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Beaverhead River Floodplain Study – Phase II

Beaverhead River Hydrologic Analysis

Montana DNRC

June 19, 2017

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Beaverhead River Hydrologic Analysis

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

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EXECUTIVE SUMMARY

Flood flow frequency calculations were conducted for a 41.4-mile reach of the mainstem Beaverhead River. The study reach extends from the Beaverhead\Madison County border, 1.0-miles upstream of USGS Gage Beaverhead River at Barretts (06016000). 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 summer precipitation events. Land use in the Beaverhead River basin is primarily agricultural with irrigated farming and ranching operations.

The Beaverhead River is a major tributary to the Jefferson River and uppermost headwaters of the Missouri River located east of the continental divide in southwestern Montana. Originally the river was formed by the confluence of the Red Rock River and Horse Prairie Creek, which is now inundated by the Clark Canyon Reservoir (completed in 1964) approximately 23 miles southwest of Dillon (Uthman and Beck, 1998). The mainstem Beaverhead River now begins at the Clark Canyon Reservoir and flows northeast for approximately 64-miles where it joins the Big Hole River and Ruby River to form the Jefferson River. The entire Beaverhead watershed area encompasses approximately 4,778 square miles. The study watershed basin area from the Clark Canyon Reservoir to the Madison County border is approximately 3,619 square miles.

Beaverhead River basin elevations within the study area range from approximately 5,100 feet in Dillon to approximately 4,800 feet at Beaverhead Rock (Butler and Abdo, 2013). The watershed terrain varies from a high alpine environment in its headwaters to a heavily cultivated landscape in the northern reaches with expansive irrigated pasture lands, bracketed by rolling foothills, and low gradient slough networks. The hydrology of the basin is primarily snowmelt driven that is heavily regulated by the Clark Canyon Reservoir. During the summer and fall, flow in the Beaverhead is heavily reduced due to irrigation operations.

Rattlesnake Creek and Blacktail Deer Creek join the Beaverhead River near Dillon.

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

Past flood studies for the mainstem of the Beaverhead River are limited. Within the mainstem Beaverhead River basin, a 1982 FEMA FIS exists for a portion of Beaverhead County. The USGS Report *Methods for Estimating Flood Frequency at Ungaged Sites in Montana Based on Data through Water Year 2011*, (Sando et al, 2015) was also an important study, which included flood frequency analyses for the Beaverhead River.

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 10 locations (flow nodes) within the watershed (6 gaged sites and 4 ungaged sites). Estimates at the gaged sites were conducted using Bulletin #17C methodologies. At the ungaged sites, peak flow estimates were calculated using the Two Station Logarithmic Interpolation method and the Drainage Area Gage Transfer method. These methods conform to standard engineering practice.

In the Beaverhead River watershed, the flood flow frequency estimates from this study produced significantly lower peak discharge estimates at the 1% and 0.2% annual chance flood potential than the 1982 FIS. In the middle and lower watershed reaches, the significant differences in peak flow estimates between this study and previous studies can be attributed to the longer gage record and periods of lower flows.

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

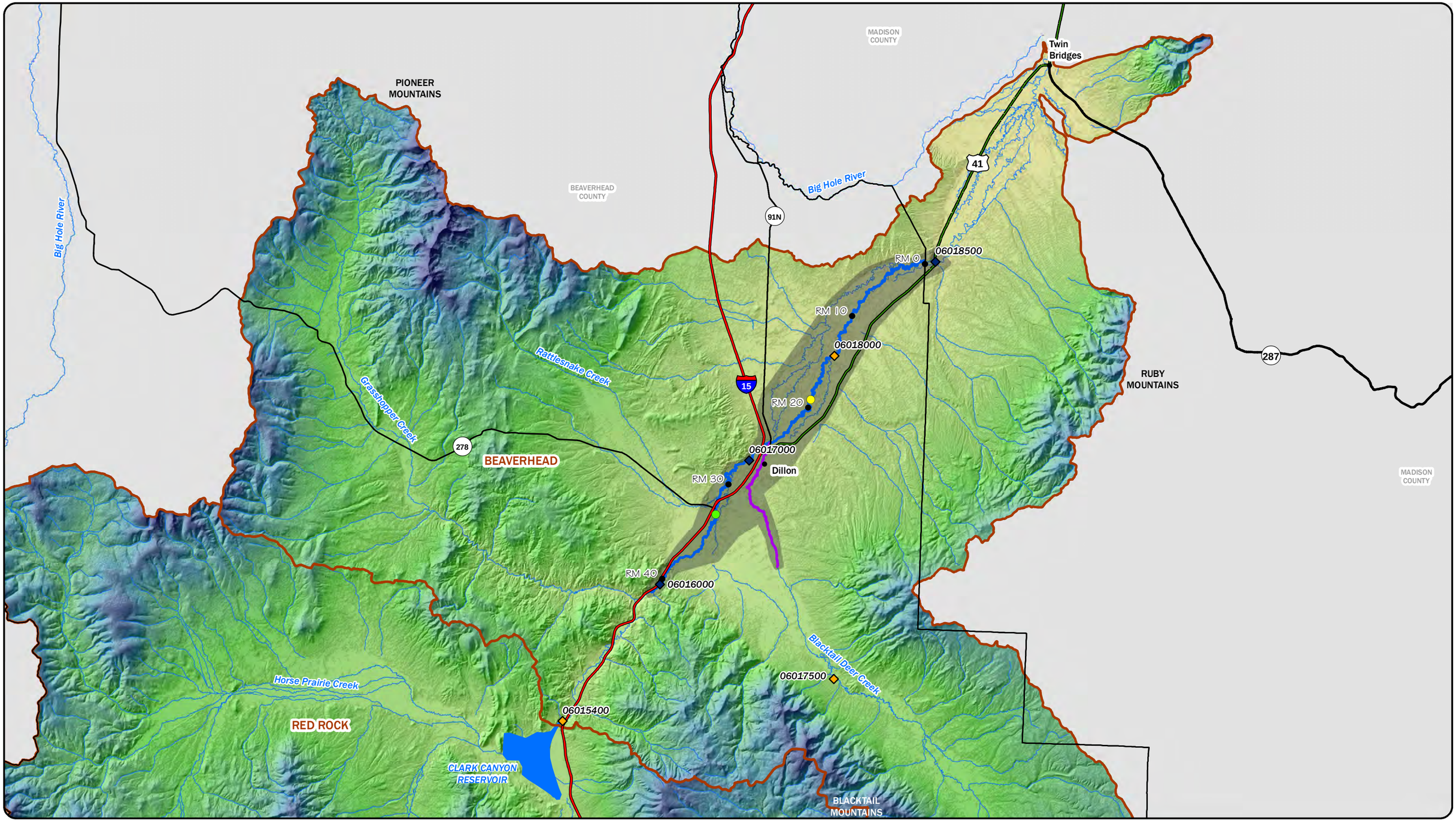
As part of the Beaverhead River Floodplain Study activities, the Montana Department of Natural Resources and Conservation (DNRC) contracted Pioneer Technical Services, Inc. (Pioneer) to complete a comprehensive peak flow hydrologic analysis for the mainstem Beaverhead River and Blacktail Deer Creek study reaches. Flood flow frequency calculations were conducted for a 41.4-mile reach of the mainstem Beaverhead River and 11-miles of Blacktail Deer Creek, a tributary to the Beaverhead River. The study does not include other tributaries. The Beaverhead River study reach extends from the river intersection with Madison County line north of Dillon upstream to a point 1-mile upstream from the USGS "Beaverhead River at Barretts" gage. This study area watershed encompasses approximately 3,618 square miles. The Blacktail Deer Creek study area watershed encompasses, approximately 377 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 Federal Emergency Management Agency (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 Beaverhead River in Beaverhead County is sparsely populated outside of Dillon with a predominantly rural environment. The existing floodplain mapping for the mainstem Beaverhead River includes either Approximate Zone A, Zone A0, or Zone A1-A30. These existing floodplain mapping studies terminate downstream of Dillon near Riverside Drive, typically date back to the early 1980s.

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 500-year floodplain delineation, and may allow some flexibility in the acquisition and modeling of bathymetric and structure survey data.



LEGEND

- RIVER MILES
- 1982 FIS STUDY DOWNSTREAM EXTENT
- 1982 FIS STUDY UPSTREAM EXTENT
- TOWNS
- MONTANA COUNTY BOUNDARIES
- ACTIVE USGS GAGE
- INACTIVE USGS GAGE
- NHS INTERSTATE
- NHS NON-INTERSTATE
- PRIMARY
- SECONDARY
- HUC 8 BOUNDARIES
- BLACKTAIL DEEK CREEK STUDY REACH
- BEAVERHEAD RIVER STUDY REACH
- STUDY AREA

N

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

0 2.5 5 10
Miles

FIGURE 1

BEAVERHEAD RIVER STUDY AREA

PIONEER TECHNICAL SERVICES, INC.

DATE: 4/17/2017

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

The DNRC, in partnership with FEMA, Beaverhead County, and other stakeholders, initiated work to produce new floodplain studies along a reach of the Beaverhead River below Clark Canyon Reservoir in Beaverhead County. This Beaverhead River Floodplain Study will provide the groundwork for completing floodplain mapping projects along the mainstem Beaverhead River and Blacktail Deer Creek.

This report documents the hydrologic analysis methodology and results completed along the mainstem Beaverhead River and Blacktail Deer Creek. This hydrologic 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 also includes calculation of the 1% + (plus) annual chance discharge estimates. This hydrologic analysis conforms to FEMA standards for detailed/enhanced level studies (FEMA, 2016).

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 Beaverhead River and single Blacktail Deer Creek gage through Water Year 2016. The USGS flood frequency analysis for the gaged locations was used to develop peak discharge estimates at the selected ungaged flow change locations.

1.2 Basin Description

The Beaverhead River is a major tributary to the Jefferson River and uppermost headwaters of the Missouri River located east of the continental divide in southwestern Montana. Originally the river was formed by the confluence of the Red Rock River and Horse Prairie Creek, which is now inundated by the Clark Canyon Reservoir approximately 23 miles southwest of Dillon (Uthman and Beck, 1998). The construction of Clark Canyon Dam began in 1961 with a date of closure on August 28, 1964. The river tributaries originate in the Beaverhead National Forest near the continental divide and Montana-Idaho border. The watershed is formed by the Pioneer Mountains to the west, Ruby Mountains to the east, and Tendoy, Snowcrest and Blacktail Ranges to the south (Butler and Abdo, 2013). The mainstem Beaverhead River begins at the Clark Canyon Reservoir and flows northeast for approximately 15 miles through the narrow Beaverhead Canyon before entering the upper Beaverhead basin at Barretts (Uthman and Beck, 1998). Rattlesnake Creek and Blacktail Deer Creek join the Beaverhead River near Dillon. Approximately 35 miles downstream of Dillon, the Beaverhead River joins the Big Hole River and Ruby River to form the Jefferson River (Figure 1). The entire Beaverhead watershed area encompasses approximately 4,778 square miles. The study watershed basin area from the Clark Canyon Reservoir to the Madison County border is approximately 3,619 square miles.

The Beaverhead River basin elevations within the study area range from approximately 5,100 feet in Dillon to approximately 4,800 feet at Beaverhead Rock (Butler and Abdo, 2013). The overall basin elevations range from 11,000 feet at the continental divide to 4,600 feet near the confluence with the Big Hole River (USACE, 1975). The terrain varies from a high alpine environment in its headwaters to a heavily cultivated landscape in the northern reaches with

expansive irrigated pasture lands, bracketed by rolling foothills, and low gradient slough networks. The hydrology of the basin is primarily snowmelt driven that is heavily regulated by the Clark Canyon Reservoir.

Land use in the Beaverhead River basin is primarily agricultural with irrigated farming and ranching operations. Most of the intensely farmed land is located within the Beaverhead River floodplain. Two major irrigation diversions exist on the Beaverhead: the Barretts diversion for the Canyon Ditch and East Bench Canal and West Side Canal near 10 mile Road. The Barretts Diversion does not provide any flood storage. During the summer and fall, flow in the Beaverhead is heavily reduced due to irrigation operations.

1.3 Flood History

The primary cause of flooding on the Beaverhead River is spring snowmelt and historical records of ice jams. There are historical records from several USGS stream gages on the river that document flooding history. The USGS stream gages at Barretts, at Dillon, and near Twin Bridges are representative of the mainstem Beaverhead flood history upstream of Dillon, at Dillon, and downstream of Dillon, respectively. The Barretts USGS Gage (06016000) has the longest, continuous flow record (1908-2016). The annual peak flow record for the Barretts 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 2011 (Scientific Investigations Report [SIR] 2015-5019-C) (Sando et al, 2015).

Figure 2 shows that the peak flood of record at Barretts post regulation (August 1964) occurred in 1984 with a flow of 3,000 cubic feet per second (cfs), exceeding the 1% chance annual flow of 2,480 cfs. The second highest flood on record occurred in 1971 with a flow of 2,190 cfs. In the 52-year period of record at the Barretts gage since construction of the Clark Canyon Dam, the 10-year flow has been exceeded twice.

Figure 2 Beaverhead River at Barretts (06016000)

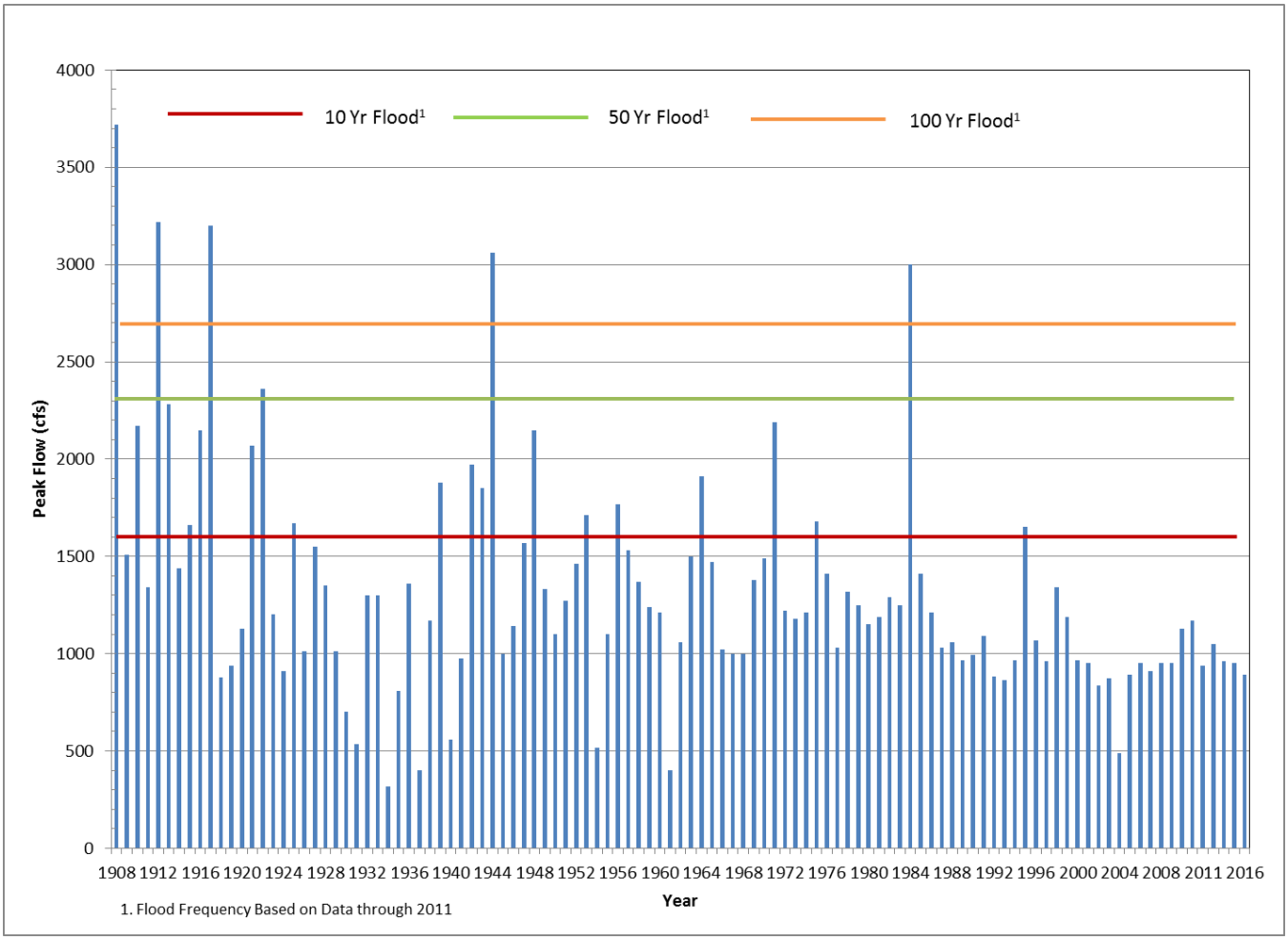


Figure 3 shows the non-continuous peak flow record from 1951 to 2016 (1951-1952, 1964-1971, 2002-2016) for the Beaverhead River gage at Dillon (USGS 06017000). Peak flow recurrence intervals shown in Figure 3 are based on previously published flood frequency analysis from SIR 2015-5019-C.

The flood of record at Dillon after 1964 regulation occurred in 1969 with a flow of 1,390 cfs, which is the only measured peak flow event greater than the 10-year flood. No recorded event since the construction of Clark Canyon Dam has exceeded the 50- or 100-year flows.

Figure 3 Beaverhead River at Dillon (06017000)

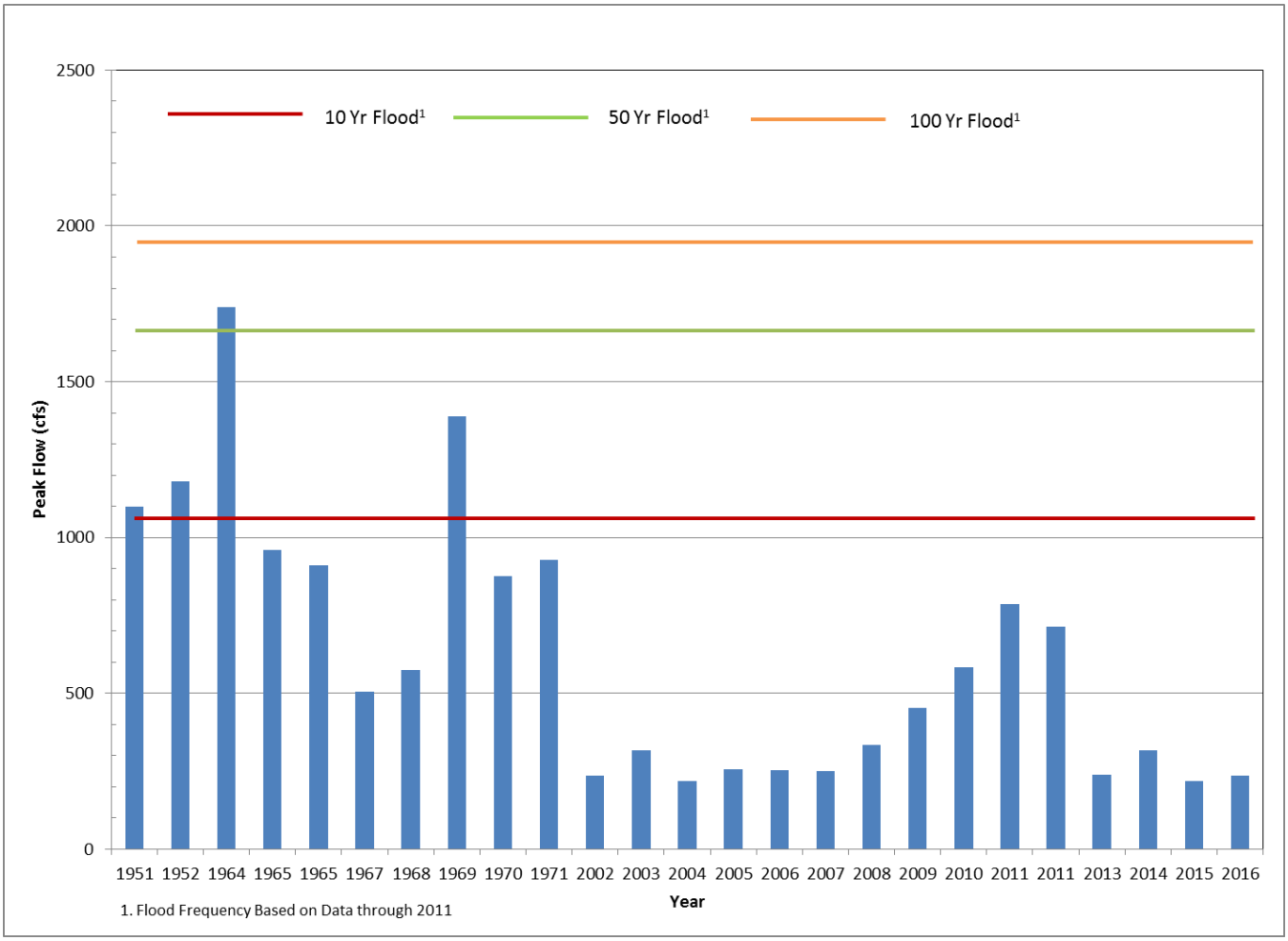
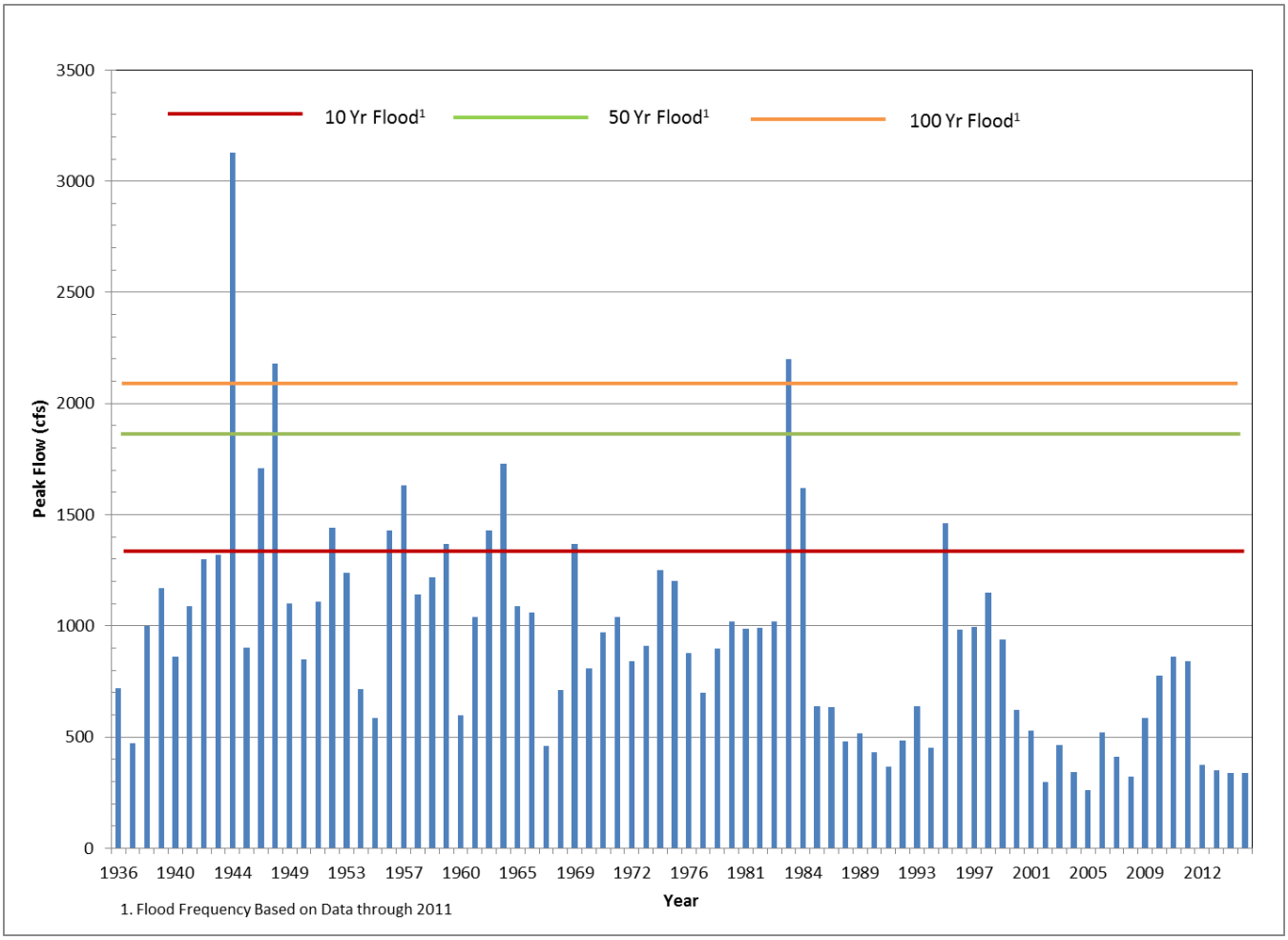


Figure 4 shows the annual peak flow record for the Beaverhead River gage near Twin Bridges (USGS 06018500) immediately downstream from Beaverhead Rock. Peak flow recurrence intervals shown in Figure 4 are based on previously published flood frequency analysis from SIR 2015-5019-C.

The Beaverhead River gage near Twin Bridges has 80 years of flow record (1936-2016). Since 1964, the gage has 52 years of record. During the post regulation period, the 10-year flow has been exceeded 4 times. The Beaverhead River post regulation flood of record near Twin Bridges occurred in 1984 with a flow of 2,200 cfs. Prior to regulation, the flood of record occurred in 1944 with a flow of 3,130 cfs.

Figure 4 Beaverhead River near Twin Bridges (06018500)



2 PAST STUDIES AND EXISTING FLOOD DATA

Past flood studies for the mainstem of the Beaverhead River are limited. Studies relevant to this hydrologic study are those that include peak flow frequency analyses. Within the mainstem Beaverhead River basin, a FEMA FIS exists for a portion of Beaverhead County. Table 1 shows a summary of the mainstem Beaverhead River and Blacktail Deer Creek Floodplain Mapping.

Table 1 Mainstem Beaverhead River and Blacktail Deer Creek 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)
Beaverhead	Beaverhead Co.	14	0	9/30/1982	1/5/1982	Beaverhead	4	13	17
	Dillon, City of	1	0	7/5/1982		Blacktail Deer	5.5	1.5	7

Source: FEMA Map Service Center and 1982 FIS

FIRM: Flood Insurance Rate Map

FIS: Flood Insurance Study

mi: Miles measured along channel alignment

In addition to the FEMA FIS, USGS WRIR 03-4308 and SIR 2015-5019-C document the flood frequency analysis on several gages along the mainstem Beaverhead River. The gage on Blacktail Deer Creek has been inactive for several decades.

Prior to the FIS, the US Army Corp of Engineers (USACE) prepared a 1975 floodplain study (USACE Study) for Beaverhead County and DNRC. Some of the information in the USACE Study was used for the basis of the hydrology in the FIS study. These studies and investigations are discussed in more detail in the following sections.

2.1 City of Dillon and Beaverhead County Flood Insurance Study

The City of Dillon and Beaverhead County FIS (Beaverhead FIS) was issued on January 5, 1982 (FEMA, 1982). As part of the FIS, the mainstem Beaverhead River was studied using detailed and approximate methods. The hydrologic and hydraulic analyses were completed by Morrison-Maierle, Inc. in December 1979. The study area included the incorporated areas of the City of Dillon, Town of Lima, and the unincorporated areas of Beaverhead County. The FIS identified a major flood on the Beaverhead River post construction of the Clark Canyon Dam. Beaverhead at Barretts peaked on June 19, 1964 at 1910 cfs; downstream near Dillon peaked on June 21 at 1740 cfs; and north of Dillon on June 22 at only 1570 cfs. The reduction in peak flow with increase drainage area indicated that the major source of the runoff event was the upper drainage basin and also attributed to the numerous canals, abandoned channels, and sloughs that tend to allow floodwater to spread out. The 1964 flood was stated as being post

construction; however the date of closure for Clark Canyon is August 28, 1964. The June 1964 peak occurred before the closure date so it is not included in the post regulation period.

Hydrologic analysis results from the 1975 USACE Study were used in the FIS. The 1975 USACE study assumes the drainage above the Clark Canyon Dam does not contribute to flooding and assumes a constant discharge of 500 cfs from the reservoir. The Beaverhead River was reevaluated during the 1982 FIS to define flows in the slough area (Selway slough, Murray, Gilbert slough, and the Guidici ditch). These evaluations were performed using independent backwater computations of the slough and river with matching water surfaces upstream of the Old State Highway 91 Bridge. The study did not evaluate the potential for flooding from ice jams. Table 2 summarizes the estimated peak discharges from the 1982 Beaverhead FIS.

Table 2 Beaverhead FIS Summary of Discharges

Flooding Source and Location	Drainage Area (Square Miles)	Peak Discharges (cfs)			
		10-Year	50-Year	100-Year	500-Year
Beaverhead River above Rattlesnake Creek	432	1,450	1,950	2,400	4,100
Beaverhead River below Rattlesnake Creek	563	1,500	2,250	2,900	5,200
Beaverhead River above Blacktail Deer Creek	574	1,400	2,300	2,800	5,000
Beaverhead River below Blacktail Deer Creek	1,016	1,850	2,900	3,500	6,200
Beaverhead River between Sections J and H	1,016	1,850	2,425	2,630	3,550
Beaverhead River at and below Section H	1,016	1,777	2,119	2,324	2,780
Beaverhead River Overbank	1,016	73	306	306	770
Blacktail Deer Creek at Dillon	442	352	550	740	940

2.2 US Army Corps of Engineers Floodplain Study

The USACE Floodplain Information for the town of Dillon (USACE Study) was issued on June 1975 (USACE, 1975). The study area included the mainstem Beaverhead River from approximately 4 miles upstream to 4 miles downstream from Dillon. The report defined the Intermediate Regional Flood (IRF) and Standard Project Flood (SPF). The IRF is defined as a flood having one percent probability of occurrence in any year, or base flood. The SPF is defined as a major flood that can be expected to occur from a severe combination of meteorological and hydrological conditions, excluding extremely rare combinations. The analysis used the operational USGS gages at the time for the Beaverhead River, Blacktail Deer Creek, and Grasshopper Creek.

At the time of the study, Dillon had experienced several floods. The study reports the following known historical floods:

- January 1937 – ice jam created flooding in Dillon;
- June 1944 – rain on snow event over several days flooded portions of Dillon with considerable damage to the Union Pacific Railroad and US Highway 91 between Lima and Dillon;
- Late May 1948 – flooding damaged road and bridges in Beaverhead County;
- January & February 1949 – ice jams at constricted channel locations resulting in overland flow that froze up to six feet in thickness;
- February 1951 – ice jam near Beaverhead Rock causing backwater flooding upstream causing evacuation of several farms and ranches; and
- January 1974 – similar event to 1951 resulting in personnel removing the ice obstructions with dynamite to relieve flood waters.

Hydrologic analyses were conducted on the gage records to estimate the peak discharge for the IRF and SRF at several locations along the Beaverhead River.

The peak discharges were based on the gaging records for Grasshopper Creek and Blacktail Deer Creek and comparison with Barretts gage. The gage analysis was used as a guide to develop similar data for the ungaged drainage areas between Clark Canyon Dam and the downstream limit of the study. Finally, the estimated floods were routed along the Beaverhead River at the selected locations. Table 3 summarizes the peak discharges from the USACE Study.

Table 3 USACE Study Peak Flow Summary

Flooding Source and Location	Drainage Area (Square Miles)	Effective Drainage Area (Square Miles)	Peak Discharges (cfs)	
			IRF	SPF
Upstream Limit	2,752	431	2,400	4,100
Beaverhead River above Rattlesnake Creek	2,753	432	2,400	4,100
Beaverhead River below Rattlesnake Creek	2,884	563	2,900	5,200
Beaverhead River above Blacktail Deer Creek	2,895	574	2,800	5,000
Beaverhead River below Blacktail Deer Creek	3,337	1,016	3,500	6,200
Downstream Limit	3,390	1,069	3,400	5,900

Source: USACE Study 1975

Effective drainage area – amount of flood-production drainage area downstream of Clark Canyon Dam

Comparison of the USACE Study to the Beaverhead FIS data shows the same peak flow values to the location downstream of Blacktail Deer Creek. After this point on the river, the Beaverhead FIS evaluated the flow reduction from overbank flows. Similar to the FIS, the USACE Study reports the peak flow attenuation downstream of Barretts. The study states that the attenuation is mainly due to the East Bench Canal and the physical characteristics of the Beaverhead River natural flood plain storage downstream from Barretts and the Beaverhead Canyon Gateway.

2.3 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 (Parret 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 4 provides the WRIR 03-4308 peak discharge summary for the USGS gages on the Beaverhead River. Table 4 shows that 100-year peak flows attenuate from Barretts to below Dillon and then begin to increase near Beaverhead Rock towards Twin Bridges. The attenuation between Barretts and below Dillon can be partly attributed to large irrigation diversions and floodplain storage and may also be influenced by non-congruent periods of records. The peak flow increase between downstream of Dillon and Beaverhead Rock is due to the inflow of major sloughs such as shown on Figure 1.

Table 4 WRIR 03-4308 Beaverhead River and Blacktail Deer Creek 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
06018500	Beaverhead River near Twin Bridges, MT	3,619	34	1,210	1,430	1,710	1,920	2,120	2,320	2,590
06018000	Beaverhead River near Dillon, MT	3,484	19	1,010	1,100	1,210	1,280	1,350	1,410	1,490
06017000	Beaverhead River at Dillon, MT	2,895	10	1,310	1,520	1,770	1,940	2,100	2,260	2,460
06016000	Beaverhead River at Barretts, MT	2,737	34	1,500	1,720	2,010	2,240	2,480	2,730	3,090
06015400	Beaverhead River near Grant, MT	2,322	19	1,080	1,130	1,170	1,190	1,210	1,220	1,240
06017500	Blacktail Deer Creek near Dillon, MT	312	21	302	386	507	608	719	842	1,030

Based on systematic data through 1998

2.4 Scientific Investigations Report 2015-5019

The USGS SIR 2015-5019-C updated annual peak discharges with annual exceedance probabilities 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. 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). 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 5 provides the SIR 2015-5019-C discharge summary for Beaverhead River gages for post Clark Canyon Dam construction and Blacktail Deer Creek.

The USGS SIR 2015-5019-F (Sando et al, 2015) 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. The gaging stations on the Beaverhead River were excluded from the dataset because the peak flow records are affected by major regulation due to the Clark Canyon Dam regulating more than 20 percent of the cumulative basin drainage area. The study used regression analyses to develop equations relating annual exceedance probability (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 (Sand et al, 2015).

Table 5 SIR-2015-5019-C Beaverhead River and Blacktail Deer Creek 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
06018500	Beaverhead River near Twin Bridges, MT	3,618	47	1,090	1,330	1,630	1,860	2,080	2,310	2,610
06018000	Beaverhead River near Dillon, MT	3,419	19	991	1,090	1,200	1,280	1,350	1,420	1,500
06017000	Beaverhead River at Dillon, MT	2,892	17	812	1,060	1,390	1,660	1,950	2,260	2,690
06016000	Beaverhead River at Barretts, MT	2,730	47	1,360	1,600	1,970	2,300	2,690	3,130	3,830
06015400	Beaverhead River near Grant, MT	2,316	19	1,120	1,170	1,230	1,270	1,300	1,330	1,360
06017500	Blacktail Deer Creek near Dillon, MT	316	21	301	384	503	603	713	834	1,010

Based on systematic data through 2011

2.5 Additional Previous Studies

Additional related previous studies conducted along the Beaverhead River involve water management, fisheries management or sediment management:

- *Hydrogeologic Investigation of the Lower Beaverhead Study Area, Beaverhead County, Montana, Groundwater Modeling Report*, *Open File Report 638*, Montana Bureau of Mines and Geology (Butler and Abdo, 2013).
- *Hydrogeology of the Upper Beaverhead Basin near Dillon, Montana, Open File Report 384*, Montana Department of Natural Resources and Conservation and Montana Bureau of Mines and Geology (Uthman and Beck, 1998).
- *Beaverhead River and Clark Canyon Reservoir Fishery Study,* US Department of the Interior, Bureau of Reclamation (Nelson, 1977).
- *Beaverhead River Flushing Flow Study, Technical Report SRH-2013-10*, Bureau of Reclamation (Klumpp and Randle, 2013).
- *Beaverhead Watershed Restoration Plan*, Beaverhead Watershed Committee (BWC), (BWC, 2013).

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 annual exceedance probability events at key flow change locations (such as at significant tributary 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, 7 locations (flow nodes) on the Beaverhead River and 3 locations on Blacktail Deer Creek were identified as having significant changes in streamflow or being at a critical location. Out of the 7 flow nodes on the Beaverhead, 2 are located at active USGS stream gage sites, 3 are located at discontinued USGS stream gage sites, and 2 are located between or downstream of stream gages (ungaged sites). Out of the 3 flow nodes on Blacktail Deer Creek, 1 is located at a discontinued USGS stream gage site, and 2 are located at ungaged sites. The river stationing used in this report is based on the Beaverhead River study alignment provided by the DNRC. The Blacktail Creek alignment is based on an alignment originally provided by the DNRC that was revised subsequently by DOWL. The Beaverhead River study alignment begins at the border of Madison and Beaverhead counties. The upstream end of this study reach ends at River Mile 41.4. The most upstream flow node is located at the Grant gaging station (USGS Station 06015400) approximately 12.8 river miles upstream from the study reach extent.

The Blacktail Deer Creek study alignment begins at the confluence with the Beaverhead River. The upstream end of the Blacktail Deer Creek study reach ends at River Mile 11.0. The most upstream flow node is located at the gaging station (USGS Station 06017500) approximately 13.0 river miles upstream from the study reach extent.

3.1 USGS Stream Gage Analysis

The USGS has historically maintained 5 stream gages along the Beaverhead River study reach, along with a single gage on Blacktail Deer Creek. USGS gaging station 06018500 Beaverhead River near Twin Bridges is downstream of the study reach but will be used in the analysis. The oldest records date back to 1908 at USGS gaging station 06016000 on the Beaverhead River at Barretts, with the period of record continuing until present. Currently, there are 3 (of the 5) USGS gaging stations being maintained on the mainstem Beaverhead River. The gage on Blacktail Deer Creek is not currently being maintained. Figure 1 shows the study reach and the locations of the USGS gaging stations used in the hydrologic analysis. The Barretts gage has the longest congruent period of record extending from 1908 to 2016 (109 years). Table 6 lists a summary of all the USGS stream gages (active and inactive) along the mainstem Beaverhead River and Blacktail Deer Creek.

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 Beaverhead 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 Beaverhead River and Blacktail Deer Creek 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 have been employed in this hydrologic analysis.

This section summarizes the Beaverhead 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). Post-regulation systematic flood frequency calculations were completed for all 6 gages (Appendix A, Table B.2) shown in Table 6, using data through 2016. Figure 5 plots the systematic flood frequency results as a function of drainage area and Table 7 tabulates the results.

Table 6 Beaverhead 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)
06018500	Beaverhead River near Twin Bridges, MT	3618	1936-1944, 1946-2016	80	N/A
06018000*	Beaverhead River near Dillon, MT	3419	1951-1952, 1964-1983	22	14.0
06017000	Beaverhead River at Dillon, MT	2892	1951-1952, 1964-1971, 2002-2016	25	26.7
06016000	Beaverhead River at Barretts, MT	2730	1908-2016	109	40.4
06015400*	Beaverhead River near Grant, MT	2316	1963-83	21	N/A
06017500*	Blacktail Deer Creek near Dillon, MT	316	1946-1953, 1955-1966, 1984	21	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 5 USGS Flood Frequency Estimates Systematic Record 1965 through 2016

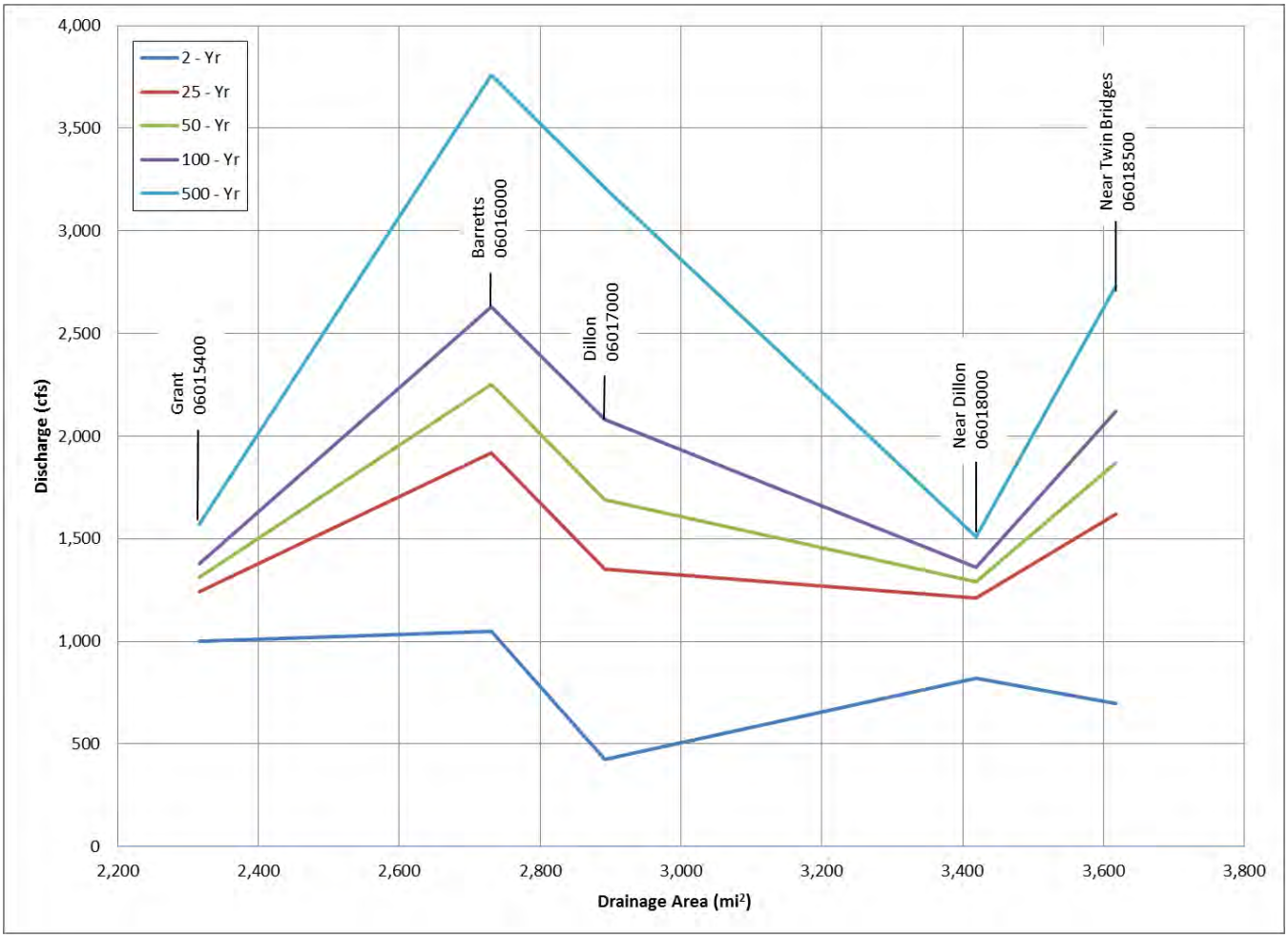


Table 7 Gage Flood Frequency Estimates Using Systematic Record

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
06018500	Beaverhead River near Twin Bridges, MT	1965–2016	562	696	1050	1300	1620	1870	2120	2380	2730
06018000	Beaverhead River near Dillon, MT	1965–83	738	820	996	1100	1210	1290	1360	1430	1510
06017000	Beaverhead River at Dillon, MT	1965–71; 2002–16	331	425	721	970	1350	1690	2080	2520	3210
06016000	Beaverhead River at Barretts, MT	1965–2016	976	1050	1320	1560	1920	2250	2630	3070	3760
06015400	Beaverhead River near Grant, MT	1965–83	974	1000	1090	1150	1240	1310	1380	1460	1570

Figure 5 indicates peak discharges do not consistently increase with increasing drainage area, as typically expected. These inconsistences can be related to non-congruent periods of record, large flow diversions, or variability in flood storage. 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 post-regulation base period of 1965-2016 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 Clark Canyon Reservoir at the headwaters of the Beaverhead River is formed by the Clark Canyon Dam. The earthfill dam was constructed between 1961 and 1964. The dam regulates the peak flows on the Beaverhead River for all the mainstem USGS gage stations starting in 1965. The USGS in consultation with DNRC determined that the regulation on the Beaverhead River was 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 8 summarizes the Beaverhead River gage analysis flood frequency estimates using the extended record. Figure 6 plots the extended record analysis results.

The peak flow flood frequency results shown in Figure 6 still exhibit significant attenuation indicating much of the attenuation observed in the systematic flood frequency estimates (Figure 5) was not associated with non-congruent periods of records. In some cases, the flood frequency estimates did not increase with increasing drainage areas. Systematic peak flow data from corresponding periods were inspected and it was determined that in many cases the peaks tended to attenuate in the downstream direction, thereby validating that the peak flow flood frequency estimates may not increase with increasing drainage areas. Between the gage at Barretts (06016000) and gage at Dillon (06017000) there are several major diversions from the Beaverhead River. The Barretts diversion downstream of the gage at Barretts includes the East Bench Canal and Canyon Ditch. Just upstream of the Dillon gage is the West Side Canal. In addition to the major diversions, several other small diversions exist and along with inflow from Rattlesnake Creek can affect the flow in this reach. The discharge capacities for the East Bench Canal and West Side Canal are 440 cfs and 160 cfs, respectively (Butler and Abdo, 2013). The combined potential discharge for these two canals (600 cfs) is approximately 23% of the base flood flow (2,630 cfs) at Barretts. The base flood flow decreases 300 cfs between Barretts and Dillon. In combination with the inflow from Rattlesnake Creek, the combined irrigation diversion flow magnitudes are large enough to account for magnitude of flow attenuation exhibited in the peak flow flood frequency estimates.

The extended gage record shows additional base flood attenuation of 370 cfs between the gage at Dillon and gage near Dillon (06018000). Blacktail Deer Creek flows into the Beaverhead River between these two gages. Six or more small diversion ditches remove flow from the mainstem within this reach as well. The Beaverhead River floodplain to the north includes several major sloughs, including Albers Slough that may provide significant floodplain storage. Albers Slough meets the Beaverhead River at Beaverhead Rock, immediately upstream from Beaverhead River near Twin Bridges (06018500). The multiple flow diversions, ponds and significant floodplain storage potentially accounts for the continued attenuation of mainstem peak flows. Once the Albers Slough reports to the Beaverhead River, peak flows once again increase at the Twin Bridges gage.

Flood frequency peak flow estimates using the extended record data set establishes a congruent period of record for the mainstem Beaverhead River stream gages. Using the extended record data set reduces the downstream attenuation magnitude observed in the systematic record flood frequency analysis and will minimize the potential error associated with non-congruent periods of record.

For these reasons, flood flow frequency estimates using the post-regulation 2016 extended record data set, were selected to represent the annual chance flood potential at the Beaverhead River gaged locations.

Blacktail Deer Creek includes a single gage located upstream from the study reach and city of Dillon. The gage includes 21 years of record, mostly in the 1940s and 1950s. USGS performed an analysis of the systematic record and also weighted the results using regional regression equations. The annual precipitation record in Dillon shows several years with above average precipitation in the mid-1990s and a few recent years (Butler and Abdo, 2013). Potential streamflow responses to these wet years would not be included in the systematic record. Weighting the peak-flow frequency estimates can reduce the uncertainty from the short and dated gage record for Blacktail Deer Creek (USGS in draft, 2016). Table 9 compares the results for the analysis. The weighted values are greater than the short systematic record. The weighted results potentially reduce the uncertainty and use regional regression equations that were updated based on data through 2011 (Sando et al, 2015). For these reasons, flood flow frequency estimates using the weighted data set, were selected to represent the annual chance flood potential at the Blacktail Deer Creek gage location.

Table 10 compares flood frequency estimates between the 2011 SIR 2015-5019-C analysis and this study's 2016 extended record analysis. The SIR 2015-5019-C flood frequency estimates are a systematic analysis based on the entire period of record. The 2016 flood frequency analysis is based on the congruent period of record 1965 to 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.

Figure 7 compares selected recurrence intervals from Table 10 for the five Beaverhead River gages. In general, differences between the 2011\2016 flood frequencies are most prevalent at

the discontinued gages at Grant (0601540) and near Dillon (06018000). These two gages were discontinued in 1983 so the record extension has the largest impact on the systematic data. The gage at Barretts (06016000) and gage near Twin Bridges (06018500) show the closest agreement for the two datasets. These two gages have the longest systematic dataset. The gage at Dillon (06017000) shows higher flow values for the 2016 analysis compared to the dataset through 2011. The 2011 systematic dataset for this gage is only 17 years of record. Other than the two discontinued gages, the other gages show increases or very similar values for the events compared to the 2011 values.

Table 8 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
06018500	Beaverhead River near Twin Bridges, MT	1965-2016	562	696	1,050	1,300	1,620	1,870	2,120	2,380	2,730
06018000	Beaverhead River near Dillon, MT	1965-2016	465	585	914	1,150	1,460	1,710	1,960	2,230	2,590
06017000	Beaverhead River at Dillon, MT	1965-2016	444	575	952	1,240	1,650	1,980	2,330	2,710	3,260
06016000	Beaverhead River at Barretts, MT	1965-2016	976	1,050	1,320	1,560	1,920	2,250	2,630	3,070	3,760
06015400	Beaverhead River near Grant, MT	1965-2016	828	889	1,100	1,280	1,570	1,820	2,120	2,460	2,990

Table 9 Blacktail Deer Creek Gage Flood Frequency Estimates

Station Number	Station name	Type of Peak Flow Estimate	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
06017500	Blacktail Deer Creek near Dillon, MT	At-site	161	203	324	417	548	655	771	897	1,080
06017500	Blacktail Deer Creek near Dillon, MT	RRE wtd	165	210	341	447	602	735	884	1,050	1,290

Figure 6 USGS Flood Frequency Estimates Extended Record (1965-2016)

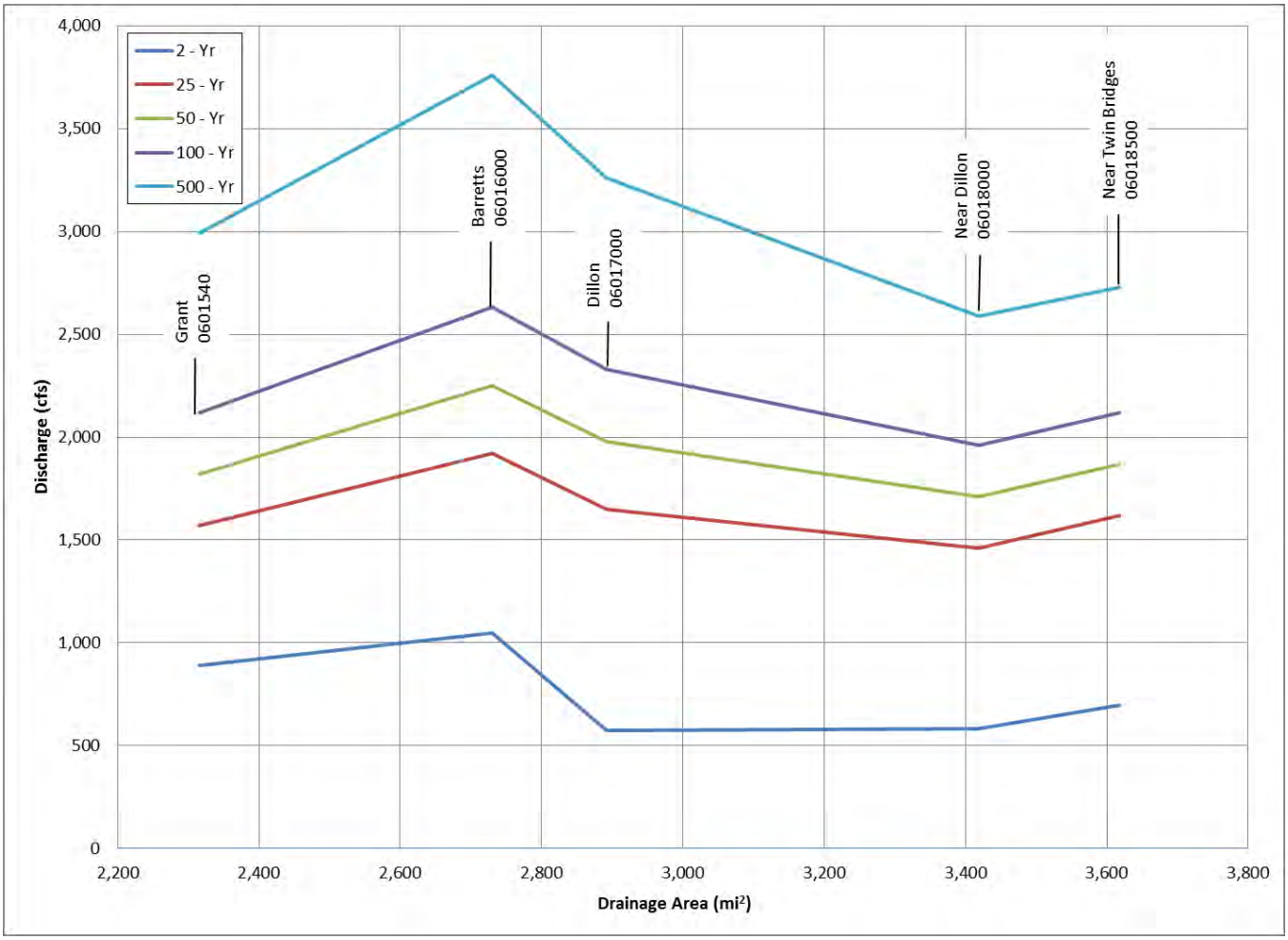


Figure 7 USGS Flood Frequency Estimates Comparison 2011 and 2016

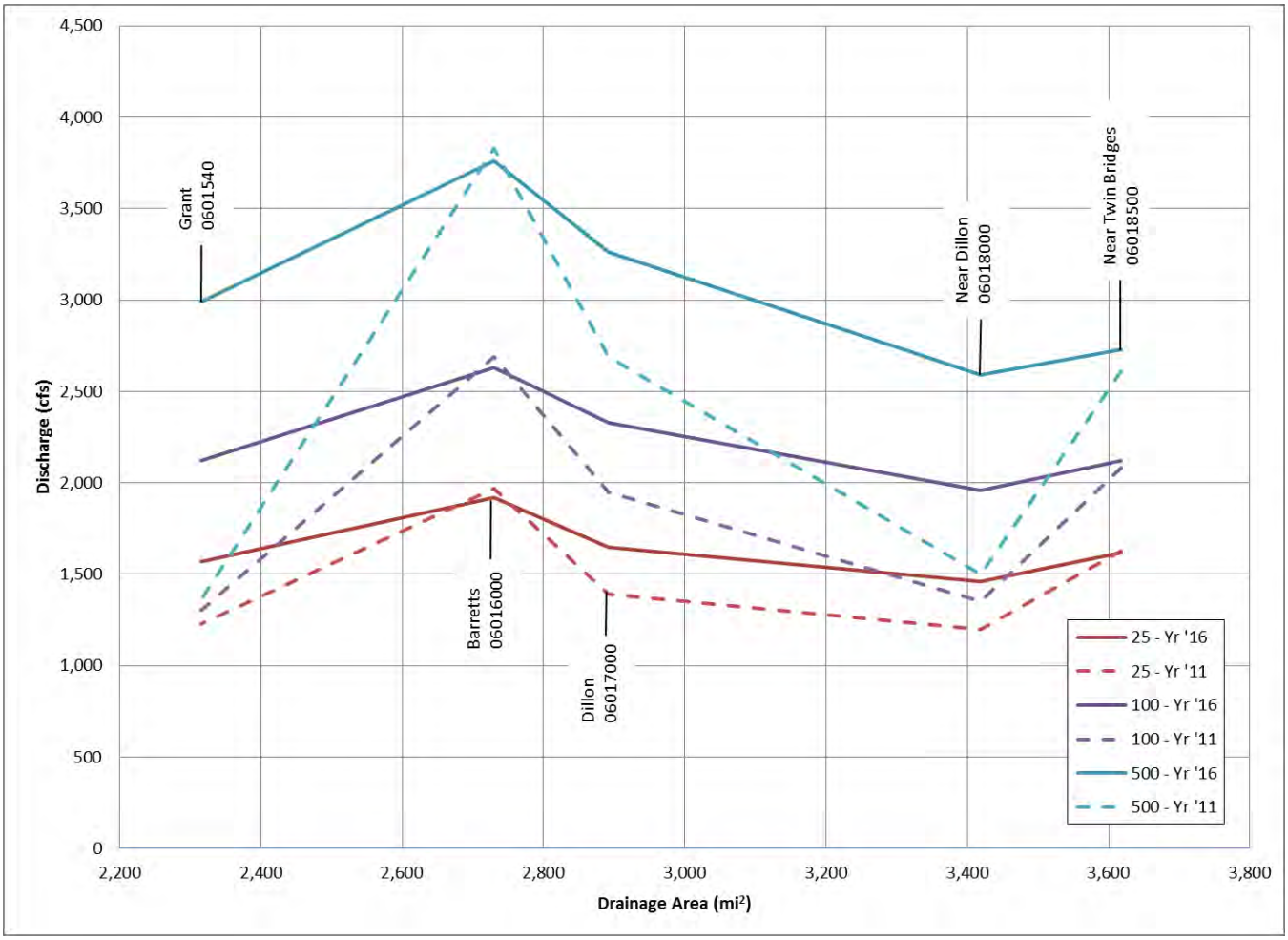


Table 10 USGS Flood Frequency Estimate Comparison 2011 and 2016

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
06018500	Beaverhead River near Twin Bridges, MT	1,090	1,050	1,330	1,300	1,630	1,620	1,860	1,870	2,080	2,120	2,310	2,380	2,610	2,730
06018000	Beaverhead River near Dillon, MT	991	914	1,090	1,150	1,200	1,460	1,280	1,710	1,350	1,960	1,420	2,230	1,500	2,590
06017000	Beaverhead River at Dillon, MT	812	952	1,060	1,240	1,390	1,650	1,660	1,980	1,950	2,330	2,260	2,710	2,690	3,260
06016000	Beaverhead River at Barretts, MT	1,360	1,320	1,600	1,560	1,970	1,920	2,300	2,250	2,690	2,630	3,130	3,070	3,830	3,760
06015400	Beaverhead River near Grant, MT	1,120	1,100	1,170	1,280	1,230	1,570	1,270	1,820	1,300	2,120	1,330	2,460	1,360	2,990
06017500	Blacktail Deer Creek near Dillon, MT	301	324	384	417	503	548	603	655	713	771	834	897	1,010	1,080

Table 11 compares the results of the 1982 Beaverhead FIS study peak flow estimates with the peak estimates from the USGS flood frequency estimates using the extended gage records through 2016. Review of Table 11 indicates the FIS and USGS 2016 peak flow estimates are similar at the Barretts gage above Rattlesnake Creek (less than 10% difference) for all the recurrence intervals. The differences increase above and below the Beaverhead River confluence with Blacktail Deer Creek. In general the flows are lower using the USGS extended gage analysis through 2016 compared to the values published in the Beaverhead FIS (FEMA, 1982). These observed differences are likely related to the greater period of record data set used in the USGS 2016 analysis compared with the 1982 FIS data set.

Table 11 Beaverhead FIS Flood Frequency Estimate Comparison

Flooding Source and Location	Drainage Area[1] Square Miles	USGS Gage Drainage Area Square Miles	Peak Discharges (cfs)							
			10-Year		50-Year		100-Year		500-Year	
			FIS	2016	FIS	2016	FIS	2016	FIS	2016
Above Rattlesnake Creek / Beaverhead River at Barretts (06016000)	2,753	2,730	1,450	1,560	1,950	2,250	2,400	2,630	4,100	3,760
Below Rattlesnake Creek	2,884	NA	1,500	NA	2,250	NA	2,900	NA	5,200	NA
Above Blacktail Deer Creek / Beaverhead River at Dillon (06017000)	2,895	2,892	1,400	1,240	2,300	1,980	2,800	2,330	5,000	3,260
Below Blacktail Deer Creek / Beaverhead River near Dillon (06018000)	3,337	3,419	1,850	1,150	2,900	1,710	3,500	1,960	6,200	2,590

1. Source: Flood Plain Information – Beaverhead River (USACE, 1975)

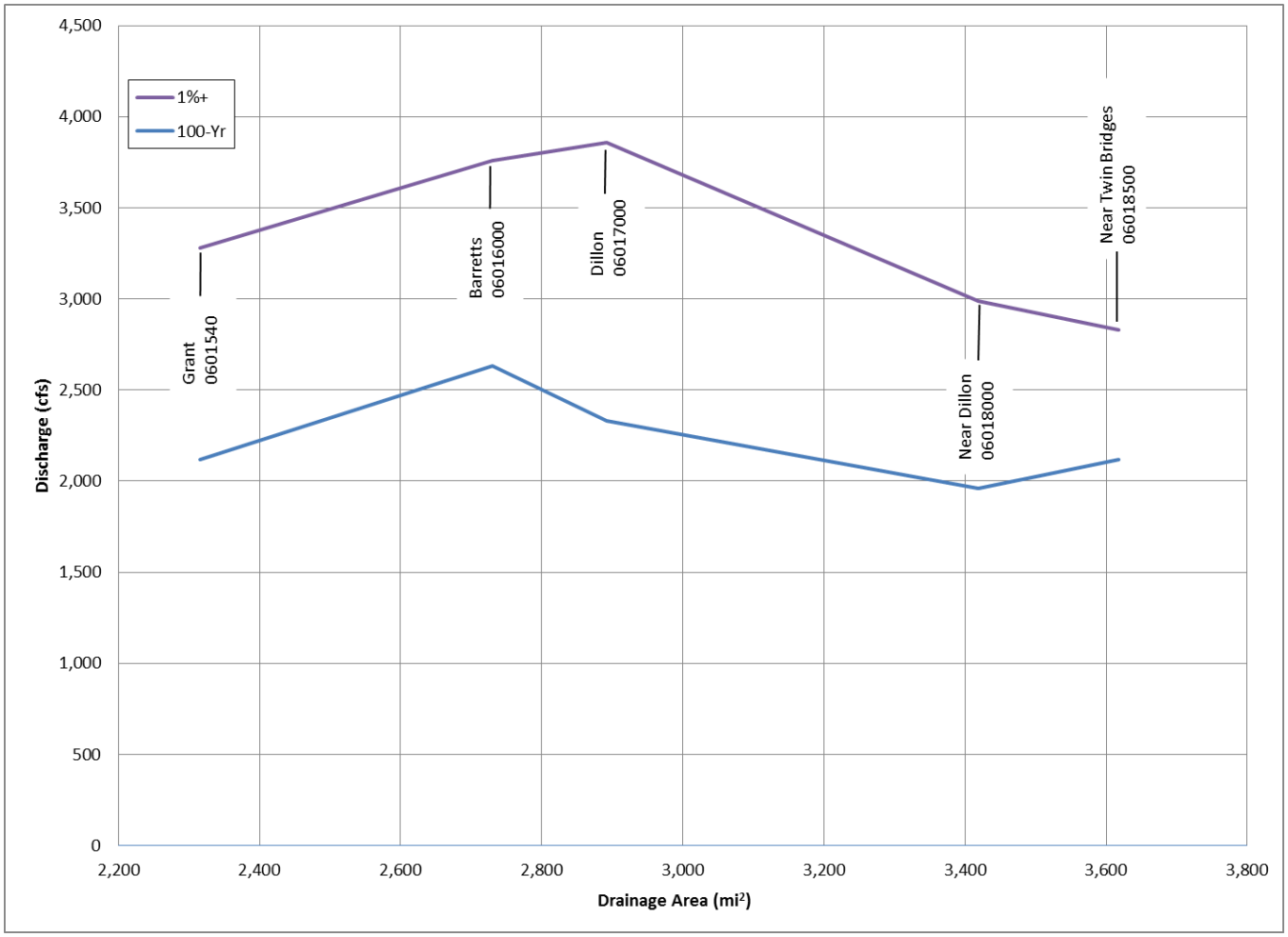
3.1.1 1% + Peak Flow Estimates

The 1%+ percent annual exceedance probability event was calculated to provide a confidence range that the 1% flood frequency peak flow estimates are likely to fall within. The flood-frequency estimates equations include an “average standard error of prediction” or “average standard error of estimate” percentage that was used to define its statistical 68% confidence interval (+/- one standard deviation). The resulting upper 84% confidence limit (+ one standard deviation) was used to determine the 1% + flood frequency peak flow estimates. The Beaverhead River 1%+ flood frequency peak flow estimates are based on the extended record 1% estimates presented in Table 8. For Blacktail Deer Creek, the 1%+ flood frequency peak flow estimate is based on the weighted “RRE wtd” 1% estimate presented in Table 9.

Table 12 USGS 1%+ Flood Frequency Estimates 2016

Station Number	Station Name	1% + Annual Exceedance Probably Peak discharge, (cfs)
06018500	Beaverhead River near Twin Bridges, MT	2,830
06018000	Beaverhead River near Dillon, MT	2,990
06017000	Beaverhead River at Dillon, MT	3,860
06016000	Beaverhead River at Barretts, MT	3,760
06015400	Beaverhead River near Grant, MT	3,280
06017500	Blacktail Deer Creek near Dillon, MT	1,350

Figure 8 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 Beaverhead River and Blacktail Deer Creek, 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 Beaverhead River and Blacktail Deer Creek. 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 is 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 (Esri's GIS mapping software), flow nodes were located just upstream of the HUC 12 boundary intersection with the Beaverhead River mainstem.

This study uses 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 Beaverhead 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 is used as the node name.

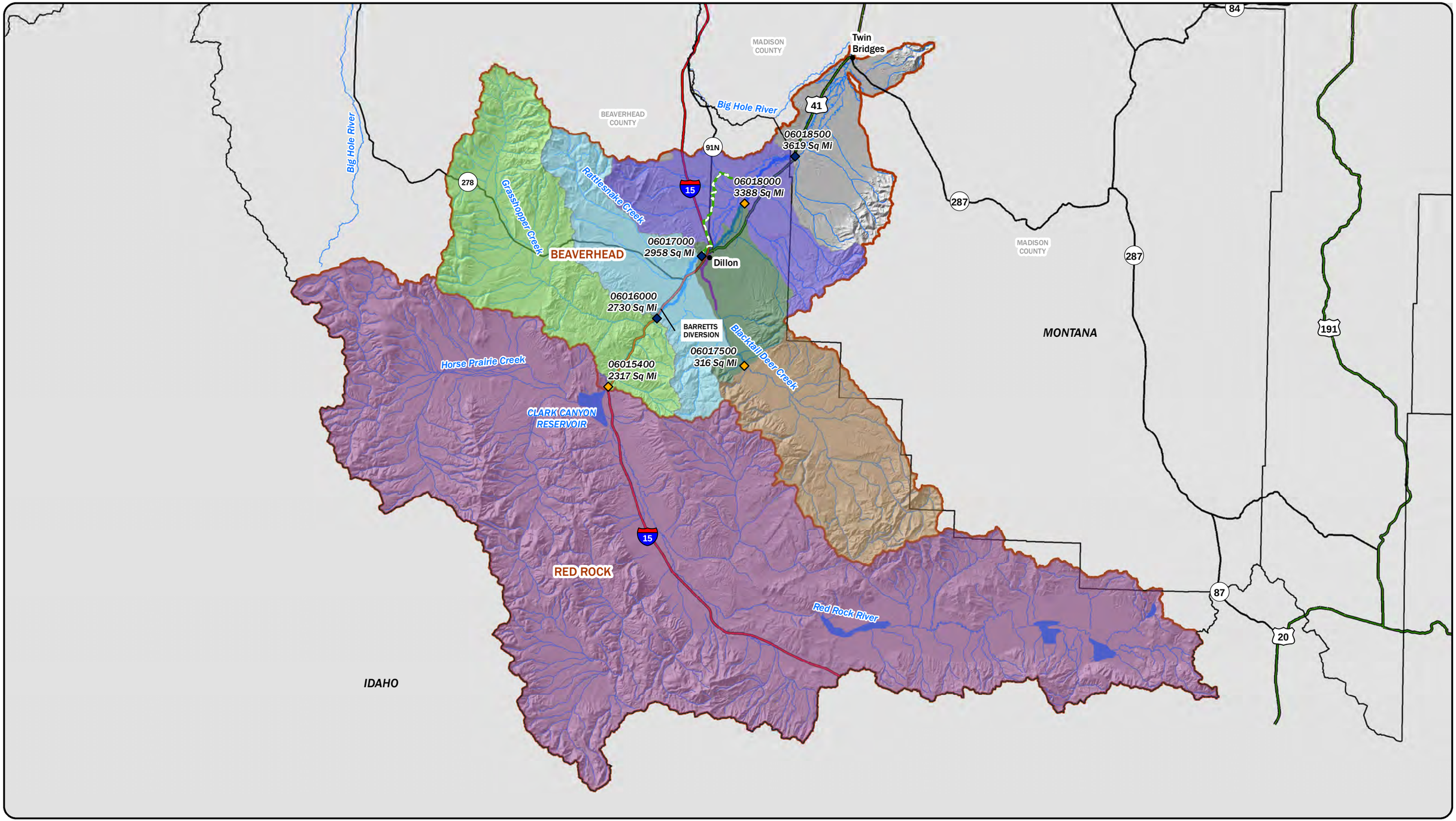
To avoid excessive flow changes between HUC 12 boundary nodes, additional flow nodes were located immediately downstream of towns, at the end of study reaches, at county borders, or where intermediate tributaries within the HUC 12 boundaries intersected the mainstem. One flow node was added downstream of Dillon. A total of 3 flow nodes were added as intermediate nodes between the HUC 12 boundaries. These town nodes and intermediate nodes are identified in Table 14.

The USGS 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 NHDPlusV2 NED uses 30-meter resolution 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 match the USGS delineations. In some cases, low gradient topography along with irrigation channels produced erroneous watershed boundaries that were

developed using GIS raster models. Where GIS raster models produced erroneous watershed boundaries, the HUC-12 polygons were used to calculate watershed areas.

As an accuracy check, the USGS gaging station watershed areas calculated using the Watershed tool or HUC-12 polygons, were compared to the USGS National Watershed Information System (NWIS) (http://waterdata.usgs.gov/nwis) published gaging station areas. Figure 9 shows the USGS gaging stations analyzed and the correlating GIS model-generated watershed areas within the study area. Table 13 shows the results of this comparison. Based on the 6 gaging stations analyzed, the ESRI GIS model calculates watershed areas that are within 1% of the USGS NWIS published areas except for the Beaverhead River at Dillon (06017000) gage (Appendix A). The GIS generated USGS watershed area boundary for this gage is aligned along a diversion ditch that intercepts flow and does not report to the Beaverhead River. LiDAR contours and elevations were reviewed along with the irrigation channel geometry and it was determined the USGS NWIS area was in error. Therefore the gage watershed area used for this analysis increases the drainage area upgradient from the diversion ditch by using the HUC-12 polygon, resulting in an area increase of 2.3%.

A total of 10 flow nodes were identified throughout the study reach, including 6 gaged locations and 4 ungaged locations. Table 14 is a summary of all flow nodes and the associated watershed areas. Figure 10 maps the flow node locations and corresponding watershed areas from Table 14.



LEGEND

- TOWNS
- MONTANA COUNTY BOUNDARIES
- ACTIVE USGS GAGE
- INACTIVE USGS GAGE
- WEST SIDE CANAL (APPROX.)
- HUC 8 BOUNDARIES
- BLACKTAIL DEEK CREEK STUDY REACH
- BEAVERHEAD RIVER STUDY REACH

USGS STATION
06017000
06017500
06018000
06015400
06018500
06016000

N

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

0 4.5 9 18
Miles

FIGURE 9

PIONEER TECHNICAL SERVICES, INC.

BEAVERHEAD RIVER & BLACKTAIL DEER CREEK USGS WATERSHEDS

DATE: 3/27/2017

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

Table 13 USGS and GIS Model Watershed Comparison

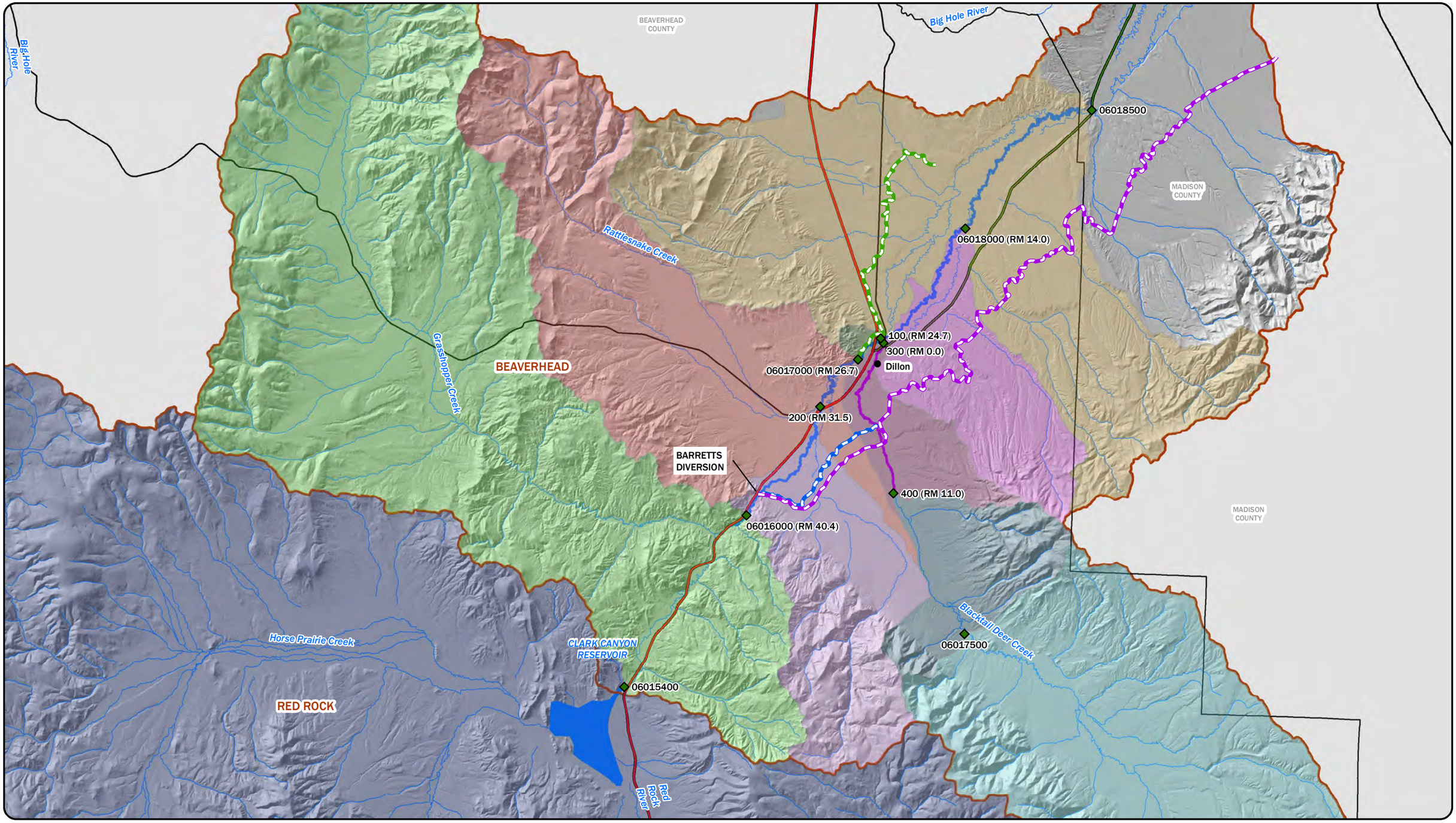
USGS Gage Station	Station Name	USGS Published Basin Area[1] (mi2)	Proposed Basin Area[2] (mi2)	Percent Change	Relative Accuracy of Areas
06018500	Beaverhead River near Twin Bridges, MT	3,618	3,619	-0.02%	100.0%
06018000	Beaverhead River near Dillon, MT	3,419	3,388	0.91%	99.1%
06017000	Beaverhead River at Dillon, MT	2,892	2,958	-2.29%	97.7%
06016000	Beaverhead River at Barretts, MT	2,730	2,730	0.00%	100.0%
06015400	Beaverhead River near Grant, MT	2,316	2,317	-0.02%	100.0%
06017500	Blacktail Deer Creek near Dillon, MT	316	316	-0.06%	99.9%

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

Table 14 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)
06015400	**Beaverhead River near Grant, MT**	**Beaverhead**		**2317**	**2317**
06016000	**Beaverhead River at Barretts, MT**	**Beaverhead**	40.4	**413**	**2730**
200[1]	Above Rattlesnake Creek	Beaverhead	31.5	71	2801
06017000	**Beaverhead River at Dillon, MT**	**Beaverhead**	**26.7**	**157**	**2958**
100[1]	Above Blacktail Deer Creek	Beaverhead	24.7	2	2960
06018000	**Beaverhead River near Dillon, MT**	**Beaverhead**	**14**	**428**	**3388**
06018500	**Beaverhead River near Twin Bridges, MT**	**Madison**		**231**	**3619**
06017500	**Blacktail Deer Creek near Dillon, Montana**	**Beaverhead**		**316**	**316**
400	Upstream extent of study area	Beaverhead	11.0	38	354
300	Confluence with Beaverhead River	Beaverhead	0	23	377

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

- FLOW NODE (RIVER MILE)
- TOWNS
- MONTANA COUNTY BOUNDARIES
- CANYON DITCH (APPROX.)
- EAST BENCH CANAL (APPROX.)
- WEST SIDE CANAL (APPROX.)
- HUC 8 BOUNDARIES
- BLACKTAIL DEEK CREEK STUDY REACH
- BEAVERHEAD RIVER STUDY REACH

FLOW CHANGE BASIN/ USGS BASIN

- 06017500
- 400
- 300
- 06015400
- 06016000
- 200
- 06017000
- 100
- 06018000
- 06018500

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 10

PIONEER TECHNICAL SERVICES, INC.

DELINEATED SUB BASIN AREAS AND FLOW NODE NOCATIONS

DATE: 3/27/2017

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3.3 Gage Transfer to Ungaged Sites

To calculate peak flood discharge estimates at the ungaged flow nodes, methods described in USGS SIR 2015-5109-F (Sando R, et al, 2015) were considered. 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 indicate the Beaverhead River flows through the Southwest Region. Most of the mainstem Beaverhead River flow nodes are classified as affected by major regulation due to the Clark Canyon Dam. 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 Beaverhead River flow node drainage areas are outside the range of values used to develop the Southwest Region regressions equations. Therefore, the regional regression equations were determined to be not applicable to the ungaged sites on the mainstem Beaverhead River.

Numerous USGS gaging stations are located on the mainstem Beaverhead River and all the ungaged Beaverhead River flow nodes are located between two gaging stations. Therefore the two site logarithmic interpolation method will be used to estimate peak flows at ungaged flow nodes on the Beaverhead River.

The ungaged flow nodes on Blacktail Deer Creek are located downstream of a single gage site. Therefore the two site logarithmic interpolation method is not applicable to the Blacktail Deer Creek Study reach. The 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). Therefore the drainage area gage transfer method peak can be used to calculate peak flow frequency estimates at ungaged flow nodes on the Blacktail Deer Creek Study reach.

In addition to the drainage area gage transfer method, the regional regression method is also applicable to the Blacktail Deer Creek Study reach. The Blacktail Deer Creek drainage is not considered regulated and flow nodes within the Southwest Region have watershed areas that are within the watershed area limits as defined by SIR 2015-5019-F. Therefore it was determined that regional regression equations are applicable to the Blacktail Deer Creek study reach and will be used in addition to the drainage area transfer method to develop peak flow estimates for ungaged flow nodes.

3.3.1 Two Site Logarithmic Interpolation Method

The log interpolation method presented in SIR 2015-5019-F was used 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

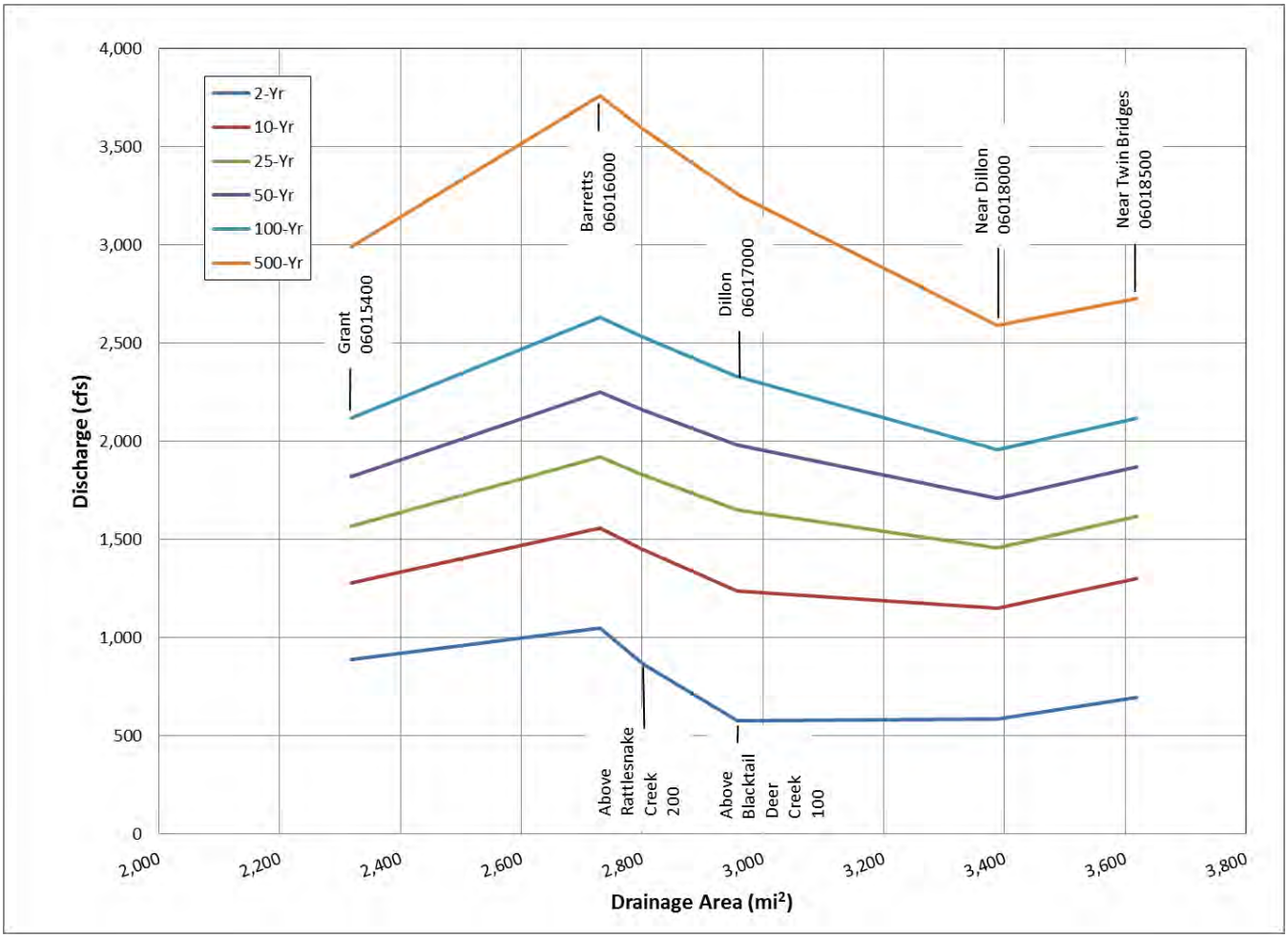
Table 15 shows the Beaverhead River calculation results. Figure 11 plots the relationship between the calculated discharge estimates and correlating drainage area. Results indicate estimated flows at the ungaged flow nodes are consistent with the gage site estimates and reach attenuation trends observed in the gaged sites data.

Table 15 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	
06015400	**Beaverhead River near Grant, MT**	**889**	**1,280**	**1,570**	**1,820**	**2,120**	**2,990**	**3,280**
06016000	**Beaverhead River at Barretts, MT**	**1,050**	**1,560**	**1,920**	**2,250**	**2,630**	**3,760**	**3,760**
200	Above Rattlesnake Creek	866	1,449	1,829	2,160	2,530	3,592	3,792
06017000	**Beaverhead River at Dillon, MT**	**575**	**1,240**	**1,650**	**1,980**	**2,330**	**3,260**	**3,860**
100	Above Blacktail Deer Creek	575	1,240	1,649	1,979	2,328	3,256	3,855
06018000	**Beaverhead River near Dillon, MT**	**585**	**1,150**	**1,460**	**1,710**	**1,960**	**2,590**	**2,990**
06018500	**Beaverhead River near Twin Bridges, MT**	**696**	**1,300**	**1,620**	**1,870**	**2,120**	**2,730**	**2,830**

* Sites on Blacktail Deer Creek were not included in the log linear interpolation method calculations.

Figure 11 Beaverhead River Log Interpolation Gage Analysis Results



3.3.2 Drainage Area Gage Transfer Method

Ungaged flow nodes located downstream of the Blacktail Deer Creek Gaging Station 06017500 near Dillon do not lie between two gaged stations on the same stream, therefore, the two site interpolation method cannot be employed. Estimating flood-frequency discharges for the ungaged flow nodes downstream of USGS Gaging Station 06017500 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 R. et al, 2015):

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

where

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

$Q_{T,G}$ 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 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. All 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 16 were used in these calculations. The drainage area transfer method results are shown in Table 17, and Figure 12.

Results indicate Blacktail Deer Creek estimated peak flow magnitudes are reasonable in comparison with the mainstem Beaverhead River estimated peak flow magnitudes and increase with increasing drainage area.

Table 16 Drainage Area Gage Transfer Regression Coefficients

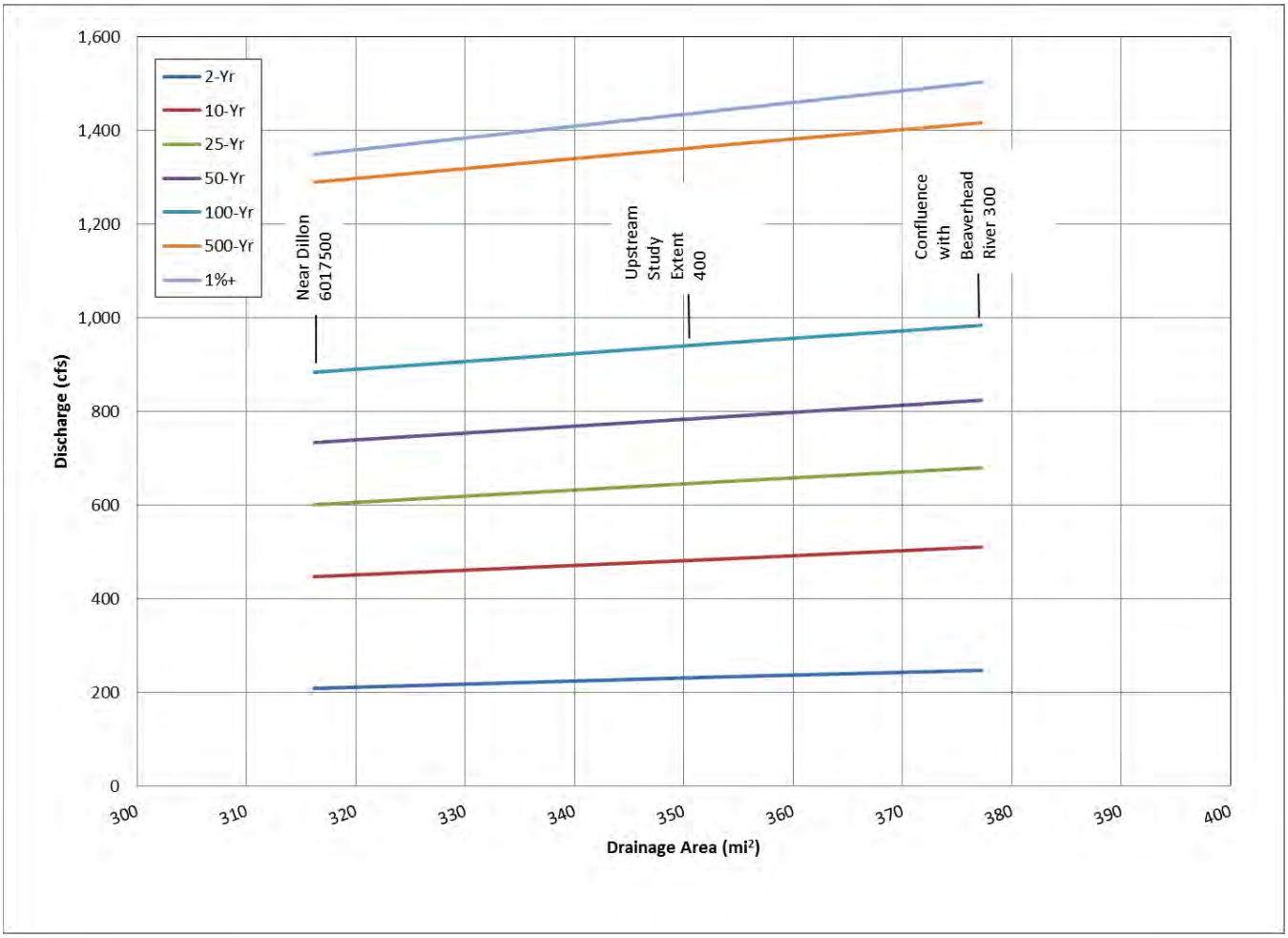
AE-percent Peak Flow	Regression Coefficient Relating AEP Flows to Drainage Area for Southwest Region
Q_{50}	0.939
Q_{10}	0.755
Q_4	0.690
Q_2	0.647
Q_1	0.609
$Q_{0.2}$	0.533

Source: SIR 2015-5019-F

Table 17 Drainage Area Gage Transfer Method Results for Blacktail Deer Creek Flow Node Locations Downstream of USGS Gage 06017500

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	
06017500	**Blacktail Deer Creek near Dillon, Montana**	**210**	**447**	**602**	**735**	**884**	**1,290**	**1,350**
400	Upstream extent of study area	234	487	651	791	947	1,370	1,447
300	Confluence with Beaverhead River	248	511	680	824	984	1,417	1,503

Figure 12 Blacktail Deer Creek Drainage Area Gage Transfer Results



3.3.3 Regional Regression Equations Method

Ungaged flow nodes located downstream of the Blacktail Deer Creek Gaging Station 06017500 near Dillon are not regulated and are within the drainage areas supported by the Southwest Region regression equations. The regression equations, presented in SIR 2015-5019-F, uses a drainage area (A) and percent of basin area above 6,000 feet (E_{6000}) as shown below in the following set of equations (Sando R. et al, 2015):

$$Q_{50} = 2.49A^{0.930}(E_{6000}+1)^{0.095}$$
$$Q_{10} = 31.9A^{0.796}(E_{6000}+1)^{-0.177}$$
$$Q_{4} = 79.8A^{0.750}(E_{6000}+1)^{-0.274}$$
$$Q_{2} = 142A^{0.721}(E_{6000}+1)^{-0.336}$$
$$Q_{1} = 238A^{0.696}(E_{6000}+1)^{-0.391}$$
$$Q_{0.2} = 655A^{0.649}(E_{6000}+1)^{-0.501}$$

where

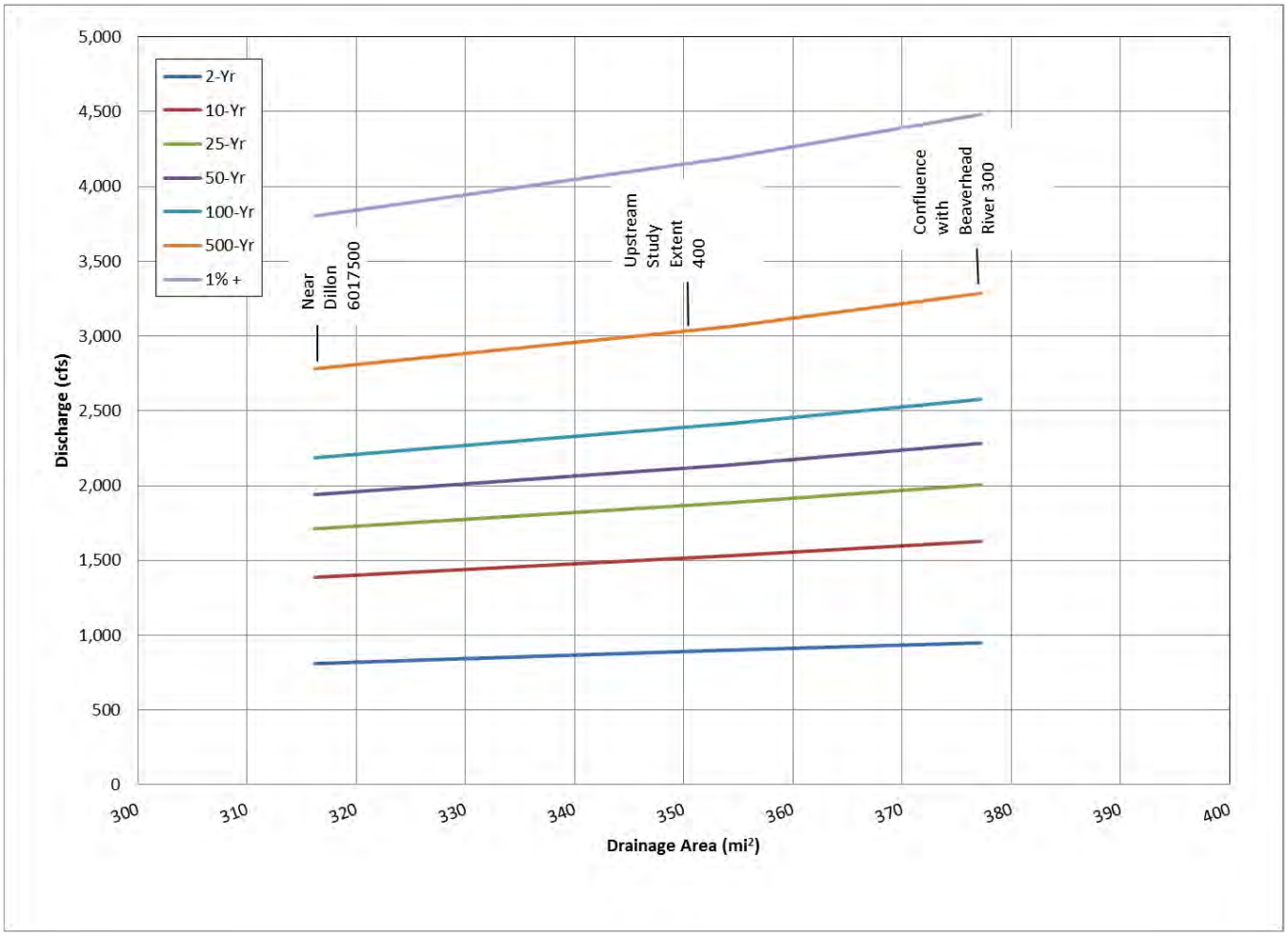
Q_x is the X annual exceedance probability peak flow magnitude, in cfs

A is the contributing drainage area, in square miles

E_{6000} is the percent of basin area above 6000 feet

The Southwest Region regression equation results are shown in Table 18, and Figure 13 shows the plot for the calculated peak discharges and correlating drainage areas. Appendix B provides the flood frequency calculations at the ungaged flow nodes.

Figure 13 Blacktail Deer Creek Regional Regression Equation Results



Regional regression calculation results indicate peak flow estimates are significantly greater than the drainage area gage transfer results and are similar in magnitude to the Beaverhead River peak flow estimates. The Beaverhead River peak flows that are similar in magnitude to the Blacktail Deer Creek regional regression peak flow estimates, are associated with much larger watershed areas than the Blacktail Deer Creek flow estimates. Due to the multiple gages on the

Beaverhead River mainstem, the Beaverhead River peak flow estimates are considered more accurate than the regression-based Blacktail Deer Creek peak flow estimates. The Blacktail Deer Creek regional regression peak flow estimates are not consistent with the mainstem Beaverhead River peak flow hydrology (i.e. the smaller Blacktail Deer Creek watershed should be producing significantly smaller peak flows than the mainstem Beaverhead River) or the Blacktail Deer Creek drainage area gage transfer results. Therefore Blacktail Deer Creek regional regression peak flow estimate were eliminated from further consideration.

Table 18 Blacktail Deer Creek Regression Results for Ungaged Flow Node Locations

Node/USGS Station ID	Location Description	Regional Regression Equations						
		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	
06017500	**Blacktail Deer Creek near Dillon, Montana**	**210**	**447**	**602**	**735**	**884**	**1,290**	**1,350**
400	Upstream extent of study area	899	1,532	1,886	2,138	2,413	3,064	4194
300	Confluence with Beaverhead River	948	1,627	2,008	2,281	2,578	3,283	4480

Appendix B provides the all flood frequency calculations at the ungaged flow nodes for both the Beaverhead River Study reach and the Blacktail Deer Creek Study reach. Appendix C provides the digital calculation files.

4 SUMMARY/DISCUSSION

A peak discharge frequency analysis was conducted for the mainstem Beaverhead River study reach and the Blacktail Deer Creek Study reach. The Beaverhead River Study reach extends 41.4-miles upstream from the Beaverhead/Madison County Boundary. The Blacktail Deer Creek Study area extends 11-miles upstream from the confluence with the Beaverhead River. Information gathered from this analysis will be used to support the Beaverhead County hydraulic analyses and floodplain mapping studies.

Previous flood studies on the Beaverhead River are limited. The most relevant earlier flood study was the City of Dillon and Beaverhead County FIS (Beaverhead FIS) (FEMA, 1982). The USGS WRIR 03-4308, published in 2004 was also an important study which included flood frequency analysis for multiple Beaverhead River gaging stations. The results of these previous studies were compared with the results of this study.

Flood frequency estimates for both gaged and ungaged sites were conducted. Peak flow estimates were calculated at 10 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, 1965-2016. The flood flow frequency estimates were calculated using Bulletin #17C methodologies.

The Beaverhead River systematic record data set had variable and discontinuous periods of record between the stream gages and produced results where flood discharge did not always increase 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 Beaverhead River watershed, the flood flow frequency estimates from this study produced significantly lower peak discharge estimates at the 1% and 0.2% annual chance flood potential than the 1982 FIS. In the middle and lower watershed reaches, the significant differences in peak flow estimates between this study and previous studies can be attributed to the longer gage record and periods of lower flows.

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 Beaverhead River basin, due to the long congruent period of record, which minimized errors associated with non-congruent periods of gage records. The flood flow frequency estimates based on the weighted gage record were determined to provide the most appropriate peak flow estimates for the

Blacktail Deer Creek basin, due to the recorded flows and larger regression dataset, which minimized errors associated with a short, discontinued and older gage record.

Flood flow frequency estimates were also developed at 4 ungaged locations. The ungaged sites (flow nodes) were located at major tributaries, population centers, and at the 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 Beaverhead River Study reach due to the regulated classification for most of the Beaverhead River mainstem gages. In the Blacktail Deer Creek Study reach, both the regional regression method and the drainage area gage transfer analysis were used to calculate flood frequency peak flow estimates. It was determined that the Blacktail Deer Creek regional regression peak flow estimates produced results that were significantly greater than peak flow estimates using gage data. Due to the higher confidence associated with flood frequency estimates that are based on measured stream flows, the regional regression method for peak flow estimates was eliminated from further consideration.

The Two Station Logarithmic Interpolation method was used on 2 ungaged flow nodes on the Beaverhead River.

As stated previously, the drainage area gage transfer method was used on the 2 flow nodes located downstream of USGS Gaging Station 06017500 Blacktail Deer Creek near Dillon. This method was required for the downstream flow nodes because only a single gage record is available for Blacktail Deer Creek.

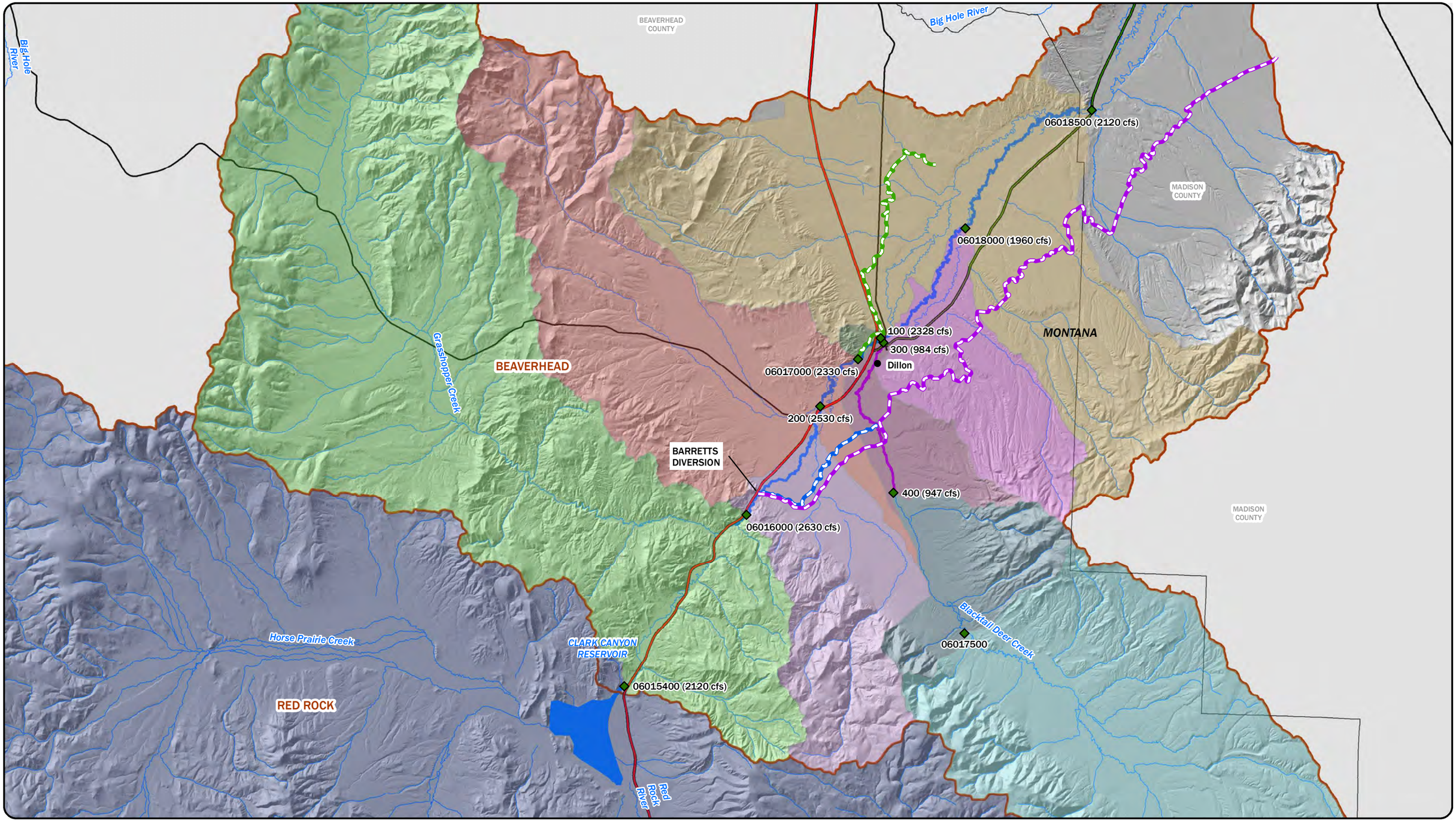
Table 19 summarizes the recommended flood frequency discharge rates for the Beaverhead River and the Blacktail Deer Creek Study reaches. Figure 14 shows the recommended 1% annual discharge for each flow node location.

The hydrologic analysis results provided in Table 19 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 and SIR 2015-5019-F) based on the Beaverhead River and Blacktail Deer Creek 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 19 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	
06015400	**Beaverhead River near Grant, MT**	**889**	**1,280**	**1,570**	**1,820**	**2,120**	**2,990**	**3,280**
06016000	**Beaverhead River at Barretts, MT**	**1,050**	**1,560**	**1,920**	**2,250**	**2,630**	**3,760**	**3,760**
200	Above Rattlesnake Creek	866	1,449	1,829	2,160	2,530	3,592	3,792
06017000	**Beaverhead River at Dillon, MT**	**575**	**1,240**	**1,650**	**1,980**	**2,330**	**3,260**	**3,860**
100	Above Blacktail Deer Creek	575	1,240	1,649	1,979	2,328	3,256	3,855
06018000	**Beaverhead River near Dillon, MT**	**585**	**1,150**	**1,460**	**1,710**	**1,960**	**2,590**	**2,990**
06018500	**Beaverhead River near Twin Bridges, MT**	**696**	**1,300**	**1,620**	**1,870**	**2,120**	**2,730**	**2,830**
06017500	**Blacktail Deer Creek near Dillon, Montana**	**210**	**447**	**602**	**735**	**884**	**1,290**	**1,350**
400	Upstream extent of study area	234	490	651	791	947	1,370	1,447
300	Confluence with Beaverhead River	248	516	680	824	984	1,417	1,503

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



LEGEND

- FLOW NODE (PEAK FLOW)
- TOWNS
- MONTANA COUNTY BOUNDARIES
- CANYON DITCH (APPROX.)
- EAST BENCH CANAL (APPROX.)
- WEST SIDE CANAL (APPROX.)
- HUC 8 BOUNDARIES
- BLACKTAIL DEEK CREEK STUDY REACH
- BEAVERHEAD RIVER STUDY REACH

FLOW CHANGE BASIN/ USGS BASIN

- 06017500
- 400
- 300
- 06015400
- 06016000
- 200
- 06017000
- 100
- 06018000
- 06018500

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 14

PIONEER TECHNICAL SERVICES, INC.

RECOMMENDED 1-PERCENT ANNUAL DISCHARGE FOR EACH LOCATION

DATE: 4/17/2017

Path: G:\DNRC\Mineral -Beaverhead County\Beaverhead County\CAD-GIS\GIS\BVRHD-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

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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		
23	06015400.11	Beaverhead River near Grant, Montana	2,316	R (MAJ–dam)	MOVE.3	52	BP 1965–2016	828	889	922	1,100	1,280	1,570	1,820	2,120	2,460	2,990	3,280	PeakFQv7.1 value adjusted for MOVE.3 analysis as described by Sando and others (2017; draft)[1]
26	06016000.10	Beaverhead River at Barretts, Montana	2,730	R (MAJ–dam)	At-site	52	1965–2016	976	1,050	1,100	1,320	1,560	1,920	2,250	2,630	3,070	3,760	3,760	PeakFQv7.1 value
28	06017000.11	Beaverhead River at Dillon, Montana	2,892	R (MAJ–dam)	MOVE.3	52	BP 1965–2016	444	575	639	952	1,240	1,650	1,980	2,330	2,710	3,260	3,860	PeakFQv7.1 value adjusted for MOVE.3 analysis as described by Sando and others (2017; draft)[1]
29	06017500.03	Blacktail Deer Creek near Dillon, Montana	316	U	RRE wtd	--	--	165	210	233	341	447	602	735	884	1,050	1,290	1,350	Confidence interval method for weighted frequency analysis (Sando and others, 2017; draft)[1] for 84-percent confidence level
30	06018000.11	Beaverhead River near Dillon, Montana	3,419	R (MAJ–dam)	MOVE.3	52	BP 1965–2016	465	585	644	914	1,150	1,460	1,710	1,960	2,230	2,590	2,990	PeakFQv7.1 value adjusted for MOVE.3 analysis as described by Sando and others (2017; draft)[1]
31	06018500.10	Beaverhead River near Twin Bridges, Montana	3,618	R (MAJ–dam)	At-site	52	1965–2016	562	696	760	1,050	1,300	1,620	1,870	2,120	2,380	2,730	2,830	PeakFQv7.1 value

[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, Drainage Area Transfer and Regional Regression 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	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 +
06015400	**Beaverhead River near Grant, MT**	**Beaverhead**		**2317**	**2317**	**889**	**1,280**	**1,570**	**1,820**	**2,120**	**2,990**	**3,280**
06016000	**Beaverhead River at Barretts, MT**	**Beaverhead**	40.4	**413**	**2730**	**1,050**	**1,560**	**1,920**	**2,250**	**2,630**	**3,760**	**3,760**
200	Above Rattlesnake Creek	Beaverhead	31.5	71	2801	866	1,449	1,829	2,160	2,530	3,592	3,792
06017000	**Beaverhead River at Dillon, MT**	**Beaverhead**	**26.7**	**157**	**2958**	**575**	**1,240**	**1,650**	**1,980**	**2,330**	**3,260**	**3,860**
100	Above Blacktail Deer Creek	Beaverhead	24.7	2	2960	575	1,240	1,649	1,979	2,328	3,256	3,855
06018000	**Beaverhead River near Dillon, MT**	**Beaverhead**	**14**	**428**	**3388**	**585**	**1,150**	**1,460**	**1,710**	**1,960**	**2,590**	**2,990**
06018500	**Beaverhead River near Twin Bridges, MT**	**Madison**		**231**	**3619**	**696**	**1,300**	**1,620**	**1,870**	**2,120**	**2,730**	**2,830**

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)

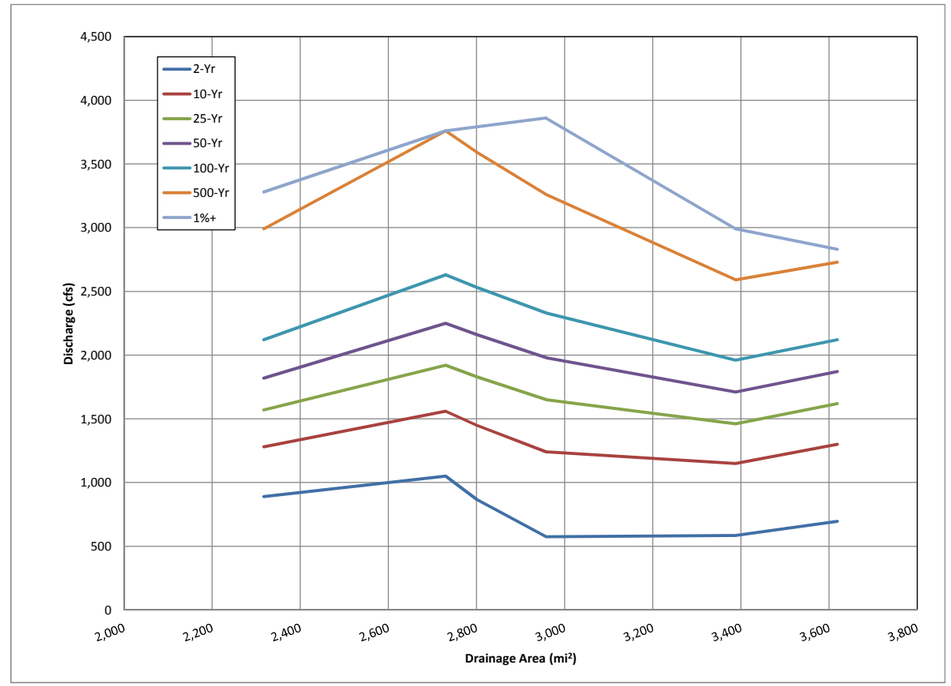
$Q_{AEP,G1}$ is the AEP-percent peak flow for the upstream gaging station $G1$, in cubic feet per second;

$Q_{AEP,G2}$ 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.

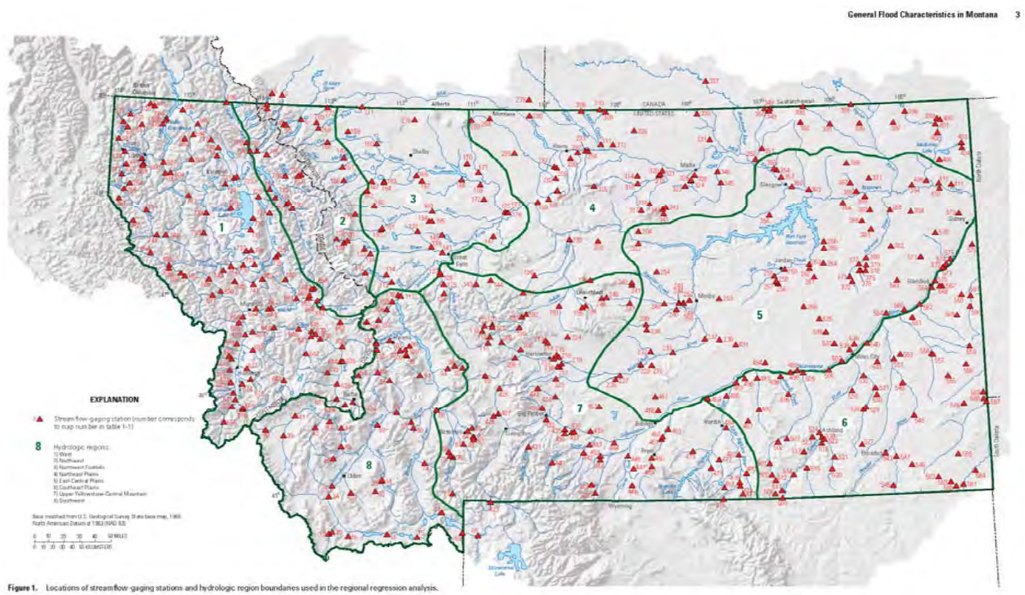


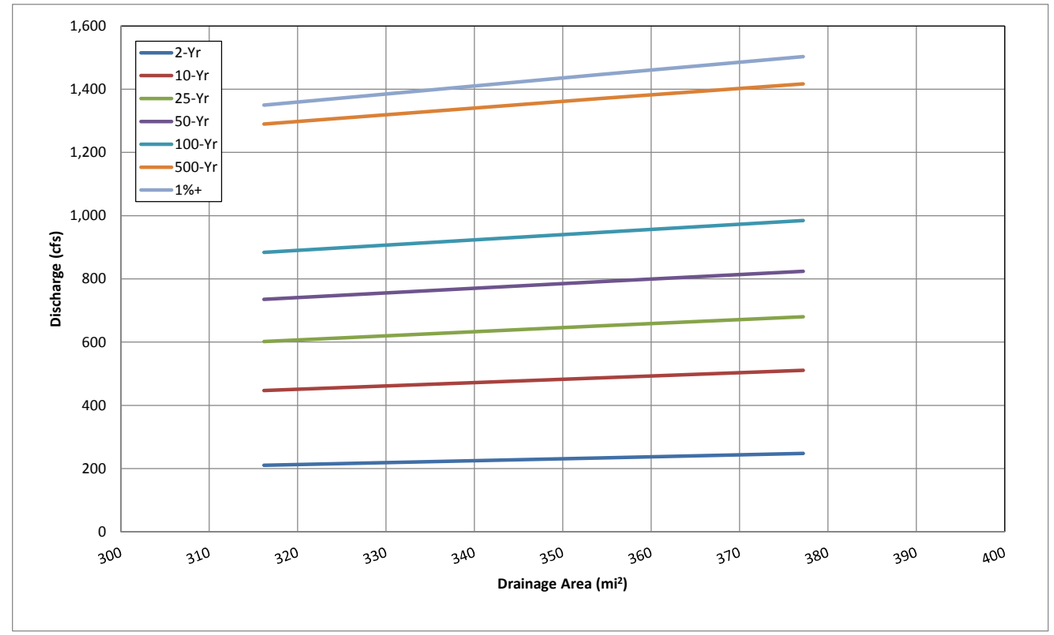
Node/USGS Station ID	Location Description	County	Study Reach River Station (miles)	Individual Basin Area (mi^2)	Cumulative Basin Area (mi^2)	DA_U/DA_G	Drainage Area Gage Transfer Estimated Discharge (cfs) 50% Annual Chance 2-year	10% Annual Chance 10-year	4% Annual Chance 25-year	2% Annual Chance 50-year	1% Annual Chance 100-year	0.2% Annual Chance 500-year	1% + Annual Chance 100-year +
06017500	**Blacktail Deer Creek near Dillon, Montana**	**Beaverhead**		**316**	**316**	**-**	**210**	**447**	**602**	**735**	**884**	**1,290**	**1,350**
400	Upstream extent of study area	Beaverhead	11.0	38	354	1.12	234	487	651	791	947	1,370	1,447
300	Confluence with Beaverhead River	Beaverhead	0	23	377	1.19	248	511	680	824	984	1,417	1,503

For an ungaged site that is not located between two gaged locations
Recommended that the drainage ratio be within 0.5 to 1.5

*** Recommended ratio be within 0.5 to 1.5
*Southwest Region for regression coefficient

Equation recommended by SIR 2015-5019-F





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

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).

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

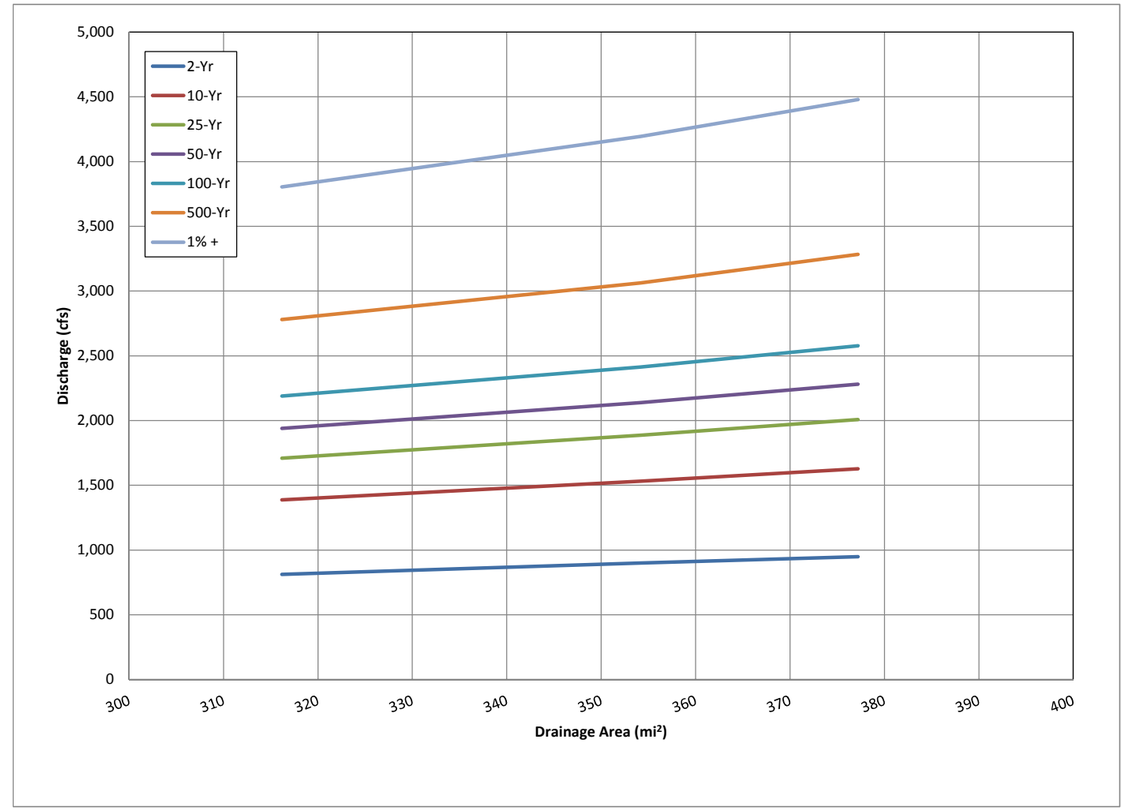
Node/USGS Station ID	Location Description	County	Study Reach River Station (miles)	Individual Basin Area (mi^2)	Cumulative Basin Area (mi^2)	E6000 (%)	Regional Regression Analysis Estimated Discharge (cfs) 50% Annual Chance 2-year	10% Annual Chance 10-year	4% Annual Chance 25-year	2% Annual Chance 50-year	1% Annual Chance 100-year	0.2% Annual Chance 500-year	1% + 100-year
06017500	**Blacktail Deer Creek near Dillon, Montana**	**Beaverhead**		**316**	**316**	96	812	1,388	1,710	1,939	2,189	2,780	3804
400	Upstream extent of study area	Beaverhead	11.0	38	354	91	899	1,532	1,886	2,138	2,413	3,064	4194
300	Confluence with Beaverhead River	Beaverhead	0	23	377	86	948	1,627	2,008	2,281	2,578	3,283	4480

Equation recommended by SIR 2015-5019-F

Southwest hydrologic region

$$Q_{66.7} = 1.04\ A^{0.971}\ (E_{6000} + 1)^{0.195}$$
$$Q_{50} = 2.49\ A^{0.930}\ (E_{6000} + 1)^{0.095}$$
$$Q_{42.9} = 3.61\ A^{0.910}\ (E_{6000} + 1)^{0.053}$$
$$Q_{20} = 13.4\ A^{0.842}\ (E_{6000} + 1)^{0.088}$$
$$Q_{10} = 31.9\ A^{0.796}\ (E_{6000} + 1)^{-0.177}$$
$$Q_{4} = 79.8\ A^{0.750}\ (E_{6000} + 1)^{-0.274}$$
$$Q_{2} = 142\ A^{0.721}\ (E_{6000} + 1)^{-0.336}$$
$$Q_{1} = 238\ A^{0.696}\ (E_{6000} + 1)^{-0.391}$$
$$Q_{0.5} = 377\ A^{0.675}\ (E_{6000} + 1)^{-0.442}$$
$$Q_{0.2} = 655\ A^{0.649}\ (E_{6000} + 1)^{-0.501}$$

[Q_{AEP}, peak-flow magnitude, in cubic feet per second, for annual exceedance probability (AEP) in percent; n, number of streamflow-gaging stations used in developing regression equations for indicated hydrologic region; σ_{δ}^{2}, model error variance; MVP, mean variance of prediction; SEP, mean standard error of prediction; SEM, mean standard error of model; Pseudo R^2, pseudo coefficient of determination; A, contributing drainage area, in square miles; P, mean annual precipitation, in inches; F, percentage of basin that is forest; E_{5000}, percentage of basin above 5,000 feet elevation; SLP_{30}, percentage of basin with slope greater than 30 percent; ET_{SPR}, Mean spring (March–June) evapotranspiration, in inches per month; E_{6000}, percent of basin above 6,000 feet elevation]



Appendix C: Digital Data and Calculation Files