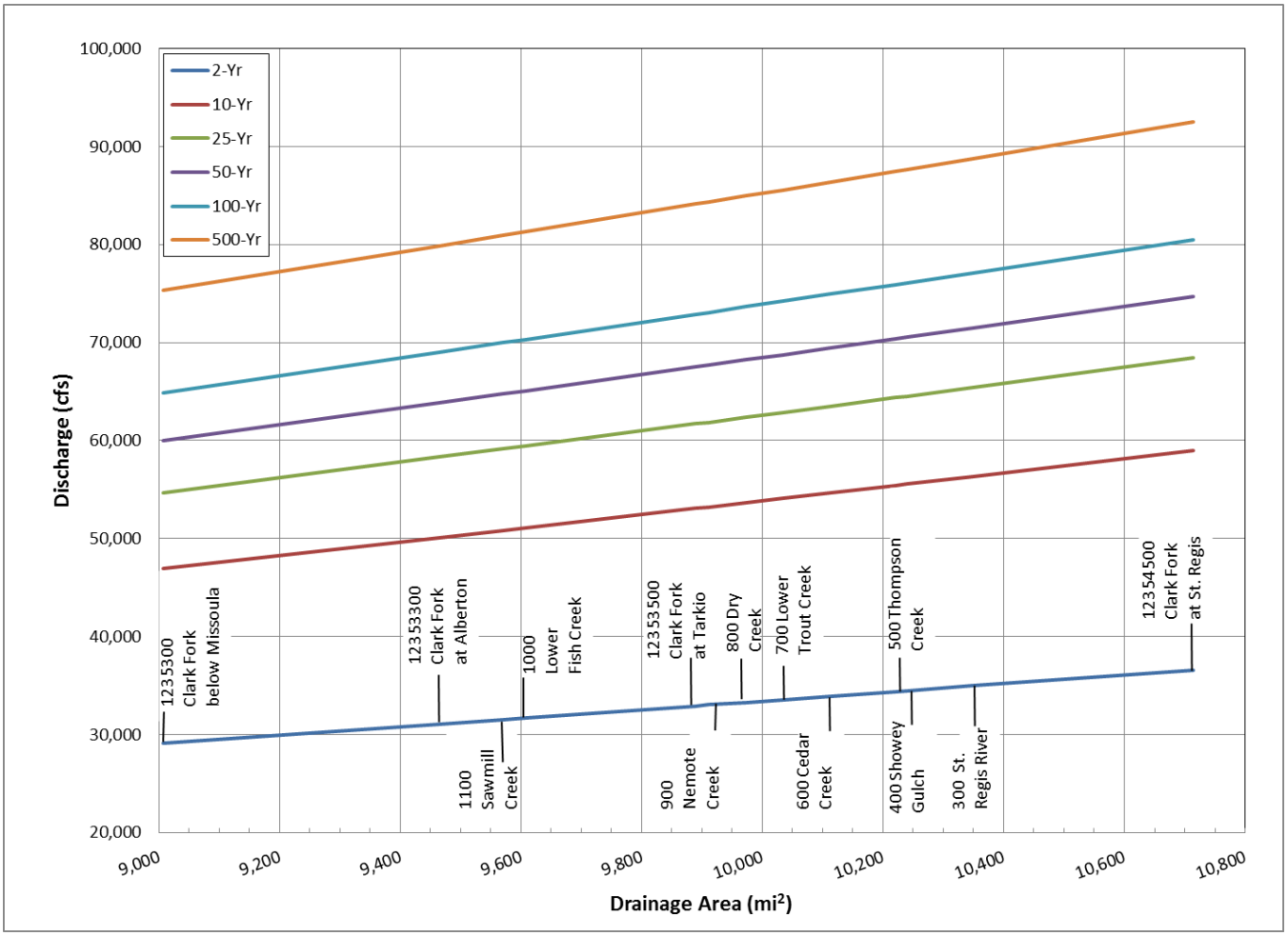
Table 11 shows the Clark Fork River calculation results. Figure 10 plots the relationship between the calculated discharge estimates and correlating drainage area. Results indicate estimated flows at the ungaged flow nodes increase with increasing drainage area.

Table 11 Log Interpolation of 2016 Extended Period of Record Gage Results to Ungaged Flow Nodes

Node/USGS Station ID	Location Description	Log Interpolation of Gaged Analysis						
		Discharge (cfs)						
		50% Annual Chance	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance	1% +
		2-year	10-year	25-year	50-year	100-year	500-year	
12353000	**Clark Fork below Missoula, MT**	**29,100**	**46,900**	**54,700**	**60,000**	**64,900**	**75,300**	**73,600**
12353300	Clark Fork at Alberton, MT	31,064	50,068	58,295	63,863	69,006	79,843	78,136
1100	Sawmill Creek	31,523	50,809	59,135	64,766	69,964	80,902	79,194
1000	Lower Fish Creek	31,687	51,073	59,434	65,087	70,305	81,278	79,570
12354500	Clark Fork at Tarkio, MT	32,922	53,067	61,692	67,511	72,878	84,117	82,408
900	Nemote Creek	33,019	53,222	61,869	67,700	73,079	84,338	82,629
800	Dry Creek	33,290	53,660	62,363	68,231	73,642	84,959	83,250
700	Lower Trout Creek	33,558	54,093	62,854	68,756	74,200	85,573	83,864
600	Cedar Creek	33,913	54,665	63,501	69,451	74,936	86,385	84,676
500	Thompson Creek	34,385	55,427	64,363	70,375	75,916	87,463	85,755
400	Showey Gulch	34,475	55,572	64,527	70,551	76,102	87,668	85,961
300	St. Regis River	34,962	56,357	65,415	71,502	77,111	88,778	87,071
12354500	**Clark Fork at St. Regis MT**	**36,600**	**59,000**	**68,400**	**74,700**	**80,500**	**92,500**	**90,800**

* Sites on below St. Regis were not included in the log linear interpolation method calculations.
cfs: cubic feet per second.

Figure 10 Clark Fork River Log Interpolation Gage Analysis Results



3.3.2 Drainage Area Gage Transfer Method

Ungaged flow nodes located downstream of the Clark Fork River gaging station at St. Regis (12354500) do lie between two gaged stations on the same stream, however the USGS gaging stations downstream of the study reach are affected by major regulation, and those gages were not used to estimate flows at ungaged flow nodes. Therefore, the two site interpolation method cannot be employed. Estimating flood-frequency discharges for the ungaged flow nodes downstream of USGS gaging station 12354500 requires using the Drainage Area Gage Transfer method. This method, presented in SIR 2015-5019-F, uses a drainage area ratio of the ungaged flow node to the gaged station to transfer flow estimates from the gaged site to the ungaged site as shown below in the following equation (Sando et al., 2015a):

$$Q_{AEP,U} = Q_{AEP,G}\left(\frac{\mathrm{DA}_U}{\mathrm{DA}_G}\right)^{\exp_T}$$

where

$Q_{AEP,U}$ is the AEP-percent peak flow at the ungaged site, in cfs

$Q_{AEP,G}$ is the AEP-percent peak flow at the gaged site, in cfs

DA_G is the drainage area at the gaged site, in square miles

DA_U is the drainage area at the ungaged site, in square miles

$\exp_T$ is the regression coefficient for a simple ordinary least squares (OLS) regression relating to the log of the AEP-percent peak flow to log of drainage area within each region

Limitations for this method include a recommended drainage area ratio between 0.5 and 1.5. These two flow node drainage area ratios were verified to be within the recommended range.

Regression coefficients shown in the equation above vary based on the hydrologic region and the AEP. The applicable regression coefficients provided in Table 12 were used in these calculations. The drainage area transfer method results are shown in Table 13, and Figure 11. Figure 11 shows that a relatively small increase in drainage area produces a relatively small increase in discharge, while a greater increase in drainage area produces a greater increase in discharge.

Table 12 Drainage Area Gage Transfer Regression Coefficients

AE-percent Peak Flow	Regression Coefficient Relating AEP Flows to Drainage Area for Southwest Region
Q_{50}	0.843
Q_{10}	0.794
Q_4	0.777
Q_2	0.766
Q_1	0.755
$Q_{0.2}$	0.735

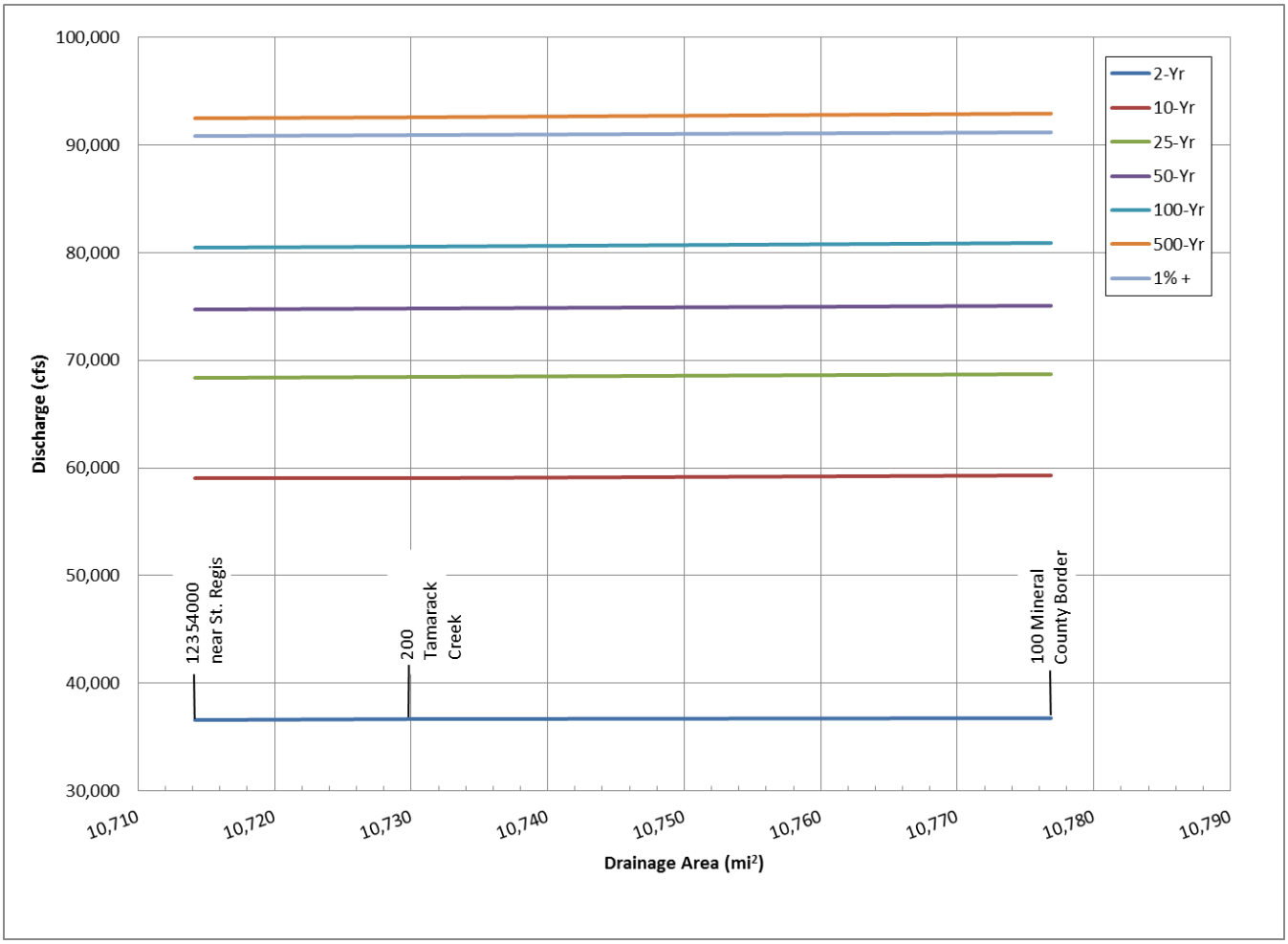
Source: SIR 2015-5019-F (Sando et al., 2015a).

Table 13 Drainage Area Gage Transfer Method Results for Clark Fork River Flow Node Locations Downstream of USGS Gage 12354500

Node/USGS Station ID	Location Description	Drainage Area Gage Transfer						
		Discharge (cfs)						
		50% Annual Chance	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance	1% +
		2-year	10-year	25-year	50-year	100-year	500-year	
12354500	**Clark Fork at St. Regis, MT**	**36,600**	**59,000**	**68,400**	**74,700**	**80,500**	**92,500**	**90,800**
200	Tamarack Creek	36,645	59,068	68,477	74,783	80,588	92,598	90,899
100	Mineral County Boundary	36,780	59,274	68,711	75,034	80,855	92,897	91,201

cfs: cubic feet per second.

Figure 11 Clark Fork River Drainage Area Gage Transfer Results



Appendix B provides the all flood frequency calculations at the ungaged flow nodes for both the Clark Fork River Study reach. Appendix C provides the digital calculation files.

4 SUMMARY/DISCUSSION

Pioneer conducted a peak discharge frequency analysis for the mainstem Clark Fork River study reach. The Clark Fork River Study reach extends 55 miles upstream from the Mineral/Sanders County Boundary. Information gathered from this analysis will be used to support the Clark Fork County hydraulic analyses and floodplain mapping studies.

Previous flood studies on the Clark Fork River are limited. The most relevant earlier flood study was the SIR 2015-5019-C (Sando et al., 2015b). The USGS WRIR 03-4308, published in 2004 (Parrett and Johnson, 2004) was also an important study that included flood frequency analysis for multiple Clark Fork River gaging stations. The results of these previous studies were compared with the results of this study.

This hydrologic analysis included conducting Flood frequency estimates for both gaged and ungaged sites. Peak flow estimates were calculated at 15 mainstem locations (flow nodes) within the watershed (6 gaged sites and 4 ungaged sites).

At the gaged sites, flood frequency estimates were conducted using two different gage record data sets: a systematic data set through 2016 and an extended record data set for 1899–1908, 1911–23, and 1929–2016. The flood flow frequency estimates were calculated using Bulletin #17C methodologies (USGS, 2016).

The Clark Fork River systematic record data set had variable and discontinuous periods of recorded information between the stream gages and produced results where flood discharge increased with increasing drainage area. To address these non-congruent periods of record, data extension methods were used to extend the historical gage records and create an extended record data set.

Flood flow frequency results from this study were compared with flood flow frequency estimates from the previous studies. In the Clark Fork River watershed, the flood flow frequency estimates from this study produced peak discharge estimates that are 5 to 8 percent higher than the systematic record estimates.

The flood flow frequency estimates based on the gage extended record data set were determined to provide the most accurate peak flow estimates for the Clark Fork River basin, due to the long congruent period of record, which minimized errors associated with non-congruent periods of gage records. Flood flow frequency estimates were also developed at 11 ungaged locations. The ungaged sites (flow nodes) were located at major tributaries, population centers, and at end of study reaches. Peak flow 1%+ (plus) estimates were developed for all gaged locations using standard FEMA methodologies.

Three methods were considered for estimating peak flood discharges at ungaged flow nodes: 1) Regional Regression; 2) Two Station Logarithmic Interpolation method; and 3) the Drainage Area gage transfer method.

The Regional Regression method for ungaged flow nodes was not selected for the Clark Fork River Study reach due to the size of the drainage areas of the flow nodes, which were not within the range of values recommended for the Western Region. The Two Station Logarithmic Interpolation method was used on 9 ungaged flow nodes on the Clark Fork River. The Drainage Area Gage Transfer method was used on the 2 flow nodes located downstream of USGS gaging station 12354500 Clark Fork at St. Regis. This method was required for the downstream flow nodes because only a single, unregulated gage record was available for those flow nodes.

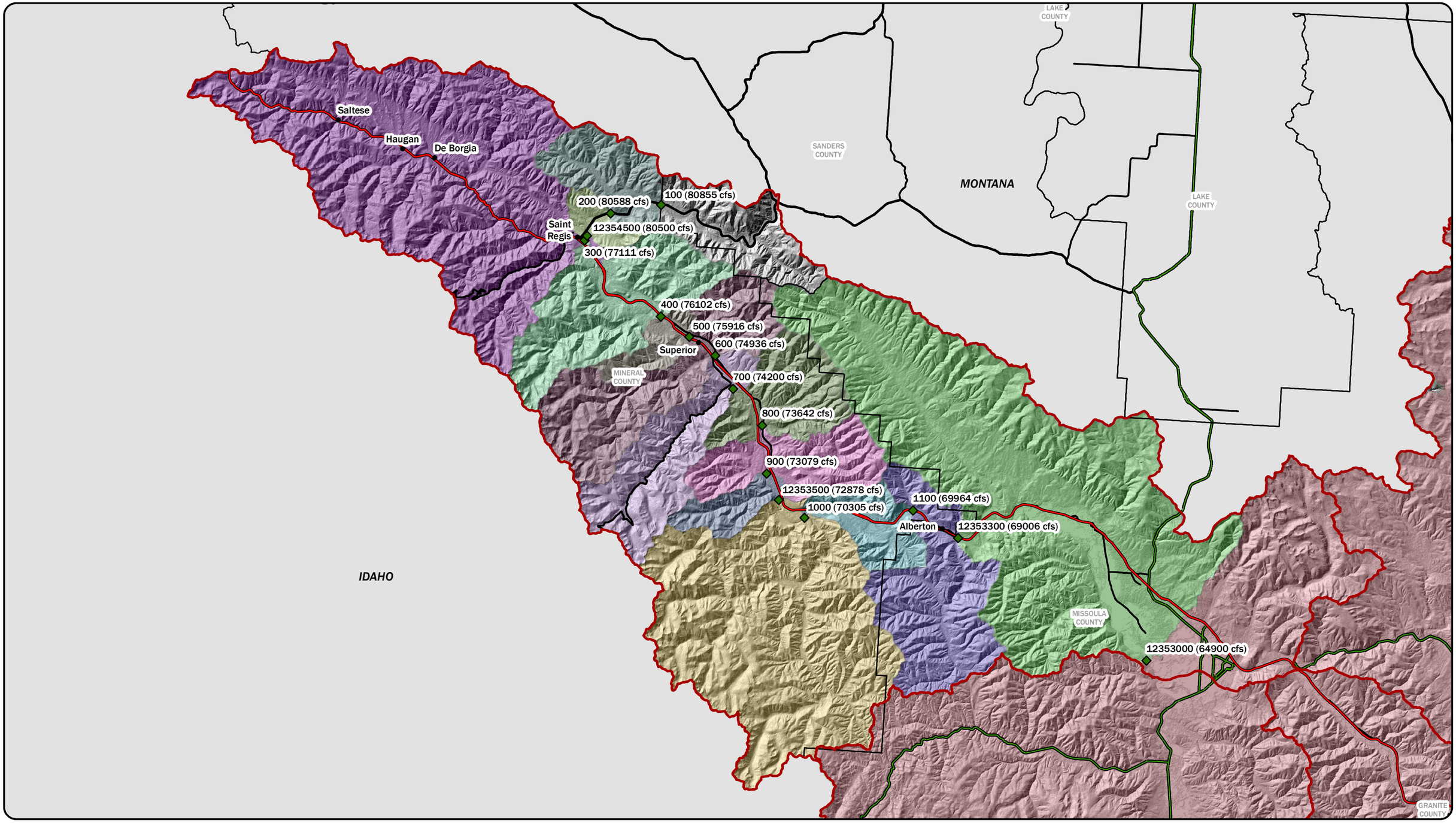
Table 14 summarizes the recommended flood frequency discharge rates for the Clark Fork River Study reach. Figure 12 shows the recommended 1% annual discharge for each flow node location. The hydrologic analysis results provided in Table 14 represent the recommended discharges at each flow node location throughout the study reach. The methods used for hydrological analysis are industry accepted methods (Bulletin #17C [USGS, 2016] and SIR 2015-5019-F [Sando et al., 2015a]) based on the Clark Fork River basin characteristics. This hydrologic analysis conforms to FEMA standards for detailed/enhanced level studies, and the recommended flows of this analysis are deemed reliable and suitable for future floodplain studies and hydraulic analyses.

Table 14 Flood Discharge Estimates from the Log Interpolation Method and Drainage Area Transfer Method

Node/USGS Station ID	Location Description	Peak Discharge (cfs)						
		50% Annual Chance	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance	1% +
		2-year	10-year	25-year	50-year	100-year	500-year	
12353300	**Clark Fork at Alberton, MT**	**31,064**	**50,068**	**58,295**	**63,863**	**69,006**	**79,843**	**78,136**
1100	Sawmill Creek	31,523	50,809	59,135	64,766	69,964	80,902	79,194
1000	Lower Fish Creek	31,687	51,073	59,434	65,087	70,305	81,278	79,570
12353500	**Clark Fork at Tarkio, MT**	**32,922**	**53,067**	**61,692**	**67,511**	**72,878**	**84,117**	**82,408**
900	Nemote Creek	33,019	53,222	61,869	67,700	73,079	84,338	82,629
800	Dry Creek	33,290	53,660	62,363	68,231	73,642	84,959	83,250
700	Lower Trout Creek	33,558	54,093	62,854	68,756	74,200	85,573	83,864
600	Cedar Creek	33,913	54,665	63,501	69,451	74,936	86,385	84,676
500[1]	Thompson Creek	34,385	55,427	64,363	70,375	75,916	87,463	85,755
400	Showey Gulch	34,475	55,572	64,527	70,551	76,102	87,668	85,961
300	St. Regis River	34,962	56,357	65,415	71,502	77,111	88,778	87,071
12354500	**Clark Fork at St. Regis, MT**	**36,600**	**59,000**	**68,400**	**74,700**	**80,500**	**92,500**	**90,800**
200	Tamarack Creek	36,645	59,068	68,477	74,783	80,588	92,598	90,899
100	Mineral County Boundary	36,780	59,274	68,711	75,034	80,855	92,897	91,201

1. **Denotes an additional flow node change downstream of a town or intermediate tributary not associated with HUC-12 boundary**

cfs: cubic feet per second.



LEGEND

- FLOW NODE (PEAK FLOW)
- HUC 8 BOUNDARIES
- TOWNS
- MONTANA COUNTY BOUNDARIES
- NHS INTERSTATE
- NHS NON-INTERSTATE
- PRIMARY
- SECONDARY

FLOW CHANGE NODE: 12353000, 12353300, 1100, 1000, 12353500, 900, 800, 700, 600, 500, 400, 300, 12354500, 200, 100

N

DISPLAYED AS:
PROJECTION/ZONE: MONTANA STATE PLANE
DATUM: NAD 1983
UNITS: INT'L FEET
SOURCE: PIONEER, MSL, USGS

0 3.5 7 14
Miles

FIGURE 12

RECOMMENDED 1-PERCENT ANNUAL DISCHARGE FOR EACH LOCATION

PIONEER TECHNICAL SERVICES, INC.

DATE: 5/2/2017

Path: G:\DNRC\Mineral -Beaverhead County\Mineral County\CAD-GIS\GIS\CLKFK-GI-HYD-004-17.mxd

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Appendix A: USGS Flood Frequency Analysis

United States Department of the Interior

U.S. GEOLOGICAL SURVEY
Wyoming-Montana Water Science Center

Helena Office
3162 Bozeman Avenue
Helena, Montana 59601

Cheyenne Office
521 Progress Circle, Suite 6
Cheyenne, WY 82007

February 16, 2017

Mr. Steve Story
Montana Department of Natural Resources
And Conservation
P.O. Box 201601
Helena, Montana 59620-1601

Dear Mr. Story:

The U. S. Geological Survey (USGS) recently prepared a draft Scientific Investigations Report ([1]Sando and others, 2017) documenting USGS' current (February 2017) peak-flow frequency analysis methods that are used in frequency analyses for a large Montana-wide streamgage network (of 725 streamgages). Reporting frequency analyses for a large statewide streamgage network poses several challenges. The frequency analyses reported by the USGS are used for many different applications, including bridge and culvert design, flood-plain mapping, dam and spillway design, analysis, and assessment, and instream-flow water rights requests. Design criteria and risk tolerance can substantially differ among these various frequency applications. Further, uncertainties related to effects of regulation and frequency-adjustment methods are important to consider when using frequency analyses for various purposes. Within this context, in many cases the USGS impartially reports multiple frequency analyses for a given streamgage to allow frequency-analysis users to make informed decisions relevant to their needs.

In cooperation with Montana Department of Natural Resources and Conservation (MT DNRC), the USGS recently computed frequency analyses for 14 streamgages in the Beaverhead River and Clark Fork Basins for publication in a data release; which currently is in draft form ([2]McCarthy and others, 2017). The frequency analyses were based on the methods described by [1]Sando and others (2017). For most of the 14 streamgages, there are multiple frequency analyses reported in the data release.

USGS and MT DNRC have had extensive discussions concerning the intended application of the frequency analyses in flood-plain mapping projects in relation to the selection of the most appropriate reported frequency analyses for the application. Based on the stated purpose of using the flood frequency analyses for flood plain mapping and the period of record and basin characteristics for each station, the type of flood frequency estimate listed for each station in Table 1 will yield the most appropriate peak-flow frequency estimate of the types of peak-flow estimates described in [1]Sando and others (2017). The following discussion explains briefly why each type of peak-flow estimate is most appropriate for each station.

[1]Sando, S.K., McCarthy, P.M., Chase, K.J., and Dutton, D.M., 2017, Methods for Peak-Flow Frequency Analysis and Reporting by the U.S. Geological Survey Wyoming-Montana Water Science Center Based on Data through Water Year 2015: U.S. Geological Survey Scientific Investigations Report 2017–XXXX, xx p.

[2]McCarthy, P.M., Sando, S.K., and Chase, K.J., 2017, Results of peak-flow frequency analysis for streamgages in the Beaverhead River and Clark Fork Basins, based on data through water year 2016: U.S. Geological Survey Data Release, XXXXXXXXXXXXXX.

Table 1. Most appropriate frequency analyses selected by MT DNRC based on discussions with USGS.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. PILF, potentially influential low flow; U, unregulated; --, not applicable; R, regulated; BP, base period used in the Maintenance of Variance Type III record extension]

Streamgage identification number and analysis designation[1]	Streamgage name	Contributing drainage area, in square miles	Regulation status for analysis period[2]	Type of peak-flow frequency estimate[3]	Number of years of peak-flow records in analysis period	Analysis period of record, in water years
Most appropriate frequency analyses for Beaverhead River streamgages						
06015400.11	Beaverhead River near Grant, Montana	2,316	R (MAJ–dam)	MOVE.3	52	BP 1965–2016
06016000.10	Beaverhead River at Barretts, Montana	2,730	R (MAJ–dam)	At-site	52	1965–2016
06017000.11	Beaverhead River at Dillon, Montana	2,892	R (MAJ–dam)	MOVE.3	52	BP 1965–2016
06017500.03	Blacktail Deer Creek near Dillon, Montana	316	U	RRE wtd	--	--
06018000.11	Beaverhead River near Dillon, Montana	3,419	R (MAJ–dam)	MOVE.3	52	BP 1965–2016
06018500.10	Beaverhead River near Twin Bridges, Montana	3,618	R (MAJ–dam)	At-site	52	1965–2016
Most appropriate frequency analyses for Clark Fork streamgages						
12331800.01	Clark Fork near Drummond, Montana	2,516	U	MOVE.3	111	BP 1899–1908; 1911–23; 1929–2016
12334550.01	Clark Fork at Turah Bridge, near Bonner, Montana	3,657	U	MOVE.3	111	BP 1899–1908; 1911–23; 1929–2016
12340500.01	Clark Fork above Missoula, Montana	6,021	U	MOVE.3	111	BP 1899–1908; 1911–23; 1929–2016
12353000.01	Clark Fork below Missoula, Montana	9,017	U	MOVE.3	111	BP 1899–1908; 1911–23; 1929–2016
12354000.00	St. Regis River near St. Regis, Montana	304	U	At-site	42	1911–17; 1934; 1948; 1954; 1959–75; 2002–16
12354500.01	Clark Fork at St. Regis, Montana	10,728	U	MOVE.3	111	BP 1899–1908; 1911–23; 1929–2016
12389000.10	Clark Fork near Plains, Montana	19,964	R (MAJ–dam)	At-site	79	1938–2016
12391400.11	Clark Fork below Noxon Rapids Dam, near Noxon, Montana	21,709	R (MAJ–dam)	MOVE.3	79	BP 1938–2016

[1]The streamgage identification number and analysis designation is defined by XXXXXXXX.AB,
where,
XXXXXXXX is the streamgage identification number; A is the regulation status for the analysis period; and B is the type of peak-flow frequency analysis.
Values of A (regulation status) are defined as: A = 0, unregulated; and A = 1, regulated by major regulation.
Values of B (type of peak-flow frequency analysis) are defined as:
B = 0, at-site peak-flow frequency analysis conducted on recorded data;
B = 1, peak-flow frequency analysis conducted on combined recorded and synthesized data; synthesized data from maintenance of variance type III (MOVE.3) record extension procedure;
B = 3, at-site peak-flow frequency analysis weighted with results from RREs.

[2]Abbreviations for regulation status are defined as follows:
U, unregulated, where the cumulative drainage area upstream from all dams is less than 20 percent of the drainage area of the streamgage.
R (MAJ–dam): major dam regulation, where a single upstream dam has a drainage area that exceeds 20 percent of the drainage area of the streamgage.

[3]Abbreviations for type of frequency analysis are defined as follows:
At-site: peak-flow frequency analysis on recorded data.
RRE wtd: the at-site peak-flow frequency analysis was weighted with results from regional regression equations (RREs).
MOVE.3: peak-flow frequency analysis on combined recorded and synthesized data; synthesized data from maintenance of variance type III (MOVE.3) record extension procedure.

Discussion of Beaverhead River Basin streamgages

For the five main-stem Beaverhead River streamgages, the most appropriate frequency analyses are based on the regulated period of 1965–2016, which primarily is defined by the closure of Clark Canyon Dam in August 1964. Clark Canyon Reservoir has more than 300,000 acre-feet of storage capacity including dedicated flood-control storage; the location of Clark Canyon Dam accounts for between 65 to 100 percent of the drainage areas of the six Beaverhead River streamgages, substantially affecting the peak-flow records of these streamgages.

During the 1965–2016 regulated period, the five main-stem Beaverhead River streamgages have variable periods of record, ranging from 19 to 52 years of data collection. Differences in the timing of the periods of record can result in substantial inconsistencies in frequency estimates for hydrologically similar streamgages. The USGS uses Maintenance of Variance Type III (MOVE.3) record extension in cases of multiple streamgages on the same large river with variable periods of record but high cross correlation. For each streamgage, the MOVE.3 record extension procedure synthesizes estimated peak flows for years of missing record; this allows synchronization of the variable periods of record to a common long-term base period. Frequency analysis of the combined recorded and synthesized datasets provides synchronized frequency estimates that might be useful for several frequency applications, including floodplain mapping. The USGS considers MOVE.3 record extension as the preferred alternative for adjusting at-site frequency estimates for streamgages that qualify for application of the MOVE.3 procedure. Two of the main-stem Beaverhead River streamgages (06016000 and 06018500; table 1) have complete periods of record within the 1965-2016 regulated period; for these streamgages, the at-site frequency analyses are most appropriate. Three of the main-stem Beaverhead River

streamgages (06015400, 06017000, and 06018000; table 1) have years of missing record within the 1965–2016 regulated period; for these streamgages, the frequency analyses on the combined recorded and MOVE.3 synthesized datasets are most appropriate.

Blacktail Deer Creek near Dillon, Montana (streamgage 06017500; table 1) is on a tributary to the Beaverhead River and has a somewhat short period of record (21 years). The peak-flow dataset for streamgage 06017500 does not qualify for application of the MOVE.3 procedure. Uncertainties in the frequency analysis for streamgage 06017500 can be reduced by weighting the at-site frequency analysis with frequency results obtained from regional regression equations (RREs). For streamgage 06017500, the RRE-weighted frequency analysis is most appropriate.

Discussion of Clark Fork Basin streamgages

The seven streamgages on the main-stem Clark Fork are variable with respect to regulation effects. The five upstream streamgages (12331800, 12334550, 12340500, 12353000, and 12354500; table 1) are considered unregulated, with less than 20 percent of their basins affected by major dam regulation. The two downstream streamgages (12389000 and 12391400; table 1) are affected by major dam regulation.

The five unregulated main-stem Clark Fork streamgages (12331800, 12334550, 12340500, 12353000, and 12354500; table 1) have variable periods of record, ranging from 31 to 101 years of data collection. For each streamgage, MOVE.3 record extension was used to synthesize estimated peak flows for years of missing record to provide synchronization of the variable periods of record to a common 111-year base period. For the five unregulated main-stem Clark Fork streamgages (12331800, 12334550, 12340500, 12353000, and 12354500; table 1), frequency analyses on the combined recorded and MOVE.3 synthesized datasets are most appropriate.

Clark Fork near Plains, Montana (streamgage 12389000; table 1) and Clark Fork below Noxon Rapids Dam, near Noxon, Montana (streamgage 12391400; table 1) are downstream from the confluence of the Clark Fork and the Flathead River. Hungry Horse and Salish-Kootenai Dams in the upper Flathead River Basin are major regulation structures with more than 3 million acre-feet of storage capacity including dedicated flood-control storage. Locations of major dams account for between 40 to 43 percent of the drainage areas of streamgages 12389000 and 12391400, substantially affecting the peak-flow records of the two downstream Clark Fork streamgages (12389000 and 12391400). The regulated period for the two downstream streamgages is 1938–2016, which primarily is defined by the completion of Salish-Kootenai Dam in 1938.

During the 1938–2016 regulated period, the two downstream Clark Fork streamgages have variable periods of record, ranging from 54 to 79 years of data collection. Streamgage 12389000 has a complete period of record within the 1938–2016 regulated period; for this streamgage, the at-site frequency analysis is most appropriate. For streamgage 12391400 MOVE.3 record extension was used to synthesize estimated peak flows for years of missing record to provide synchronization with the 1938–2016 regulated period; for this streamgage, the frequency analysis on the combined recorded and MOVE.3 synthesized datasets is most appropriate.

St. Regis River near St. Regis, Montana (streamgage 12354000; table 1) is on a tributary to the Clark Fork and has 42 peak flow records between 1922 and 2016. The peak-flow dataset for streamgage 12354000 does not qualify for the application of the MOVE.3 procedure. The peak-flow dataset for streamgage 12354000 is a mixed population dataset and therefore a station skew was used in the analysis. Streamgage 12354000 is in the West hydrologic region of Montana, which has limited representation of mixed-population streamgages, and the independent estimates from the regional regression equations do not well represent sites with mixed-populations of peak-flows. Therefore, the most appropriate peak-flow frequency analysis for streamgage 12354000 is the at-site analysis.

Summary

Based on the information/data and statistical approaches described in [1]Sando and others (2017), the USGS considers the peak-flow analyses listed in Table 1 to be most appropriate for flood-plain mapping for these 14 streamgages. Other types of analyses might be more appropriate for other applications and methods developed in the future might be more appropriate for flood-plain mapping.

We hope you find this discussion of our study results useful and appreciate you choosing USGS as a provider of unbiased scientific information to use in your floodplain management activities.

Sincerely,

John M. Kilpatrick
Center Director

1

Table. Selected frequency analyses and estimated upper 84-percent confidence levels for the 1-percent annual exceedance probability peak flows.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. U, unregulated; R, regulated; <, less than; NR, not reported; --, not applicable; BP, base period used in the Maintenance of Variance Type III record extension]

Map number (fig. 1)	Streamgage identification number and analysis designation[1]	Streamgage name	Contributing drainage area, in square miles	Regulation status for analysis period[2]	Type of peak-flow frequency estimate[3]	Number of years of peak-flow records in analysis period	Analysis period of record, in water years	Annual peak flow, in cubic feet per second, for indicated annual exceedance probability (AEP), in percent										Upper 84-percent confidence level for the 1-percent AEP peak-flow	Method for determining the upper 84-percent confidence level
								66.7	50	42.9	20	10	4	2	1	0.5	0.2		
646	12331800.01	Clark Fork near Drummond, Montana	2,516	U	MOVE.3	111	BP 1899–1908; 1911–23; 1929–2016	2,510	3,250	3,630	5,550	7,440	10,300	12,700	15,500	18,600	23,300	26,600	PeakFQv7.1 value adjusted for MOVE.3 analysis as described by Sando and others (2017; draft)[1]
650	12334550.01	Clark Fork at Turah Bridge, near Bonner, Montana	3,657	U	MOVE.3	111	BP 1899–1908; 1911–23; 1929–2016	4,550	5,880	6,520	9,510	12,100	15,600	18,300	21,000	23,800	27,700	29,000	PeakFQv7.1 value adjusted for MOVE.3 analysis as described by Sando and others (2017; draft)[1]
665	12340500.01	Clark Fork above Missoula, Montana	6,021	U	MOVE.3	111	BP 1899–1908; 1911–23; 1929–2016	12,000	14,900	16,200	21,800	26,300	31,800	35,700	39,500	43,100	47,900	46,100	PeakFQv7.1 value adjusted for MOVE.3 analysis as described by Sando and others (2017; draft)[1]
688	12353000.01	Clark Fork below Missoula, Montana	9,017	U	MOVE.3	111	BP 1899–1908; 1911–23; 1929–2016	24,200	29,100	31,300	40,200	46,900	54,700	60,000	64,900	69,500	75,300	73,600	PeakFQv7.1 value adjusted for MOVE.3 analysis as described by Sando and others (2017; draft)[1]
697	12354500.01	Clark Fork at St. Regis, Montana	10,728	U	MOVE.3	111	BP 1899–1908; 1911–23; 1929–2016	30,300	36,600	39,300	50,700	59,000	68,400	74,700	80,500	85,900	92,500	90,800	PeakFQv7.1 value adjusted for MOVE.3 analysis as described by Sando and others (2017; draft)[1]
746	12389000.10	Clark Fork near Plains, Montana	19,964	R (MAJ–dam)	At-site	79	1938–2016	64,100	73,600	77,700	94,000	106,000	118,000	127,000	134,000	141,000	150,000	150,000	PeakFQv7.1 value
752	12391400.11	Clark Fork below Noxon Rapids Dam, near Noxon, Montana	21,709	R (MAJ–dam)	MOVE.3	79	BP 1938–2016	66,300	76,500	80,800	98,000	110,000	123,000	132,000	139,000	146,000	154,000	155,000	PeakFQv7.1 value adjusted for MOVE.3 analysis as described by Sando and others (2017; draft)[1]

[1]Sando, S.K., McCarthy, P.M., Chase, K.J., and Dutton, D.M., 2017, Methods for Peak-Flow Frequency Analysis and Reporting by the U.S. Geological Survey Wyoming-Montana Water Science Center Based on Data through Water Year 2015: U.S. Geological Survey Scientific Investigations Report 2017–XXXX, xx p.

Appendix B: Logarithmic Interpolation and Drainage Area Transfer Calculations

Node/USGS Station ID	Location Description	County	Study Reach River Station (miles)	Incremental Basin Area (mi^2)	Cumulative Basin Area (mi^2)	Log Interpolation of Gaged Analysis Estimated Discharge (cfs) 50% Annual Chance 2-year	10% Annual Chance 10-year	4% Annual Chance 25-year	2% Annual Chance 50-year	1% Annual Chance 100-year	0.2% Annual Chance 500-year	1% + Annual Chance 100-year +
12353000	**Clark Fork below Missoula, Montana**	**Missoula**	**NA**	**456**	**9007**	**29,100**	**46,900**	**54,700**	**60,000**	**64,900**	**75,300**	**73,600**
12353300	Clark Fork at Alberton, MT	Missoula	NA	106	9463	31,064	50,068	58,295	63,863	69,006	79,843	78,136
1100	Sawmill Creek	Mineral	54	38	9569	31,523	50,809	59,135	64,766	69,964	80,902	79,194
1000	Lower Fish Creek	Mineral	43.8	282	9607	31,687	51,073	59,434	65,087	70,305	81,278	79,570
12353500	Clark Fork at Tarkio, MT	Mineral	40.3	22	9889	32,922	53,067	61,692	67,511	72,878	84,117	82,408
900	Nemote Creek	Mineral	37.8	62	9911	33,019	53,222	61,869	67,700	73,079	84,338	82,629
800	Dry Creek	Mineral	33.5	61	9972	33,290	53,660	62,363	68,231	73,642	84,959	83,250
700	Lower Trout Creek	Mineral	28.96	80	10033	33,558	54,093	62,854	68,756	74,200	85,573	83,864
600	Cedar Creek	Mineral	25.3	106	10113	33,913	54,665	63,501	69,451	74,936	86,385	84,676
500	Thompson Creek	Mineral	22.5	20	10220	34,385	55,427	64,363	70,375	75,916	87,463	85,755
400	Showey Gulch	Mineral	19.8	109	10240	34,475	55,572	64,527	70,551	76,102	87,668	85,961
300	St. Regis River	Mineral	9.4	365	10349	34,962	56,357	65,415	71,502	77,111	88,778	87,071
12354500	**Clark Fork at St. Regis MT**	**Mineral**	**9**	**16**	**10714**	**36,600**	**59,000**	**68,400**	**74,700**	**80,500**	**92,500**	**90,800**

For locations that are ungaged and located between two gaged locations with reliable period of record (10 yrs)
Equation utilizes drainage areas and flows.

$$\log Q_{AEP,U} = \log Q_{AEP,G1} + [(\log Q_{AEP,G2} - \log Q_{AEP,G1}) / (\log DA_{G2} - \log DA_{G1})](\log DA_U - \log DA_{G1})$$

where

$Q_{AEP,U}$ is the AEP-percent peak flow at ungaged site U, in cubic feet per second; (7)

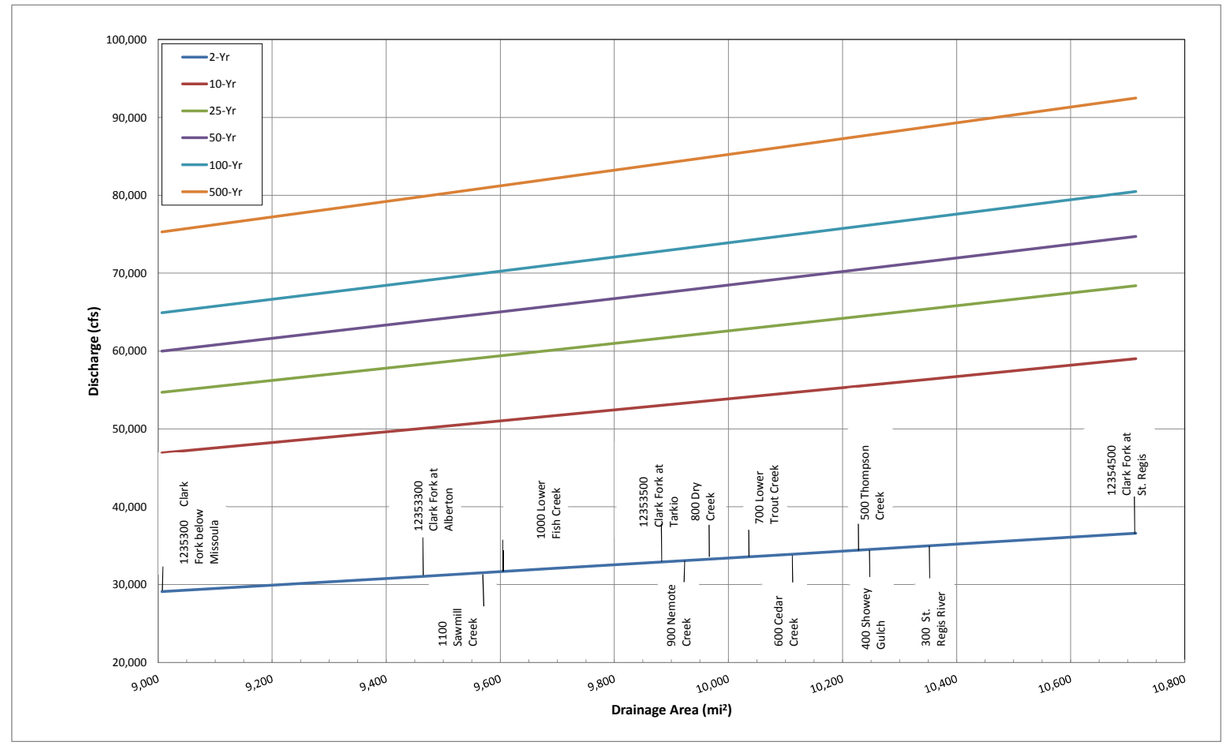
$Q_{AEP,G1}$ is the AEP-percent peak flow for the upstream gaging station $G1$, in cubic feet per second;

$Q_{AEP,G2}$ is the AEP-percent peak flow at the downstream gaging station $G2$, in cubic feet per second;

DA_{G2} is the drainage area at the downstream gaging station $G2$, in square miles;

DA_{G1} is the drainage area at the upstream gaging station $G1$, in square miles; and

DA_U is the drainage area at ungaged site U, in square miles.



Node/USGS Station ID	Location Description	County	Study Reach River Station (miles)	Individual Basin Area (mi^2)	Cumulative Basin Area (mi^2)	DA_U/DA_G	Drainage Area Gage Transfer Estimated Discharge (cfs) — Estimated Discharge (cfs)						
							50% Annual Chance	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance	1% + Annual Chance
							2-year	10-year	25-year	50-year	100-year	500-year	100-year +
12354500	**Clark Fork at St. Regis, Montana**	**Mineral**	**9.0**	**16**	**10714**	**-**	**36,600**	**59,000**	**68,400**	**74,700**	**80,500**	**92,500**	**90,800**
200	Tamarack Creek	Mineral	4.6	47	10730	1.0	36,645	59,068	68,477	74,783	80,588	92,598	90,899
100	Mineral County Boundary	Mineral	0	0	10777	1.0	36,780	59,274	68,711	75,034	80,855	92,897	91,201

*** Recommended ratio be within 0.5 to 1.5

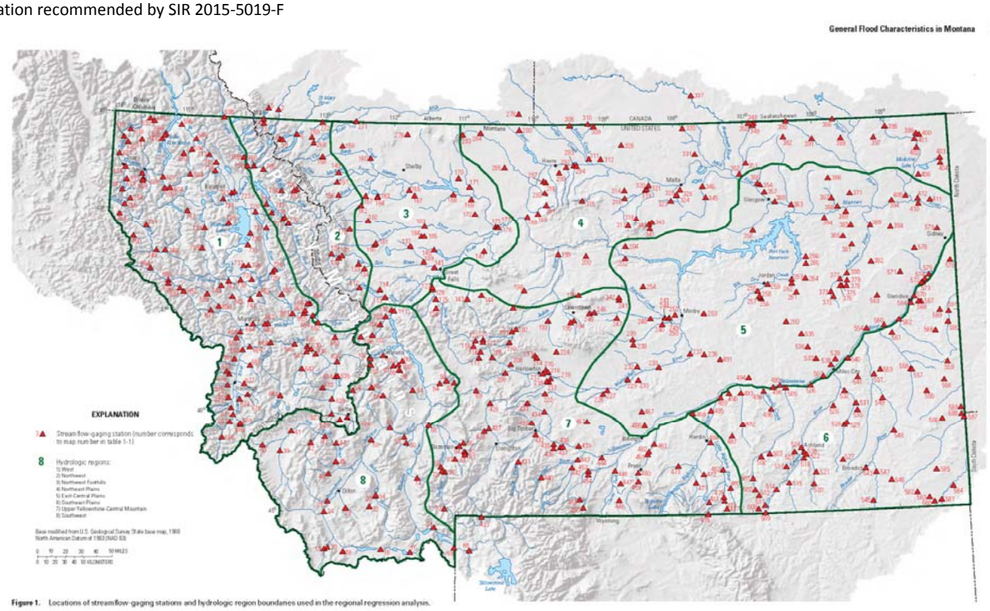
For an ungaged site that is not located between two gaged locations

*West Region for regression coefficient

Recommended that the drainage ratio be within 0.5 to 1.5

Regression Coefficient expAEP =	0.843	0.794	0.777	0.766	0.755	0.735	0.755

Equation recommended by SIR 2015-5019-F



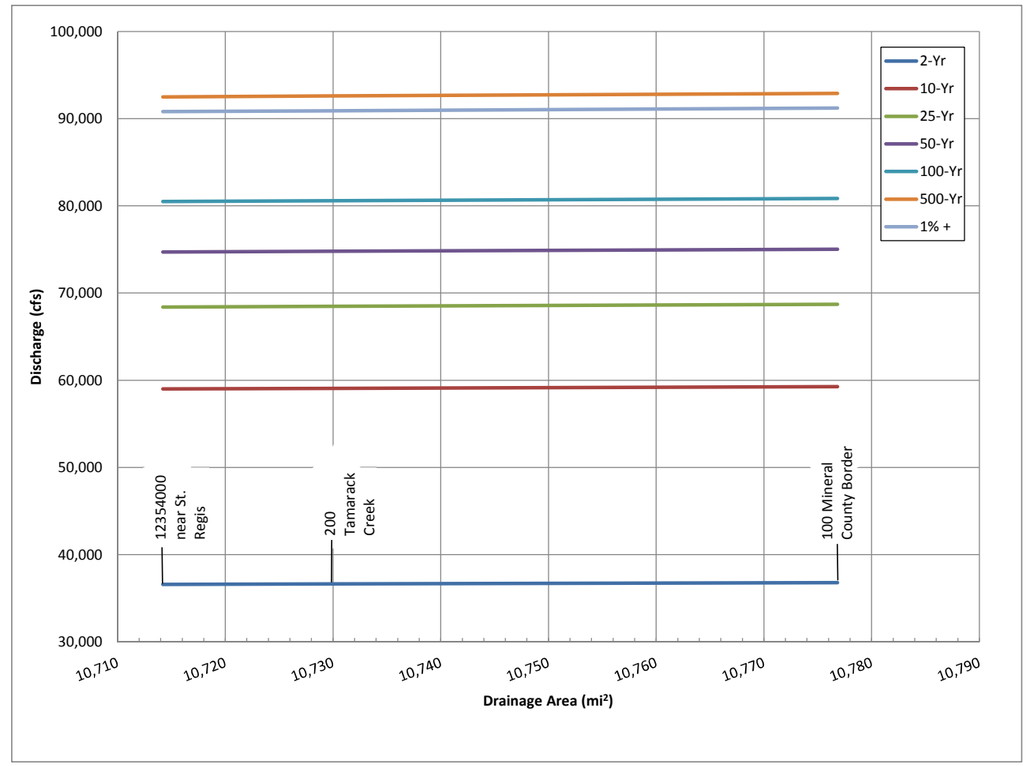


Table 5. Regression coefficients for ordinary least squares regressions relating annual exceedance probability percent peak flow to contributing drainage area for use with ungaged sites on gaged streams.

AEP-percent peak flow (Q_{AEP})	Regression coefficient relating Q_{AEP} to drainage area for indicated region							
	West Region	Northwest Region	Northwest Foothills Region	Northeast Plains Region	East-Central Plains Region	Southeast Plains Region	Upper Yellowstone-Central Mountain Region	Southwest Region
$Q_{66.7}$	0.858	0.922	0.606	0.684	0.500	0.541	0.942	0.999
Q_{50}	0.843	0.904	0.575	0.690	0.488	0.527	0.896	0.939
$Q_{42.9}$	0.836	0.890	0.564	0.681	0.483	0.523	0.866	0.911
Q_{20}	0.813	0.832	0.534	0.639	0.463	0.502	0.761	0.818
Q_{10}	0.794	0.790	0.522	0.611	0.449	0.487	0.697	0.755
Q_4	0.777	0.741	0.516	0.579	0.434	0.471	0.634	0.690
Q_2	0.766	0.707	0.517	0.557	0.423	0.460	0.595	0.647
Q_1	0.755	0.675	0.521	0.537	0.414	0.450	0.561	0.609
$Q_{0.5}$	0.746	0.644	0.526	0.519	0.404	0.441	0.532	0.576
$Q_{0.2}$	0.735	0.605	0.536	0.496	0.393	0.430	0.498	0.533

$$Q_{AEP,U} = Q_{AEP,G}\left(\frac{DA_U}{DA_G}\right)^{exp_{AEP}} \qquad (6)$$

where

$Q_{AEP,G}$ is the AEP-percent peak flow for gaging station G, in cubic feet per second;

DA_U is the drainage area at ungaged site U, in square miles;

DA_G is the drainage area at gaging station G, in square miles; and

exp_{AEP} is the regression coefficient for an OLS regression relating the log of the AEP-percent peak flow to the log of the drainage area within each region (table 5).

Appendix C: Digital Data and Calculation Files