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Physical Map Revision
Silver Bow Creek
Silver Bow County, Montana
Hydrologic Analysis Report

Montana Department of Environmental Quality

August 2, 2018

Pioneer Technical Services, Inc. 201 E. Broadway, Ste C, Helena Montana 59601

www.pioneer-technical.com

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Silver Bow Creek
Silver Bow County, Montana
Hydrologic Analysis Report

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Physical Map Revision

Silver Bow Creek

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Hydrologic Analysis Report

August 2, 2018

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 the Streamside Tailings (SST) Operable Unit (OU), a 17-mile reach of Silver Bow Creek (SBC). The SBC study reach extends from the Deer Lodge/Silver Bow County boundary upstream to the Flood Insurance Rate Map (FIRM) panel 30093C0302E boundary, located approximately 250 feet upstream of the westbound Interstate 90 (I-90) bridge east of Butte, Montana. The FIRM panel 30093C0302E boundary is 200 feet upstream of the SST OU boundary. Information gathered from this analysis will be used for future floodplain studies and mapping projects.

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

Silver Bow Creek is located west of the continental divide in western Montana. It is a major tributary to the Clark Fork River, which is a major tributary to the Pend Oreille River and upper Columbia River headwaters. Beginning at the Upper Silver Bow Creek and Blacktail Creek confluence in Butte, Montana, SBC flows northwest for approximately 34 miles before it combines with Warm Spring Creek to form the Clark Fork River. The entire SBC watershed area encompasses approximately 473 square miles. The study watershed basin area from the Deer Lodge County border to 200 feet upstream of the SST OU boundary (east side of Butte) is approximately 335 square miles.

The basin elevations within the SBC study area range from over 8,900 feet in the mountains to approximately 5,070 feet at the Deer Lodge County border. The watershed terrain varies from a high alpine environment at the river's headwaters to a heavily cultivated landscape in the Deer Lodge valley with expansive irrigated pasture lands, bracketed by rolling foothills. The basin hydrology is primarily snowmelt driven.

The primary flooding cause on SBC is spring snowmelt mixed with rain (according to historical records). There are historical records from several U.S. Geological Survey (USGS) stream gages on the creek that date back to 1984, which document basin flood history.

Past SBC flood studies within Silver Bow County are numerous. Within the SBC basin, a Federal Emergency Management Agency (FEMA) Flood Insurance Survey (FIS) exists for Silver Bow County. Various reports dating from 1987 to 2015 (and detailed in this report) developed flood frequency estimates for SBC to support SST OU remedial action (RA) activities and to perform a regional regression flood frequency analyses.

For this hydrologic analysis, a flood flow frequency analysis was conducted to develop peak flow discharge estimates for the 50-, 10-, 4-, 2-, 1-, and 0.2-percent annual exceedance probability (AEP). The 1%+ (plus) AEP was also calculated. Peak flow estimates were calculated at 8 locations (flow nodes) within the watershed (2 gaged sites and 6 ungaged sites). Estimates at the active

gaged sites were conducted using Bulletin #17C methodologies. At the ungaged sites, peak flow estimates were calculated using the Two Site Logarithmic Interpolation method and Regional Regression Equation method. These methods conform to standard engineering practice.

The recommended gage-based flood flow frequency estimates from this study are lower than regional regression estimates and estimates from the current FIS and the previous design studies. The recommended gage-based flood flow frequency estimates are within 1 standard error of the regional regression peak flow estimates. This study's peak discharge estimates are similar to the USGS studies.

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

1 INTRODUCTION

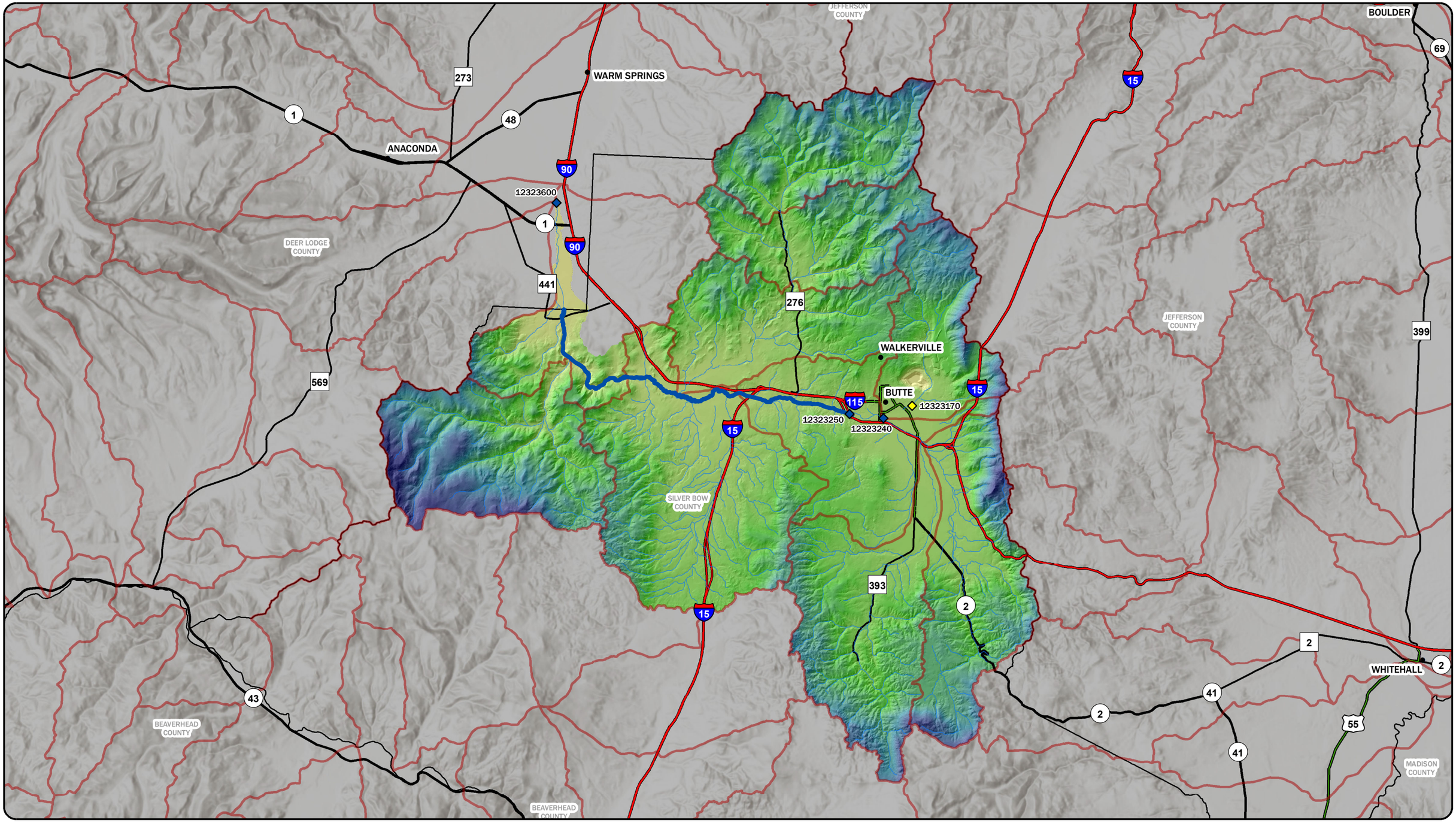
Portions of SBC and its floodplain located in Silver Bow County were reconstructed under the SST OU Remedial Action (RA). Following the RA completion, the Montana Department of Environmental Quality (DEQ) contracted Pioneer Technical Services, Inc. (Pioneer) to update the FIRMs on SBC within the SST OU RA area through FEMA. As part of the FIRM updates, a comprehensive peak flow hydrologic analysis for a 17-mile SBC study reach located within the SST OU boundary was conducted. The study did not include tributaries. The SBC study reach extends from the Deer Lodge/Silver Bow County boundary upstream to the FIRM panel 30093C0302E boundary located approximately 250 feet upstream of the westbound I-90 bridge east of Butte, Montana. The FIRM panel 30093C0302E boundary is 200 feet upstream of the SST OU boundary. This study area watershed encompasses approximately 335 square miles. Information gathered from this analysis will be used for both enhanced level and base level hydraulic analyses and floodplain mapping. Figure 1 shows the project study reach.

1.1 Background Information

The FEMA administers the National Flood Insurance Program (NFIP). As part of this program, FEMA supports flood hazard studies and prepares flood hazard maps and related documents. The Silver Bow County study reach is located downstream of Butte; therefore, the SBC in Silver Bow County is sparsely populated in a predominantly rural environment. The existing floodplain mapping for SBC in the study area includes 13.2 miles of Approximate Zone A and 3.2 miles of Detailed Zone AE near Rocker, Montana, and near Fairmont Hot Springs Resort (towards Anaconda, Montana). The existing mapping study was completed in 1977.

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.

Enhanced and base level 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, base level mapping does not include floodway delineation, may not include a 500-year floodplain delineation, and may allow some flexibility in the acquisition and modeling of bathymetric and structure survey data.



LEGEND

- INACTIVE USGS GAGE
- ACTIVE USGS GAGE
- SILVER BOW CREEK PROFILE BASELINE
- NHD HYDROGRAPHY
- HUC 12 BOUNDARIES
- MONTANA COUNTY BOUNDARIES
- NHS INTERSTATE
- NHS NON-INTERSTATE
- PRIMARY
- SECONDARY

N

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

0 1.75 3.5 7
Miles

FIGURE 1

SILVER BOW CREEK STUDY AREA

PIONEER TECHNICAL SERVICES, INC.

DATE: 8/2/2018

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The DEQ, in partnership with the Montana Department of Natural Resources and Conservation (DNRC), FEMA, and Butte-Silver Bow Local Government, initiated work to produce a new floodplain study along a reach of SBC in Silver Bow County. The SBC Floodplain Study will provide the groundwork for completing floodplain mapping along SBC. This report documents the hydrologic analysis methodology and results completed on SBC. The analysis includes peak discharge estimate calculations 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. The hydrologic analysis also included calculation of the 1% + (plus) annual chance discharge estimates and conformed to FEMA standards for detailed/enhanced level studies (FEMA, 2018).

1.2 Basin Description

Silver Bow Creek combines with Warm Springs Creek to form the Clark Fork River, which is a major tributary to the Pend Oreille River and Columbia River's upper headwaters located west of the continental divide in western Montana. The creek originates in the Deerlodge National Forest near the continental divide. The watershed is formed by the Pioneer and Highland Mountains. Beginning in Butte, Montana, at the Upper Silver Bow Creek and Blacktail Creek confluence, SBC flows northwest for approximately 34 miles before it combines with Warm Spring Creek to form the Clark Fork River near Warm Spring, Montana. The entire SBC watershed area encompasses approximately 473 square miles. The study watershed basin area upstream of the Deer Lodge/ Silver Bow County boundary is approximately 335 square miles.

The SBC basin elevations within the study area range from approximately 8,900 feet in the mountains to approximately 5,070 feet at the county border. The terrain varies from a high alpine environment in its headwaters to a heavily cultivated landscape in the Deer Lodge valley, with expansive irrigated pasture lands bracketed by rolling foothills. The basin hydrology is primarily snowmelt driven.

Land use in SBC basin is primarily agricultural with irrigated farming and ranching operations. The intensely farmed land is predominately located in the Deer Lodge Valley within the SBC floodplain.

1.3 Flood History

The primary flooding cause on SBC is spring snowmelt mixed with rain (according to historical records). The greatest flood on record for SBC occurred in June 1908. The Clark Fork Watershed Education Program (CFWEP, 2015) states that it was one of the most devastating floods to hit the region. In early June, the ground was already saturated from weeks of hard rain when temperatures dropped, and several inches of snow covered the area. As temperatures warmed, the drenched earth began to flood, sending torrents into the creek, which was estimated to be a mile in width. The flood forced residents to flee and railroads to shut down—even the mines in Butte, Montana, closed.

There are historical records from one USGS stream gage within the study area and three USGS stream gages near the study area that document flooding history. The gages are listed below:

1. Silver Bow Creek at Opportunity, MT (12323600)—referred to as SBC at Opportunity, MT (12323600).
2. Silver Bow Creek below Blacktail Creek at Butte, MT (12323250) —referred to as SBC below Blacktail Creek at Butte, MT (12323250).
3. Blacktail Creek at Butte, MT (12323240).
4. Silver Bow Creek above Blacktail Creek at Butte, MT (12323170)—referred to as SBC above Blacktail Creek at Butte, MT (12323170).

The SBC at Opportunity, MT (12323600) gage has a 29-year period of record (1989-2017). The annual peak flow record for the gage is shown in Figure 2. The gage is located downstream of the study area.

The SBC below Blacktail Creek at Butte, MT (12323250) gage has a 34-year period of record (1984-2017). The annual peak flow record for the gage is shown in Figure 3. The gage is located within the study area near the upstream boundary.

Blacktail Creek at Butte MT (12323240) gage has a 29-year period of record (1989-2017). The annual peak flow record for the gage is shown in Figure 3. The gage is located upstream of the study area on a main tributary to SBC.

The SBC above Blacktail Creek at Butte, MT (12323170) gage has an 11-year period of record (1984-1994). The annual peak flow record for the gage is shown in Figure 5. The gage is located upstream of the study area.

The AEP flows shown on Figure 2, Figure 3, Figure 4, and Figure 5 are based on previously published flood frequency analysis through Water Year 2011 (Scientific Investigations Report [SIR] 2015-5019-C) (Sando et al., 2015a).

Figure 2 shows that the peak flood of record for SBC at Opportunity, Montana, occurred in 1996 with a flow of 1,300 cubic feet per second (cfs), exceeding the 2% (50-yr) AEP flow of 1,210 cfs. The second highest flood on record occurred in 2011 with a flow of 772 cfs, exceeding the 10% (10-year) AEP flow of 718 cfs. The third highest flood on record occurred in 1989 with a flow of 654 cfs. The fourth highest flood on record occurred in 1997 with a flow of 648 cfs. In the 29-year period of record at the SBC at Opportunity, MT (12323600) gage, the 1996 and 2011 floods are the only flow events that exceeded the 10% (10-year) AEP flow.

Figure 2 Silver Bow Creek at Opportunity, MT (12323600)

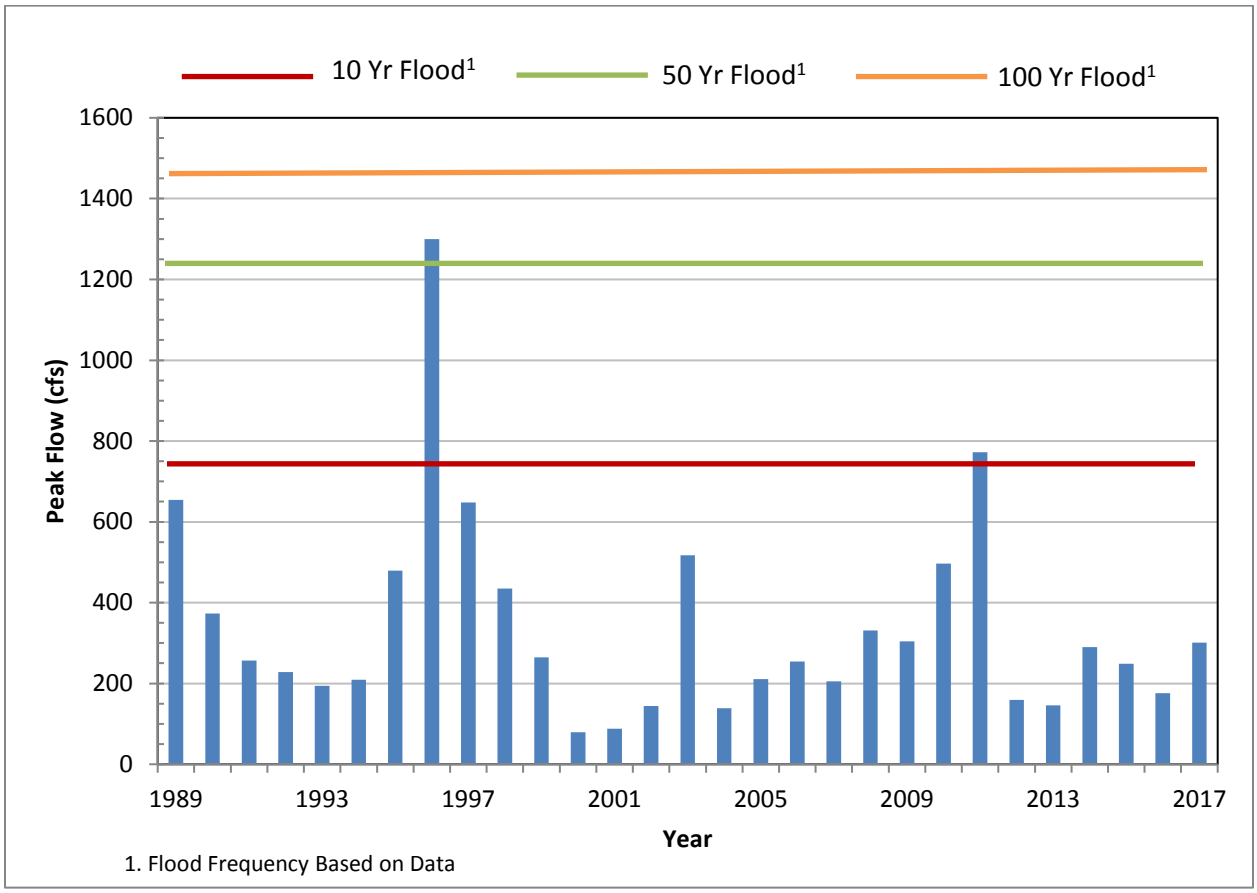


Figure 3 shows that the peak flood of record for SBC below Blacktail Creek occurred in 1998 with a flow of 447 cfs, exceeding the 2% (50-year) AEP flow of 435 cfs. The second highest flood on record occurred in 1990 and again in 1995 with a flow of 320 cfs. The third highest flood on record occurred in 2003 with a flow of 314 cfs. In the 34-year period of record at the SBC below Blacktail Creek at Butte, MT (12323250) gage, the 1998 flood is the only flow event that exceeded the 10% (10-year) AEP flow of 328 cfs.

Figure 3 Silver Bow Creek below Blacktail Creek at Butte, MT (12323250)

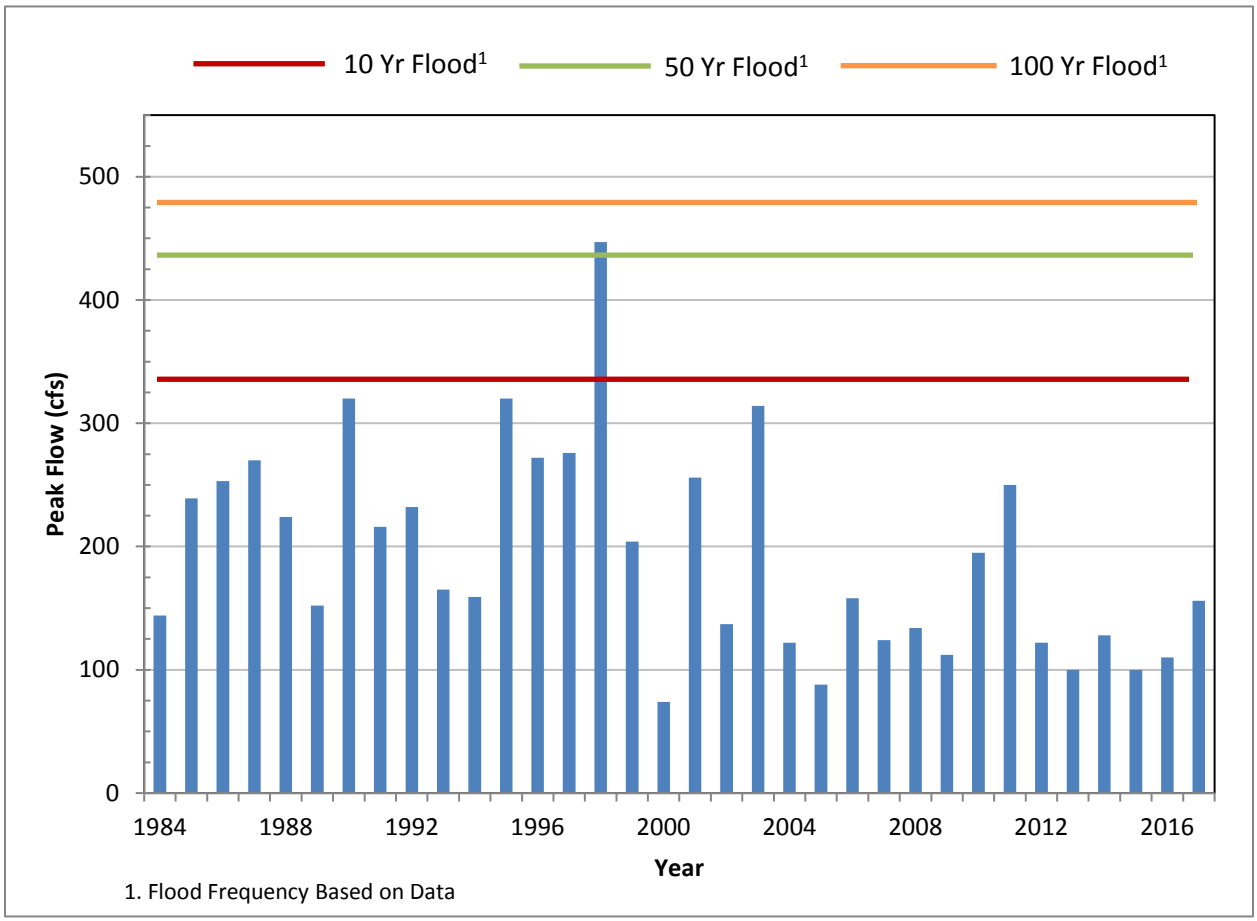


Figure 4 shows that the peak flood of record for Blacktail Creek occurred in 1995 with a flow of 303 cfs, exceeding the 10% (10-year) AEP flow of 241 cfs. The second highest flood on record occurred in 2003 with a flow of 234 cfs. The third highest flood on record occurred in 2011 with a flow of 230 cfs. In the 29-year period of record at the Blacktail Creek gage, the 1995 flood is the only flow event that exceeded the 10% (10-year) AEP flow.

Figure 4 Blacktail Creek at Butte, MT (12323240)

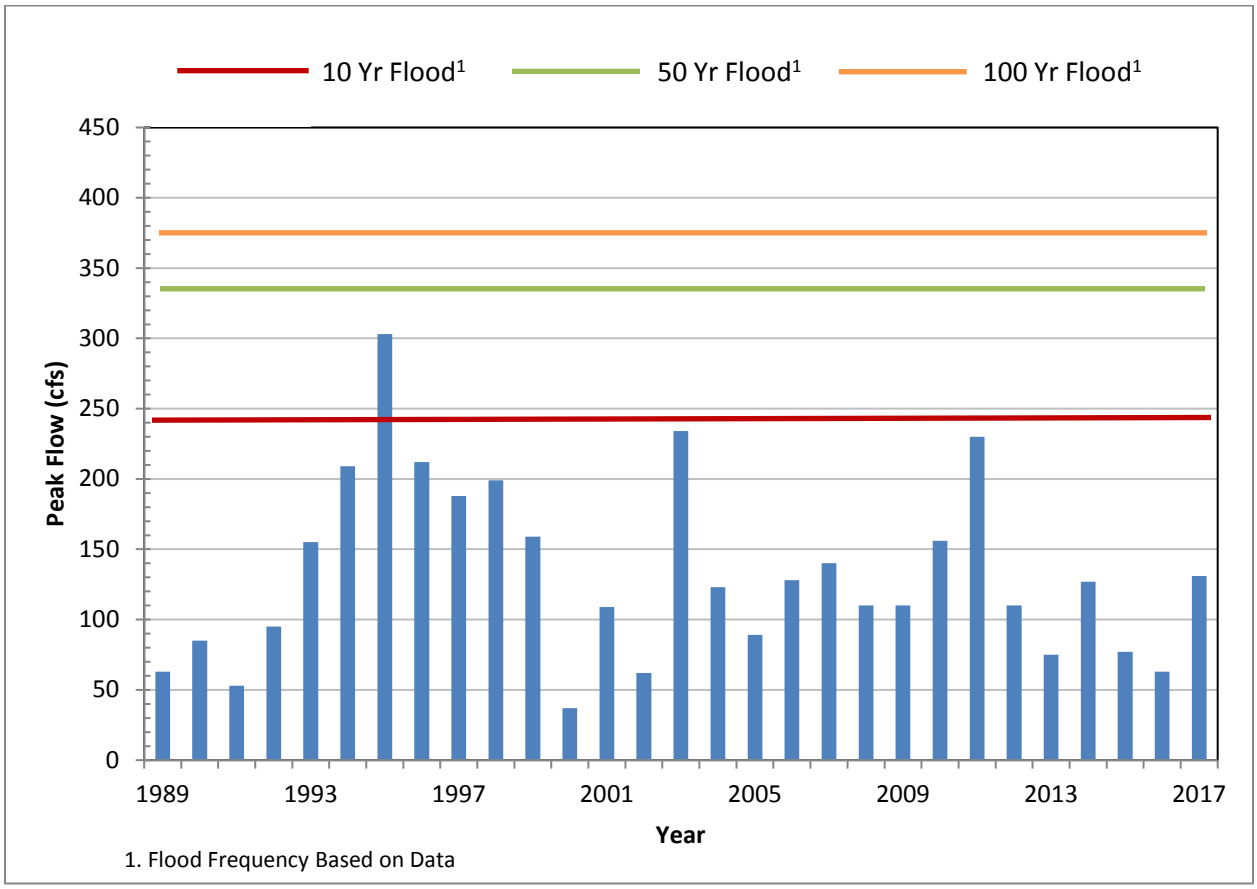
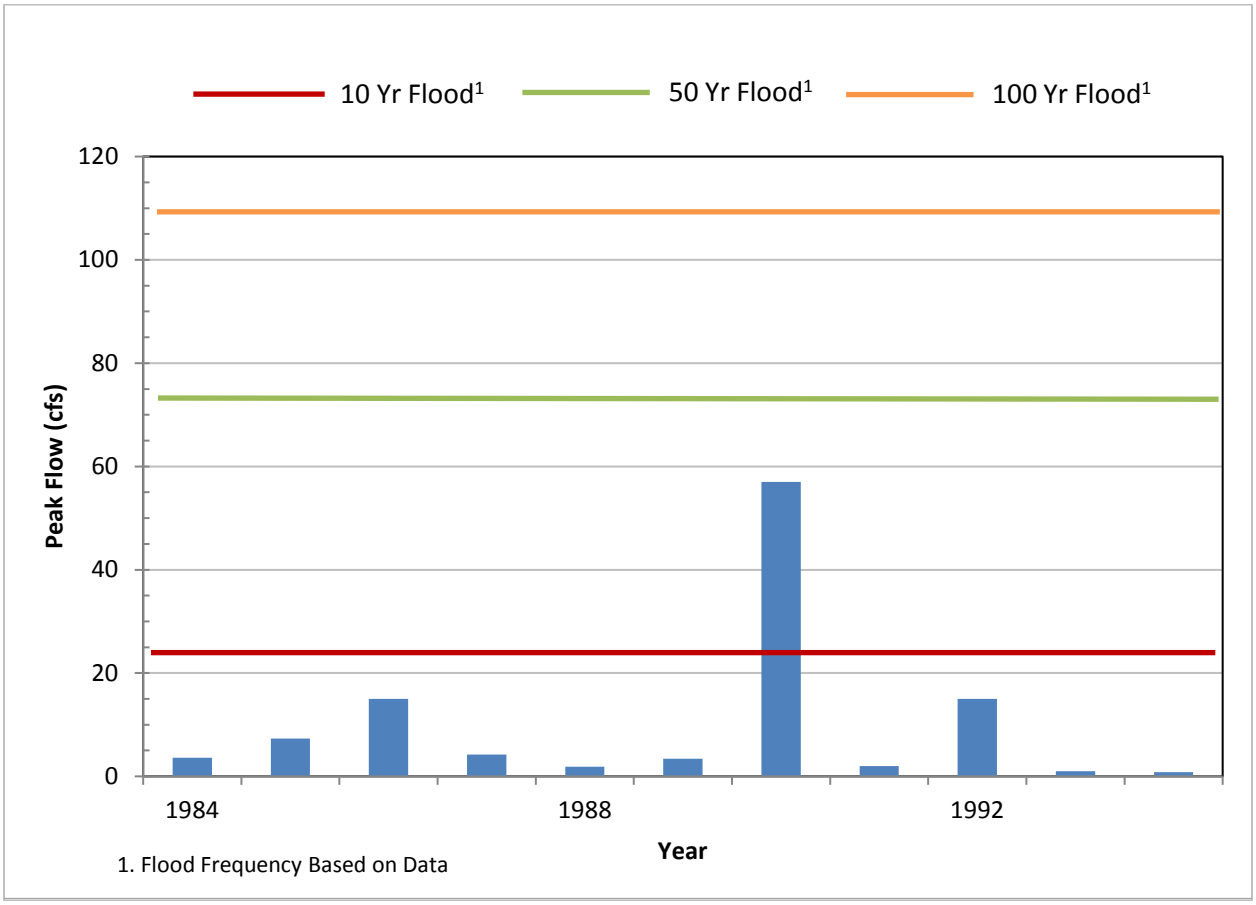


Figure 5 shows that the peak flood of record for SBC above Blacktail Creek occurred in 1990 with a flow of 57 cfs, exceeding the 10% (10-year) AEP flow of 24 cfs. The second highest flood on record occurred in 1986 and again in 1992 with a flow of 15 cfs. In the 11-year period of record at the SBC above Blacktail Creek at Butte, MT (12323170), the 1990 flood is the only flow event that exceeded the 10% (10-year) AEP flow.

Figure 5 Silver Bow Creek above Blacktail Creek at Butte, MT (12323170)



2 PAST STUDIES AND EXISTING FLOOD DATA

There are numerous past flood studies on SBC within Butte-Silver Bow County. Studies relevant to this hydrologic study are those that include peak flow frequency analyses. Within the SBC basin, a FEMA FIS exists for Silver Bow County. Table 1 shows a summary of SBC Floodplain Mapping.

Table 1 Silver Bow 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)
Silver Bow	Butte-Silver Bow	8	0	1/6/2012	1/6/2012	SBC	13	3	16

Source: FEMA Map service Center.
FIRM: Flood Insurance Rate Map. FIS: Flood Insurance Studies. FBFM: Flood Boundary and Floodway Map.
SBC: Silver Bow Creek. mi: Miles measured along channel alignment

In addition to two FEMA FIS reports, there are three USGS reports and six other reports completed to support Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial activities that document flood frequency analysis on several gages along SBC. These studies and investigations are discussed in more detail in the following sections.

2.1 Butte-Silver Bow Flood Insurance Study (1979)

The initial Butte-Silver Bow FIS was issued in March of 1979 (USDHUD, 1979). As part of the FIS, SBC was studied using detailed and approximate methods. The hydrologic and hydraulic analyses were completed by Morrison-Maierle, Inc. in June 1977. The study area included the community of Butte-Silver Bow. The City of Butte and Silver Bow County were combined in 1977 to form a city-county government.

The FIS identified SBC near Rocker as an area of severe historic flooding. No other flood problem areas on SBC were identified. The area of SBC between Montana Street and the weed concentrator (concentrator located below the Berkeley Pit) had been straightened with embankments on both sides of the creek in some segments. This stretch has since been reconstructed following CERCLA remedial activities. Peak-discharge-drainage area relationships were developed using *A Method for Estimating Magnitude and Frequency of Floods in Montana* (Johnson and Omang, 1976) to estimate AEP peak discharges with recurrence intervals of 10, 50, 100, and 500 years for 4 ungaged sites. Table 2 provides the peak discharge summary for the 4 sites.

The Butte-Silver Bow FIS originally issued in 1979 was updated and reissued on January 6, 2012 (FEMA, 2012). The 2012 FIS did not update the hydrology and hydraulics information for SBC or include any new discussion of flood problems and flood protection measures.

Table 2 Butte-Silver Bow FIS Summary of Discharges

Flooding Source and Location (Flow Node)	Drainage Area (sq mi)	Peak Discharges (cfs)			
		10-Year	50-Year	100-Year	500-Year
SBC at Fairmont Hot Springs	323.7	1,672	2,402	2,763	3,854
SBC at the Town of Rocker	118.0	833	1,217	1,413	1,989
SBC at Montana Avenue	103.8	683	997	1,158	1,630
SBC at Confluence with Blacktail	21.8	104	153	179	232

sq mi: square miles. cfs: cubic feet per second. SBC: Silver Bow Creek.

2.2 Silver Bow Creek Flood Modeling Study

The SBC Flood Modeling Study was conducted in 1989 by CH2M Hill (CH2M Hill, 1989) for the Department of Health and Environmental Sciences Solid Hazardous Water Bureau, which was restructured under the Montana DEQ in 1994. The study developed probable maximum flood hydrographs for 12 gaged sites located within the Clark Fork River Basin, including 1 gaged site on SBC near Warm Springs, MT. The study also included a regional flood-frequency analysis for the 12 gaged sites using Bulletin 17 regression analysis methods described by the U.S. Water Resources Council (USWRC, 1976). Envelope curves were developed to show the estimated range from the regional flood-frequency analysis. From the envelope curves, upper and lower AEP peak discharges with recurrence intervals of 10, 25, and 100 years for 5 ungaged sites and 1 gaged site on SBC were estimated. Table 3 provides the peak discharge summary for the 6 sites on SBC.

Table 3 Silver Bow Creek Flood Modeling Study Regional Flood Frequency Peak Discharge Summary

Flooding Source and Location (Flow Node)	Drainage Area (sq mi)	Peak Discharges (cfs)					
		10-Year		25-Year		100-Year	
		Lower	Upper	Lower	Upper	Lower	Upper
SBC below Blacktail Creek (#12323240)	103	800	1,450	1,150	2,050	1,900	3,000
SBC below Canada Creek	117	850	1,550	1,200	2,200	2,050	3,250
SBC above Browns Gulch	166	1,100	2,000	1,600	2,800	2,600	4,000
SBC above German Gulch	266	1,550	2,750	2,200	3,800	3,600	5,400
SBC above Diversion Works	347	1,900	3,300	2,700	4,500	4,300	6,300
SBC at Old USGS Gage Site above Warm Springs Creek	452	2,300	3,900	3,300	5,400	5,000	7,400

SBC: Silver Bow Creek. sq mi: square miles. cfs: cubic feet per second.

A rainfall/runoff model was created using the HEC-1 Flood Hydrograph Package (USACE, 1985) to simulate river basin surface runoff response from precipitation and snowmelt. The HEC-1 model was calibrated to SBC basin flows using historic flood events from individual river basins to develop hydrographs for 23 SBC sub-basins. This calibrated rainfall-runoff model was used to estimate the SBC AEP peak discharges with recurrence intervals of 10, 25, and 100 years for 5 ungaged sites and 1 gaged site on SBC. Table 4 provides the peak discharge summary for the 6 sites on SBC. Table 4 shows that peak flows do not increase with an increase in drainage area due to hydrograph routing, hydrograph timing, and limited local inflow.

Table 4 Silver Bow Creek Flood Modeling Study HEC-1 Model Peak Discharge Summary

Flooding Source and Location	Drainage Area (sq mi)	AEP Peak Discharges (cfs)		
		10-Year	25-Year	100-Year
SBC below Blacktail Creek at Butte, MT (#12323240)	103	1,270	1,570	2,330
SBC below Canada Creek	117	1,180	1,450	2,160
SBC above Browns Gulch	166	1,240	1,560	2,420
SBC above German Gulch	266	1,580	1,990	3,050
SBC above Diversion Works	347	2,190	2,820	4,000
SBC at Warm Springs, MT	452	2,490	3,480	4,950

SBC: Silver Bow Creek. sq mi: square miles. AEP: annual exceedance probability. cfs: cubic feet per second.

2.3 Silver Bow Creek Hydrologic Model

The SBC Hydrologic Model created by Clear Creek Hydrology (CCH) in 1997 (CCH, 1997) developed AEP peak discharges with recurrence intervals of 2, 10, 50, 100 years for the SBC below Blacktail Creek at Butte, MT gage using the Hydrologic Simulation Program – Fortran (EPA, 1993). The model used the 13 years of daily and peak flow data at the SBC below Blacktail Creek at Butte, MT gage. The modeling results were used in conjunction with meteorological data to synthesize a 96-year flow record. For the model, CCH then developed flood frequency estimates by fitting a flood frequency distribution to the synthesized peak flow data. Table 5 provides the peak discharge summary for the gage.

Table 5 Silver Bow Creek Flood Hydrologic Model Peak Flow Estimates

USGS Station Number	USGS Station Name	AEP Peak Discharges (cfs)			
		2-Year	10-Year	50-Year	100-Year
12323250	SBC below Blacktail Creek at Butte, MT	200	550	1,250	1,750

USGS: U.S. Geological Survey. SBC: Silver Bow Creek cfs: cubic feet per second.

2.4 Expedited Response Action Work Plan/Final Design Report for Lower Area One

The Expedited Response Action Work Plan/Final Design Report for Lower Area One Operable Unit (LAO OU) Phase I Segment II was prepared in 1996 by ESA Consultants, Inc. The analysis estimated AEP peak discharges for the SBC below Blacktail Creek at Butte, MT gage using regional regression equations that were listed in USGS Water Resources Investigations Report (WRIR) 92-4048 (Omang, 1992). The AEP peak discharges were developed excluding and including the area drained by the Berkeley Pit. Table 6 lists the peak discharge summary for the gage.

Table 6 Expedited Response Action Work Plan/Final Design Report for LAO OU Phase I Segment II Peak Flow Estimates

USGS Station Number	USGS Station Name	Drainage Area (sq mi)	Peak Discharges (cfs)
			100-Year
12323250	SBC below Blacktail Creek at Butte, MT	103[1]	1783
12323250	SBC below Blacktail Creek at Butte, MT	125[2]	1889

1. Drainage area excludes area that drains to the Berkeley Pit.
2. Drainage area includes area that drains to the Berkeley Pit.

USGS: U.S. Geological Survey. SBC: Silver Bow Creek. sq mi: square miles. cfs: cubic feet per second.

2.5 Draft Channel Stability Analysis of Silver Bow Creek Subarea 1

The Draft Channel Stability Analysis of SBC SST OU Subarea 1 was conducted in 1997 by Mussetter Engineering, Inc. and Inter-Fluve, Inc (Mussetter and Inter-Fluve, 1997). The analysis considered several methods to develop AEP peak discharges at the SBC below Blacktail Creek at Butte, MT gage. Flood Frequency estimates were developed using the following:

- Bulletin 17B (IACWD, 1982) methods for the 14-year gage flow record.
- Bulletin 17B methods for the 96-year CCH synthesized flow record.
- USGS WRIR 86-4027 Regional regression methods (Omang, Parrett, and Hull, 1986).

Table 7 provides the AEP peak discharge summary for the gage.

Table 7 Draft Channel Stability Analysis of Silver Bow Creek Subarea 1 Peak Discharge Summary

USGS Station Number	USGS Station Name	Method	Years of Record	Peak Discharges (cfs)			
				2-Year	10-Year	50-Year	100-Year
12323250	SBC below Blacktail Creek at Butte, MT	Bulletin 17B	13	229	325	395	422
12323250	SBC below Blacktail Creek at Butte, MT	Bulletin 17B	96[1]	214	502	901	1,120
12323250	SBC below Blacktail Creek at Butte, MT	Regional Regression	NA	238	610	1,042	1,282

1. CCH peak flow record synthetic extension.

USGS: U.S. Geological Survey. SBC: Silver Bow Creek. cfs: cubic feet per second.

2.6 Channel Stability Analysis and Conceptual Design Report Subarea 2

The Channel Stability Analysis and Conceptual Design Report Subarea 2 was conducted in 2003 by Maxim Technologies and Mussetter Engineering, Inc. (Maxim & Mussetter, 2003). The analysis considered two methods to develop AEP peak discharges at the SBC below Blacktail Creek at Butte, MT and SBC at Opportunity, MT gages. The AEP peak discharges were estimated using the following:

- Bulletin 17B (IACWD, 1982) methods for the gage flow record.
- USGS WRIR 92-4048 Regional regression methods (Omang, 1992).

Table 8 provides the peak discharge summary.

Table 8 Channel Stability Analysis and Conceptual Design Report Subarea 2 Peak Discharge Summary

USGS Station Number	USGS Station Name	Method	Years of Record	AEP Peak Discharges (cfs)					
				2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
12323250	SBC below Blacktail Creek at Butte, MT	Bulletin 17B	18	230	310	360	420	460	510
12323250	SBC below Blacktail Creek at Butte, MT	Regional Regression	NA	320	590	840	1,140	1,420	1,720
12323600	SBC at Opportunity, MT	Bulletin 17B	13	310	590	830	1,160	1,470	1,800
12323600	SBC at Opportunity, MT	Regional Regression	NA	930	1,730	2,380	3,100	3,850	4,660

USGS: U.S. Geological Survey. AEP: annual exceedance probability. SBC: Silver Bow Creek. cfs: cubic feet per second.

2.7 Water-Resources Investigations Report 03-4308

The investigation for USGS WRIR 03-4308 developed AEP peak discharges with recurrence intervals of 2, 5, 10, 25, 50, 100, 200, and 500 years (*T*-year floods) for 660 gaged sites in Montana and in adjacent areas of Idaho, Wyoming, and Canada, based on data through Water Year 1998 (Parrett and Johnson, 2004). The flood-frequency information was used in regression analyses to develop equations relating *T*-year floods to various basin and climatic characteristics, active-channel width, and bankfull width. The equations can be used to estimate flood frequency at ungaged sites. Flood-frequency data typically were determined by fitting a log-Pearson Type III probability distribution using methods described by the Interagency Advisory Committee on Water Data (IACWD), Bulletin #17B (IACWD, 1982). Table 9 provides the WRIR 03-4308 peak discharge summary for2 USGS gages on SBC and one on Blacktail Creek.

Table 9 WRIR 03-4308 Silver Bow Creek Peak Discharge Summary

USGS Station Number	USGS Station Name	Drainage Area (sq mi)	Years of Record	AEP Peak Discharges (cfs)						
				5	10	25	50	100	200	500
12323600	SBC at Opportunity, MT	284	10	663	884	1,210	1,490	1,810	2,160	2,690
12323250	SBC below Blacktail Creek Butte, MT	103	15	306	352	408	450	490	531	584
12323240	Blacktail Creek at Butte, MT	95.4	10	224	283	361	419	478	538	618

Based on systematic data through 1998. USGS: U.S. Geological Survey. sq mi: square miles. AEP: annual exceedance probability. cfs: cubic feet per second. SBC: Silver Bow Creek.

2.8 Channel Stability Analysis and Conceptual Design Report Subarea 3

The Channel Stability Analysis and Conceptual Design Report, SST OU Subarea 3, was prepared in 2007 by Tetra Tech and Applied Geomorphology (Tetra Tech and AGI, 2007). The analysis considered two methods to develop AEP peak discharges at the Silver Bow Creek below Blacktail Creek at Butte, MT and Silver Bow Creek at Opportunity gages. The AEP peak discharges were estimated using the following methods:

- Bulletin 17B (IACWD, 1982) methods for the gage flow record.
- USGS WRIR 03-4308 Regional regression methods (Parrett and Johnson, 2004).

Table 10 provides the Bulletin 17B analysis and regional regression peak discharge summary for the two USGS gages on SBC.

Table 10 Channel Stability Analysis and Conceptual Design Report Peak Discharge Summary

USGS Station Number	USGS Station Name	Method	Years of Record	AEP Peak Discharges (cfs)					
				2-Year	5-Year	10-Year	25-Year	50-Year	100-Year
12323250	SBC below Blacktail Creek at Butte, MT	Bulletin 17B	23	205	302	364	438	492	543
12323250	SBC below Blacktail Creek at Butte, MT	Regional Regression	NA	244	441	633	812	983	1,158
12323600	SBC at Opportunity, MT	Bulletin 17B	18	281	526	730	1,034	1,293	1,581
12323600	SBC at Opportunity, MT	Regional Regression	NA	694	1,209	1,710	2,127	2,545	2,967

USGS: U.S. Geological Survey. cfs: cubic feet per second. AEP: annual exceedance probability. SBC: Silver Bow Creek.

2.9 Scientific Investigations Report 2015-5019

The USGS SIR 2015-5019-C included updated AEP peak discharges with AEPs of 66.7, 50, 42.9, 20, 10, 4, 2, 1, 0.5, and 0.2 percent (return intervals of 1.5, 2, 2.33, 5, 10, 25, 50, 100, 200, and 500 years, respectively) for 725 gaged sites in or near Montana, based on data through Water Year 2011 (Sando et al., 2015a). Flood-frequency data were determined by fitting a log-Pearson Type III probability distribution using methods described by the IACWD, Bulletin #17B (IACWD, 1982). The study was part of a larger study to develop an online StreamStats application for Montana, in conjunction with computing streamflow characteristics at gage stations, and estimate peak flow flood frequency at ungaged sites. Table 11 provides the SIR 2015-5019-C discharge summary for SBC gages.

Table 11 SIR-2015-5019-C Silver Bow Creek Peak Discharge Summary

USGS Station Number	USGS Station Name	Drainage Area (sq mi)	Years of Record	Peak Discharge (cfs)						
				5-year	10-year	25-year	50-year	100-year	200-year	500-year
12323600	SBC at Opportunity, MT	343	23	532	718	988	1,210	1,460	1,730	2,120
12323250	SBC below Blacktail Creek Butte, MT	125	28	277	328	390	435	478	520	575
12323240	Blacktail Creek at Butte, MT	90.9	23	197	241	296	336	375	413	462
12323170	SBC above Blacktail Creek Butte, MT	21.7	11	13	24	46	72	109	160	256

Based on systematic data through 2011. USGS: U.S. Geological Survey. sq mi: square miles. cfs: cubic feet per second. SBC: Silver Bow Creek.

The USGS SIR 2015-5019-F (Sando et al., 2015b) 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 SBC at Opportunity, MT and below Blacktail Creek at Butte, MT were excluded from the dataset due to the redundancy of nearby stations; however, the Blacktail Creek at Butte, MT gage was included as well as the SBC at Warm Springs gage (downstream of the Opportunity gage in Deer Lodge County). The study used regression analyses to develop equations relating AEP flows to various basin and climatic characteristics. The relationships developed for this study resulted in lower mean standard errors of prediction than previous regression analyses.

2.10 Scientific Investigations Report 2018-5046

The USGS SIR 2018-5046 included updated AEP peak discharges with AEPs of 50, 42.9, 20, 10, 4, 2, 1, 0.5, and 0.2 percent (return intervals of 2, 2.33, 5, 10, 25, 50, 100, 200, and 500 years, respectively) for 99 gaged sites in or near Montana, based on data through Water Year 2015 (Sando and McCarthy, 2018). Flood-frequency data typically were determined by fitting a log-Pearson Type III probability distribution using an Expected Moments Algorithm analysis and other methods described by England and others in Bulletin #17C (England et al., 2018). The AEP peak discharges for the SBC below Blacktail Creek at Butte, MT gage were updated as part of the report. Table 12 provides the SIR 2018-5046 peak discharge summary for the gage.

Table 12 SIR 2018-5046 Peak Discharge Summary

USGS Station Number	USGS Station Name	Drainage Area (sq mi)	Years of Record	Peak Discharge (cfs)						
				5-year	10-year	25-year	50-year	100-year	200-year	500-year
12323250	SBC below Blacktail Creek at Butte, MT	125	32	261	315	384	436	488	541	613

USGS: U.S. Geological Survey. sq mi: square miles. cfs: cubic feet per second. SBC: Silver Bow Creek.

2.11 Additional Previous Studies

Additional related previous studies conducted along SBC within Silver Bow County involve water management, fisheries management, or sediment management:

- *Hydraulic and Water Quality Modeling of Silver Bow Creek-Upper Clark River, A Superfund Site in Montana* (Brown and Hosseinipour, 1987).
- *EPA Record of Decision Butte Priority Soils Operable Unit, Silver Bow Creek/Butte Area NPL Site* (EPA, 2006).
- *EPA Superfund Record of Decision: Silver Bow/Butte Creek, Streamside Tailings O.U., MT* (EPA, 1996).
- *Prioritization of Areas in the Upper Clark Fork River Basin for Fishery Enhancement* (Saffel et al., 2018).
- *Silver Bow Creek Watershed Restoration Plan* (Confluence Consulting, Inc. and DTM Consulting, Inc., 2005).
- *Water Quality, Bed-Sediment, and Biological Data (October 1993 thought September 1994) and Statistical Summaries of Data for Stream in the Upper Clark Fork Basin, Montana* (Lambing et al., 1995).

3 HYDROLOGIC ANALYSES AND RESULTS

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

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

Throughout the study area, 7 locations (flow nodes) on SBC were identified as having significant changes in streamflow or being at a critical location. Of the 7 flow nodes on SBC, 1 is located at an active USGS stream gage site and 6 are located downstream of that stream gage (ungaged sites). The river stationing used in this report was based on the SBC study profile baseline delineated by Pioneer using the project Light Detection and Ranging (LiDAR) information (QSI, 2017). The SBC profile baseline begins at the Silver Bow and Deer Lodge County border and extends upstream to river mile 17.1 (approximately 250 feet upstream of the westbound I-90 bridge east of Butte).

3.1 USGS Stream Gage Analysis

There is 1 USGS stream gage located in the SBC study reach and 3 additional USGS gages located near the study boundary (both upstream and downstream). The USGS gaging station 12323250 SBC below Blacktail Creek at Butte, MT is in the study reach located at river mile 17.0. The USGS gaging station 12323600 SBC at Opportunity, MT is located approximately 6.8 miles downstream of the study reach and was used in the analysis. Two other USGS gages are located upstream of the study boundary: USGS gaging station 12323240 Blacktail Creek at Butte, MT and 12323170 SBC above Blacktail Creek at Butte, MT.

The oldest records date back to 1984 at USGS gaging station 12323250 SBC below Blacktail Creek at Butte, MT and 12323170 SBC above Blacktail Creek at Butte, MT. The USGS gaging station 12323170 SBC above Blacktail Creek at Butte, MT has not been active since 1994. Currently, 3 of the 4 USGS gaging stations in or near the study reach are being maintained. Figure 1 on page 2 shows the study reach and the USGS gaging station locations along and near the study reach. The SBC below Blacktail Creek at Butte, MT gage has the longest congruent period of record extending from 1984 to 2017 (34 years). Table 13 summarizes the USGS stream gages considered in this analysis (active and inactive) along SBC. The FEMA guidance document (FEMA, 2017) indicates that gage station records equal or exceeding 10 years in length are applicable to all types of studies.

As discussed previously, the AEP peak discharges were updated for 725 gaged sites in or near Montana, based on data through Water Year 2011 (Sando et al., 2015a). Flood-frequency data were determined using methods described by the IACWD Bulletin #17B (IACWD, 1982). The

study was part of a larger study to develop an online StreamStats application for Montana. All 4 USGS gages in or near the study reach were included in this analysis.

In 2018, the USGS adopted Bulletin 17C guidelines to provide flood frequency estimates for stream gages (England et al., 2018). Pioneer performed systematic flood frequency analysis for all 4 gages in or nearby the Silver Bow study reach using Bulletin 17C methods. The calculations were conducted using the USGS PeakFQ flood frequency analysis software (version 7.1). Calculations are provided in Appendix A. Figure 6 plots the systematic flood frequency results as a function of drainage area and indicates peak discharges increase with increasing drainage area, as typically expected. The Blacktail Creek at Butte, MT gage is not on SBC, but it is a major tributary that with Upper Silver Bow Creek forms SBC. Table 14 tabulates the flood frequency estimate results.

Table 13 Silver Bow Creek USGS Gage Summary

Station number	Station name	Drainage[1] Area (sq mi)	Period of Systematic Record[2]	Number of Annual Peaks[2]	River Station (miles)
12323600	SBC at Opportunity, MT	343.0	1989-2017	29	N/A
12323250	SBC below Blacktail Creek Butte, MT	124.8	1984–2017	34	17.0
12323240	Blacktail Creek at Butte, MT	90.9	1989–2017	29	N/A
12323170*	SBC above Blacktail Creek at Butte MT	21.7	1984–1994	11	N/A

1. Source: National Watershed Information System (NWIS)
2. Data from USGS flood frequency NWIS, Web Interface

* Denotes inactive gage location

USGS: U.S. Geological Survey. sq mi: square miles. SBC: Silver Bow Creek.

Figure 6 USGS Flood Frequency Estimates Systematic Record 1984 through 2017

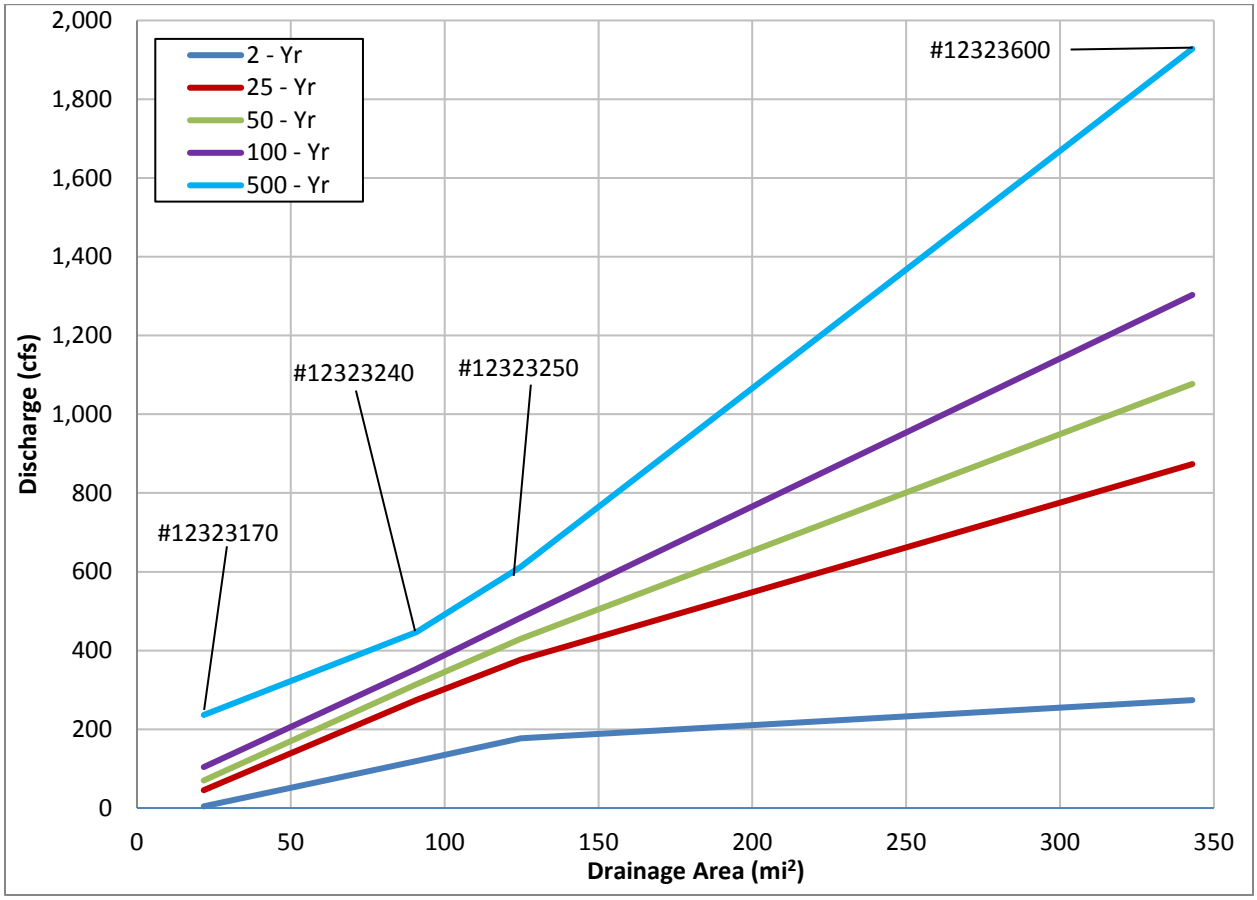


Table 14 Gage Flood Frequency Estimates Using Systematic Record

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
12323170	SBC above Blacktail Creek at Butte, MT	1984-1994	3	4	13	24	45	70	104	150	236
12323240	Blacktail Creek at Butte, MT	1989-2017	96	120	180	222	275	314	353	393	447
12323250	SBC below Blacktail Creek at Butte, MT	1984-2017	147	177	255	308	377	430	483	538	613
12323600	SBC at Opportunity, MT	1989-2017	209	274	473	635	873	1,077	1,303	1,553	1,928

cfs: cubic feet per second. SBC: Silver Bow Creek.

To address the non-congruent periods of record, the Maintenance of Variance Extension (MOVE) per Bulletin 17C (England et al., 2018) was considered to extend the historical gage records. The MOVE method correlates streamflow at a short-term gaging station with a longer-term index gaging station using a base 10 logarithmic transformation. The MOVE method can be used for record extension when a linear relationship exists between the logarithms of the same-year peak discharges at the target station and a nearby index station. A base period of 1984-2017 was selected for the record extension. Regulation occurs in a basin when flood flows are altered by reservoir operations or other water resource control structures (such as diversion dams). In this flood frequency analysis, gages were defined as regulated when greater than 20% of the basin lies upstream from reservoirs. The USGS determined that the regulation on SBC was not significant enough to affect peak flows (Sando et al., 2015c). A minimum 10 years of congruent records is required for the MOVE (England et al., 2018).

Generally, a correlation coefficient of 0.80 is considered a minimum linear relationship for the MOVE (England et al., 2018) applicability. The correlation coefficient for USGS gaging station 12323600 Silver Bow Creek at Opportunity, MT and USGS gaging station 12323250 SBC below Blacktail Creek at Butte, MT for the 29 congruent records was 0.49. This correlation coefficient indicates a weak linear relationship between the logarithms of the same-year peak discharges. Due to the proximity between USGS gaging station 12323250 SBC below Blacktail Creek at Butte, MT and USGS gaging station 12323240 Blacktail Creek at Butte, MT, the correlation coefficient was analyzed between USGS gaging station 12323600 SBC at Opportunity, MT and USGS gaging station 12323240 Blacktail Creek at Butte, MT. The corresponding coefficient was 0.62, still well below the threshold. It was determined the MOVE method was not applicable for this reach using the current peak flow data.

USGS gaging station 12323600 SBC at Opportunity, MT and USGS gaging station 12323250 SBC below Blacktail Creek at Butte, MT have 29 years of congruent records. Due to its limited period of record and distance from the project reach, USGS gaging station 12323170 SBC above Blacktail Creek at Butte, MT was not used. While the USGS gaging station 12323240 Blacktail Creek at Butte, MT is relatively close to USGS gaging station 12323250 SBC below Blacktail Creek at Butte, MT, it does not account for flow from Upper Silver Bow Creek; for these reasons the Blacktail Creek at Butte, MT gage was not used.

Using a congruent record data set minimizes the potential error associated with non-congruent periods of record. Consequently, flood flow frequency estimates using the 1989-2017 congruent record data set were selected to represent the annual chance flood potential at SBC gaged locations.

Table 15 summarizes SBC gage analysis flood frequency estimates using the congruent record. Figure 7 plots the congruent record analysis results.

Table 16 compares flood frequency estimates between the 2011 SIR 2015-5019-C analysis (Sando et al., 2015a) and this study's 2017 systematic record analysis. Figure 8 compares

selected recurrence intervals from Table 16 for the two SBC gages used in the study. The 1989-2017 data record flood frequency flows are generally lower than the 1989-2011 estimated flows.

The SIR 2015-5019-C (Sando et al., 2015a) flood frequency estimates are a systematic analysis based on the period of record through water year 2011 using methods described in Bulletin #17B (IACWD, 1982). The 2017 flood frequency analysis is based on the systematic analysis through water year 2017 using methods described in Bulletin #17C (England et al., 2018); therefore, differences between the 2011 and 2017 peak flow estimates can be attributed to the different period of records used in the analysis and the different calculation methods used.

Table 15 Gage Flood Frequency Estimates Using Congruent 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
12323250	SBC below Blacktail Creek at Butte, MT	1989-2017	139	168	247	304	380	440	503	568	661
12323600	SBC at Opportunity, MT	1989-2017	209	274	473	635	873	1,077	1,303	1,553	1,928

cfs: cubic feet per second. SBC: Silver Bow Creek.

Figure 7 USGS Flood Frequency Estimates
Congruent Record (1989-2017) vs Systematic Record

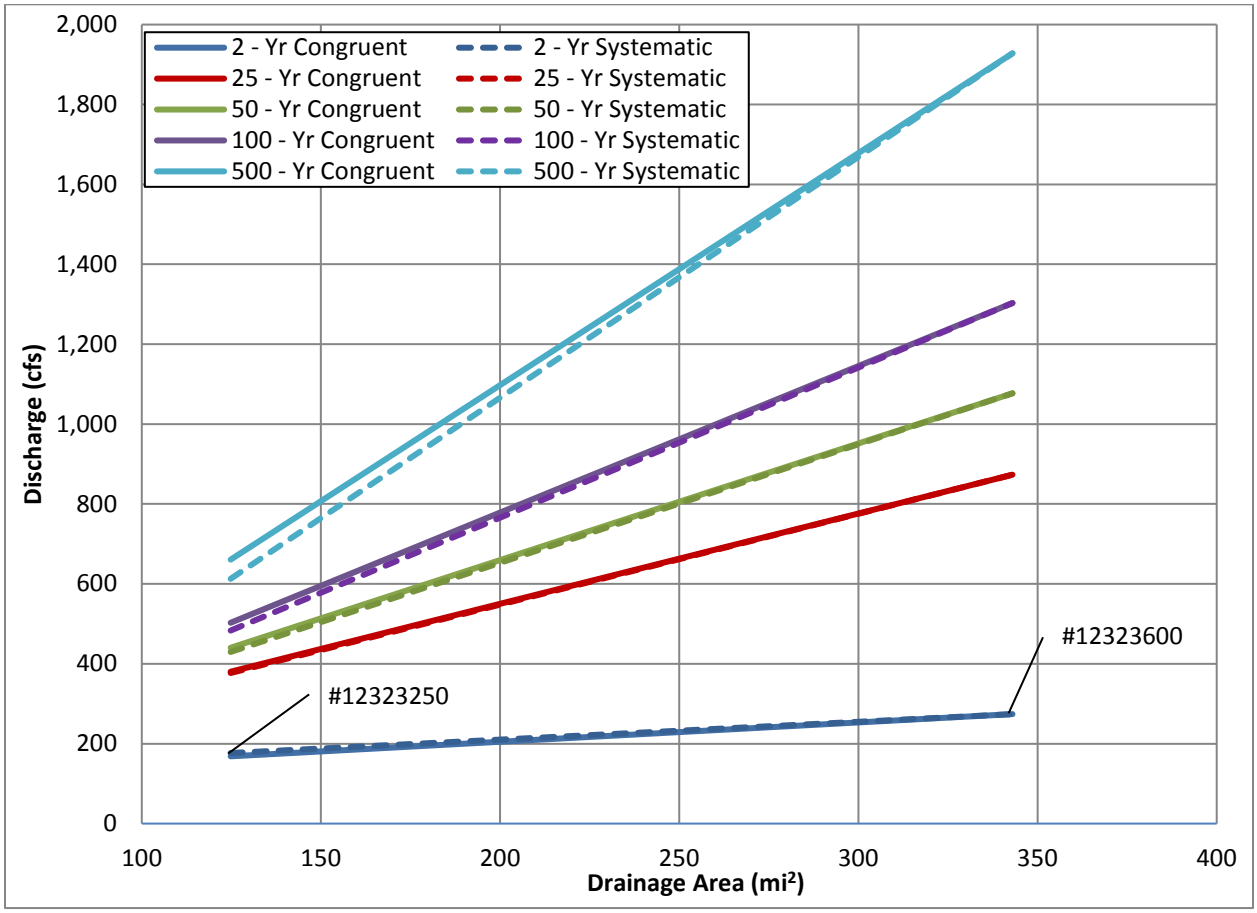
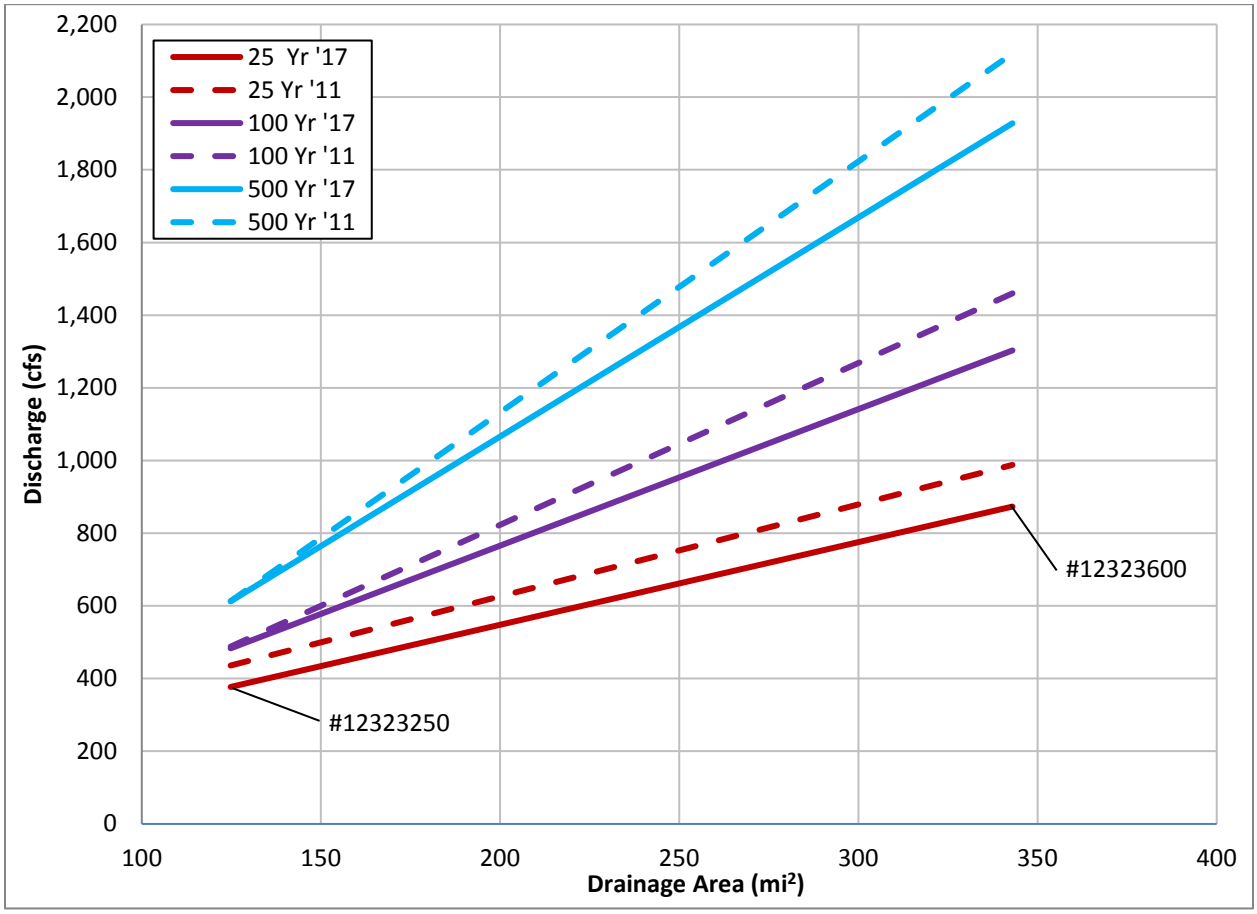


Table 16 USGS Flood Frequency Estimate Comparison 2011 and 2017

Station Number	Station Name	Peak Discharge, for Return Interval (years) (cfs)													
		5		10		25		50		100		200		500	
		2011	2017	2011	2017	2011	2017	2011	2017	2011	2017	2011	2017	2011	2017
12323250	SBC below Blacktail Creek at Butte, Montana	261	255	315	308	436	377	436	430	488	483	541	538	613	613
12323600	SBC at Opportunity, Montana	532	473	718	635	988	873	1,210	1,077	1,460	1,303	1,730	1,553	2,120	1,928

cfs: cubic feet per second. SBC: Silver Bow Creek.

Figure 8 USGS Flood Frequency Estimates Comparison 1989-2011 and 1989-2017



3.1.1 1% + Peak Flow Estimates

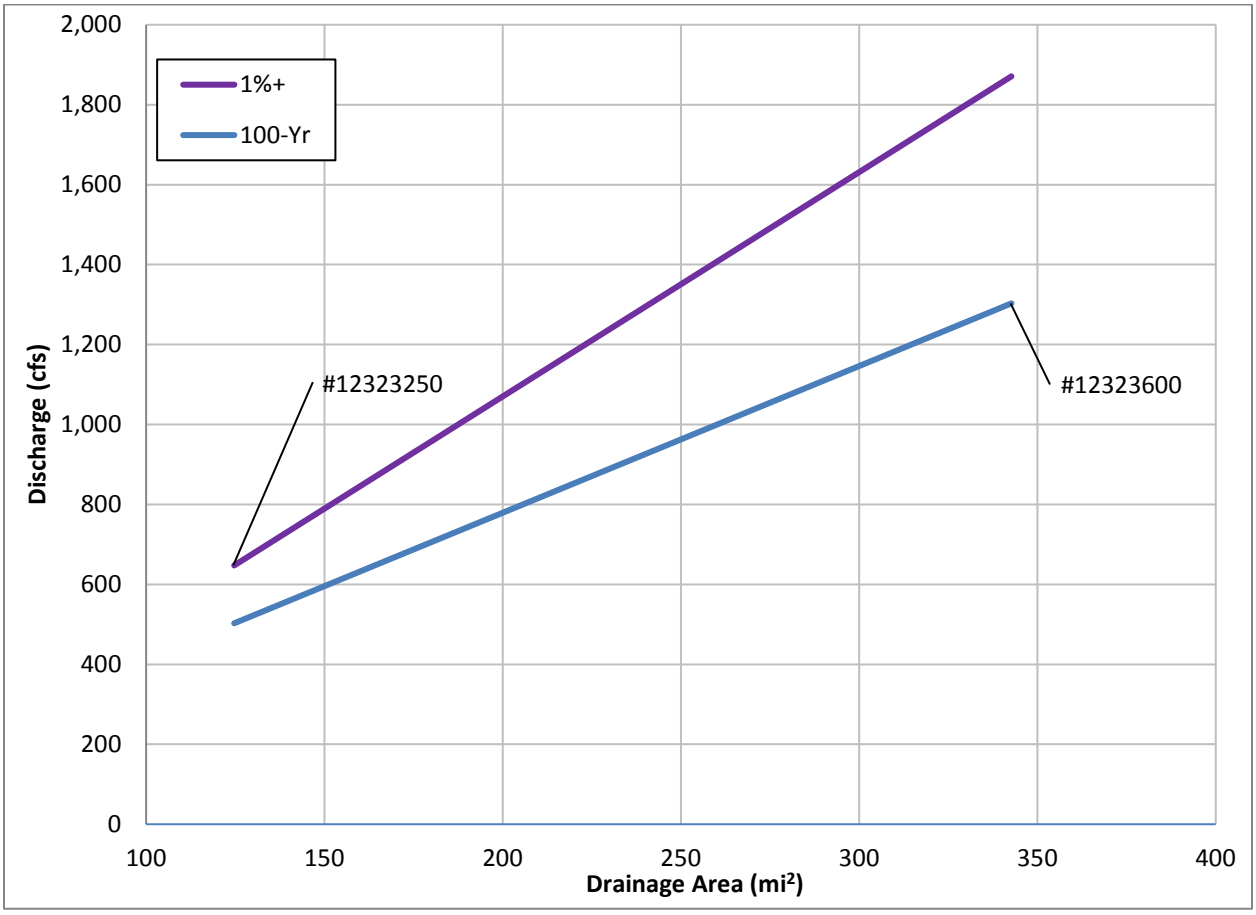
The 1%+ percent AEP event was calculated to provide a confidence range that the 1% flood frequency peak flow estimates are likely to fall within. PeakFQ calculates a confidence interval for each gage analysis. Defining a 68% confidence interval (plus or minus [+/-] one standard deviation) results in the upper 84% confidence limit (+1 standard deviation). This upper 84% confidence limit was used to determine the 1% flood frequency peak flow estimates. The SBC 1%+ flood frequency peak flow estimates are based on the congruent record 1% estimates presented in Table 17 and graphically shown in Figure 9.

Table 17 USGS 1%+ Flood Frequency Estimates 2017

Station Number	Station Name	1% + AEP Peak discharge (cfs)
12323250	SBC below Blacktail Creek at Butte, MT	595
12323600	SBC at Opportunity, MT	1,871

cfs: cubic feet per second. AEP: annual exceedance probability. SBC: Silver Bow Creek.

Figure 9 USGS 1%+ Flood Frequency Estimates 1989-2017



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 SBC, 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 SBC. At each flow node, a drainage basin area was delineated, and streamflow values were calculated for the various recurrence interval floods. Generally, the hydraulic models simulate flood events using steady-state conditions and, therefore, the peak flow rate calculated at a flow node is projected to the next upstream flow node. This method was followed for the hydrologic analysis calculations. Flow nodes were assigned immediately upstream of major tributaries; this method of locating the flow nodes was employed so that the additional flow resulting from the tributary confluence was accurately reflected to the reach downstream of the confluence.

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

This study used the nearest Geographic Naming Information System (GNIS) hydrographic feature name for the ungaged flow node names. In some cases, these features (typically tributary streams) flow into SBC just downstream of the flow node.

To avoid excessive flow changes between HUC 12 boundary nodes, additional flow nodes were located immediately downstream of towns, at the beginning of study reaches, at county borders, or where intermediate tributaries within the HUC 12 boundaries intersected the study reach. One flow node was added downstream of Rocker, Montana. These town nodes and intermediate nodes are identified in Table 18.

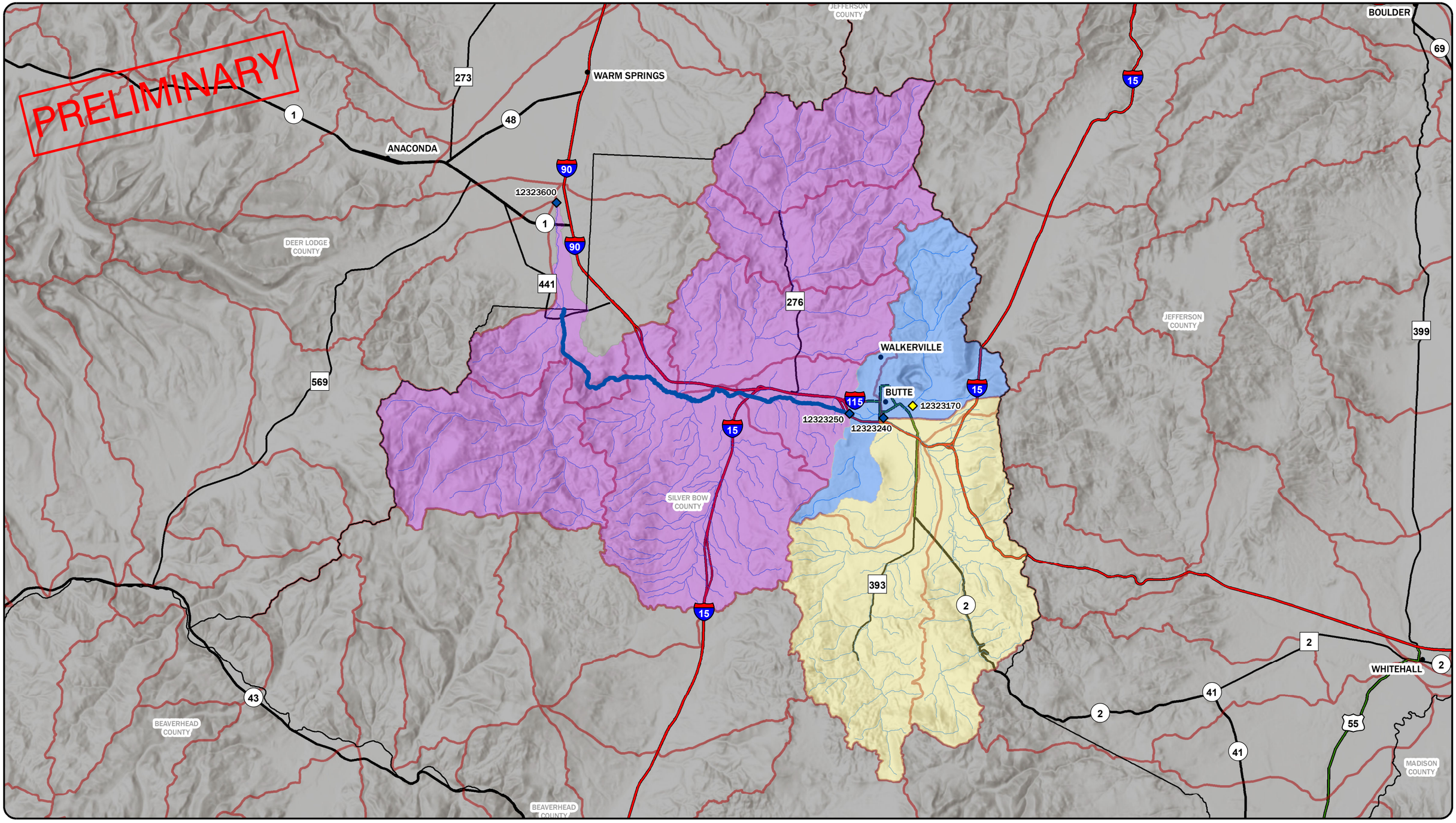
A total of 8 flow nodes were identified throughout the study reach, including 2 gaged locations and 6 ungaged locations. Figure 10 shows the USGS gaging stations analyzed and the correlating StreamStats-generated watershed areas within the study area. Figure 11 maps the flow node locations and corresponding watershed areas from Table 18.

Table 18 Flow Node and USGS Gage Station Information Used in Hydrologic Analyses

Node/USGS Station ID	Location Description	County	River Station[1] (miles)	StreamStats Calculated Basin Area[2] (sq mi)
12323600	**SBC at Opportunity, MT**	**Silver Bow**	**NA**	**342.6**
100	Silver Bow County Boundary	Silver Bow	0.0	335.2
200	German Gulch	Silver Bow	2.3	288.8
300	McCleery Gulch	Silver Bow	6.8	274.2
400	Browns Gulch	Silver Bow	8.6	188.2
500	Sand Creek	Silver Bow	11.6	139.1
600	Rocker, MT	Silver Bow	14.1	135.0
12323250	**SBC below Blacktail Creek Butte, MT**	**Silver Bow**	**17.0**	**124.7**

1. River miles start at the downstream extent of each study reach (mi: miles)
2. Source: USGS StreamStats

USGS: U.S. Geological Survey. cfs: cubic feet per second. SBC: Silver Bow Creek.



LEGEND

- INACTIVE USGS GAGE
- ACTIVE USGS GAGE
- SILVER BOW CREEK PROFILE BASELINE

USGS BASINS

- 12323600
- 12323250
- 12323240
- NHD HYDROGRAPHY
- MONTANA COUNTY BOUNDARIES
- HUC 12 BOUNDARIES
- NHS INTERSTATE
- NHS NON-INTERSTATE
- PRIMARY
- SECONDARY

N

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

0 1.75 3.5 7
Miles

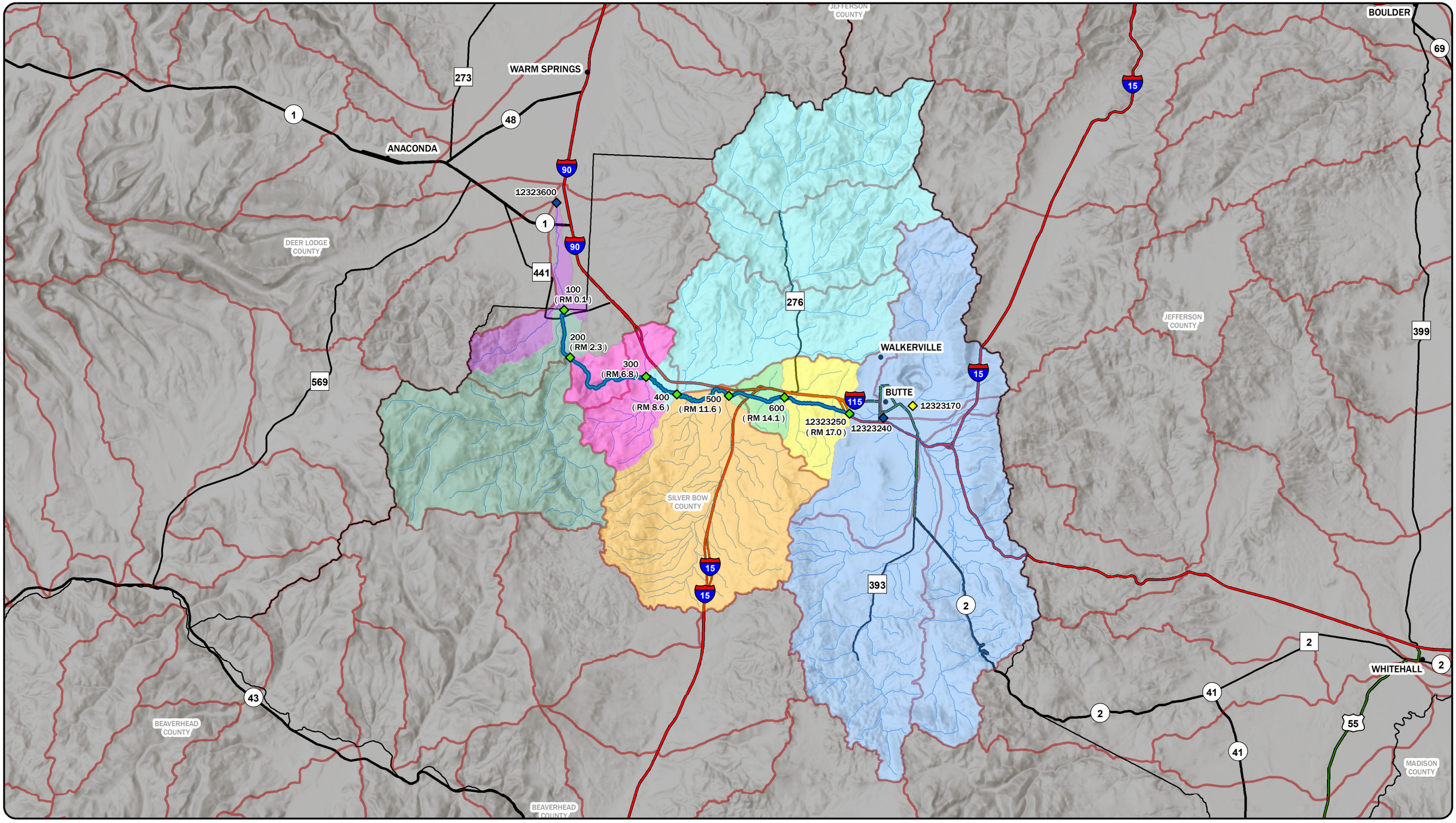
FIGURE 10

SILVER BOW CREEK
USGS WATERSHEDS

PIONEER TECHNICAL SERVICES, INC.

DATE: 8/2/2018

Path: H:\DEQ\SSTOU new\2018\FEMA_PMR\Hydrologic Assessment\Drawings\GIS\SSTOU-PMR-HYDRO-FIG-000-18.mxd



LEGEND

- INACTIVE USGS GAGES
- ACTIVE USGS GAGES
- FLOW NODES (RIVER MILES)
- SILVER BOW CREEK PROFILE BASELINE
- NHD HYDROGRAPHY
- MONTANA COUNTY BOUNDARIES
- HUC 12 BOUNDARIES
- NHS INTERSTATE
- NHS NON-INTERSTATE
- PRIMARY
- SECONDARY

FLOW CHANGE NODE

- 12323600
- 600
- 500
- 400
- 300
- 200
- 100
- 12323250

N

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

0 1.75 3.5 7
Miles

FIGURE 11

PIONEER TECHNICAL SERVICES, INC.

DATE: 8/2/2018

DELINEATED SUB BASIN AREAS AND FLOW NODE LOCATIONS

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3.3 Flood Frequency Estimates at Ungaged Sites

To calculate peak flood discharge estimates at the ungaged flow nodes, Pioneer considered methods described in USGS SIR 2015-5109-F (Sando et al., 2015b). 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 ratio adjustment or logarithmic interpolation between two gaged sites).

Two USGS gaging stations (SBC below Blacktail Creek at Butte, MT and SBC at Opportunity, MT) were used for the SBC study reach. All the ungaged SBC flow nodes are located at or between these two gaging stations, therefore the two-site logarithmic interpolation method was used to estimate peak flows at the SBC ungaged flow nodes.

3.3.1 Regional Regression Equation Method

The SIR 2015-5019-F report provides guidance on conditions where regional regression equations might not yield reliable results. These limiting guidelines include the following:

1. A site where the basin characteristics are outside the range of values used to develop the regression equations.
2. A site that is affected by regulation or urbanization.

Ungaged flow nodes located on SBC are not regulated and are within the range of values used to develop the West Region regression equations. The regression equations, presented in SIR 2015-5019-F (Sando et al., 2015b), use a drainage area (A), percentage of basin with forest land cover (F), and mean annual precipitation (P) as shown below in the following set of equations:

$$Q_{50} = 0.131A^{0.920}P^{2.24}(F+1)^{-0.845}$$
$$Q_{10} = 2.44A^{0.853}P^{1.71}(F+1)^{-0.875}$$
$$Q_{4} = 6.61A^{0.831}P^{1.53}(F+1)^{-0.890}$$
$$Q_{2} = 12.2A^{0.818}P^{1.42}(F+1)^{-0.896}$$
$$Q_{1} = 21.5A^{0.806}P^{1.32}(F+1)^{-0.904}$$
$$Q_{0.2} = 63.5A^{0.783}P^{1.12}(F+1)^{-0.915}$$

where

Q_x is the X AEP peak flow magnitude, in cfs.

A is the contributing drainage area, in square miles.

F is the percent of basin with forest land cover.

P is the mean annual precipitation in inches.

The peak flow regional regression estimates for the 8 flow nodes were calculated using the USGS StreamStats software. The 1%+ (plus) AEP event was calculated using FEMA guidance methodologies (FEMA, 2016a) for all the flow nodes to provide a confidence limit of plus 1

standard error that the 1% flood frequency peak flow estimates were likely to fall below. For the regional regression estimates, the average standard error of prediction or *average standard error of estimate* percentage (SEP, in percent) from SIR 2015-5019-F (Sando et al., 2015b) was used to define the equation's statistical confidence upper limit of plus one standard error, (FEMA, 2016a). The resulting upper limit of plus one standard error was used to determine the 1%+ (plus) flood frequency peak flow estimates. Appendix B: Logarithmic Interpolation, Regional Regression and Weighted Calculations provides the 1%+ (plus) regional regression flood frequency calculations for the study flow nodes. Appendix C: Digital Data and Calculation Files contains the calculation files.

The West Hydrologic Region regression equation input variables are shown in Table 19. Regional regression flood frequency peak flow estimates are listed in Table 20. Figure 12 plots the calculated peak discharges and correlating drainage areas. Results indicate increasing flow magnitude with increasing drainage area.

Table 19 Regional Regression Variables

Node/USGS Station ID	Location Description	Study Reach River Station (miles)	Basin Area (sq mi)	F (%)	P (in)
12323250	**SBC below Blacktail Creek at Butte, MT**	**17.0**	**124.7**	**50.8**	**16.7**
600	Rocker, MT	14.1	135.0	49.4	16.6
500	Sand Creek	11.6	139.1	45.6	16.3
400	Browns Gulch	8.6	188.2	38.8	15.7
300	McCleery Gulch	6.8	274.2	45.1	15.7
200	German Gulch	2.3	288.8	44.4	15.7
100	Silver Bow County Boundary	0	335.2	48.9	16.5
12323600	**SBC at Opportunity, MT**	**NA**	**342.6**	**48.8**	**16.4**

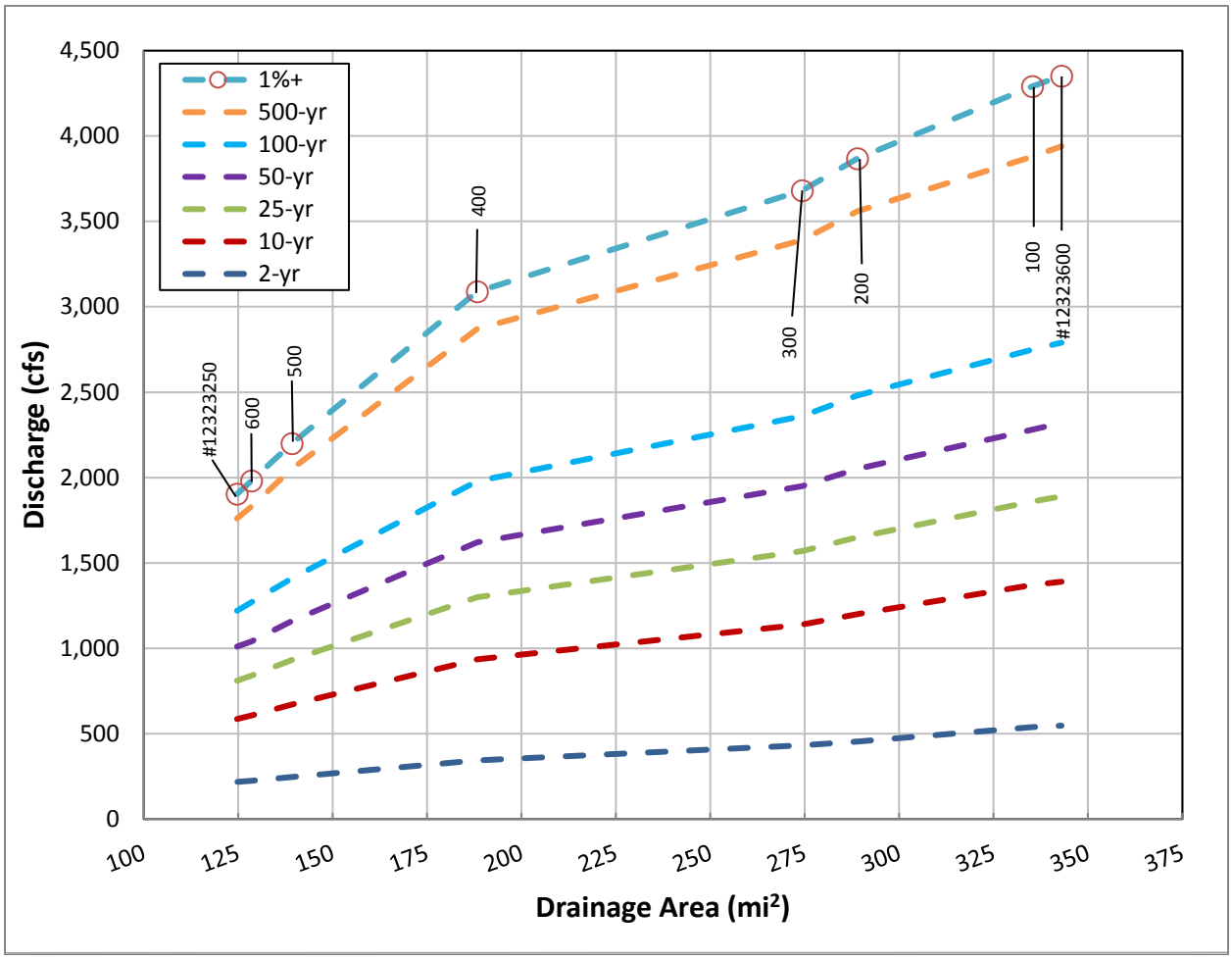
USGS: U.S. Geological Survey. sq mi: square miles. SBC: Silver Bow Creek.
F (%): percentage of basin with forest land cover. P(in): mean annual precipitation in inches.

Table 20 Regional Regression Flood Frequency Peak Flow Estimates

Node/USGS Station ID	Location Description	West Region Regression						
		Estimated 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	100-year
12323250	**SBC below Blacktail Creek at Butte, MT**	**218**	**586**	**810**	**1,010**	**1,220**	**1,760**	**1,903**
600	Rocker, MT	238	646	896	1,120	1,360	1,960	2,122
500	Sand Creek	247	671	932	1,160	1,410	2,050	2,200
400	Browns Gulch	343	936	1,300	1,620	1,980	2,870	3,089
300	McCleery Gulch	432	1,140	1,570	1,950	2,360	3,390	3,682
200	German Gulch	454	1,200	1,650	2,050	2,480	3,560	3,869
100	Silver Bow County Boundary	538	1,370	1,860	2,280	2,750	3,880	4,290
12323600	**SBC at Opportunity, MT**	**547**	**1,390**	**1,890**	**2,320**	**2,790**	**3,940**	**4,352**

USGS: U.S. Geological Survey. cfs: cubic feet per second. SBC: Silver Bow Creek.

Figure 12 Silver Bow Creek Regional Regression Flood Frequency Estimates



3.3.2 Weighting Gage Estimates with Regional Regression Equations Method

Flood frequency gage-based estimates can be affected by the climatic conditions during the time period the peak-flow data were collected, influencing how the peak-flow frequency results represent long-term hydrologic conditions (Sando et al., 2015-D). Weighting the gage analysis peak flow estimates with the regional regression peak flow estimates adjusts the gage site frequency analysis to account for climatic conditions outside the gaged site period of record (Sando et al., 2015c). The USGS report SIR 2015-5019-D (Sando et al., 2015c) tabulates gage analysis peak flow estimates, regional regression peak flow estimates, and weighted gage peak flow estimates. Table 21 summarizes the SIR 2015-5019-D comparison for the gaged sites used in this study. The SIR 2015-5019-D uses 17b bulletin methods and data through water year 2011.

To account for gage data records through water year 2017 and Bulletin 17c gage frequency analysis methods, Pioneer performed an additional weighted with regional regression equations analysis. The weighting method is described in Bulletin 17c, Appendix 9 (England et al., 2018), and is shown below:

$$X_{weighted} = \frac{X_{site} * V_{reg} + X_{reg} * V_{site}}{V_{site} + V_{reg}}$$

Where:

$X_{weighted}$ = Weighted peak flow transformed using base-10 logarithm (cfs).
X_{site} = Gage peak flow transformed using base-10 logarithm (cfs).
X_{reg} = Regression peak flow transformed using base-10 logarithm (cfs).
V_{site} = Gage peak flow Variance (per PeakFQ).
V_{reg} = Regression peak flow Variance (per SIR 2015-5019-D, Table 1-4).

Table 22 shows variance values used to weight the gage analysis peak flow estimates. Peak flows were calculated at the 2 gage locations using congruent periods of record through water year 2017 using Bulletin 17c methods and then weighted using the methodology described above.

Table 23 summarizes the 1989-2017 data record and at-site, regression and weighted results using the Bulletin 17c (England et al., 2018) and regional regression peak flow estimates. The data from Table 23 are plotted on Figure 13 and Figure 14 along with a confidence interval equal to 1 standard error of the regression model for the 2 gages used in this analysis. The average standard error of prediction or average standard error of estimate percentage (SEP in percent) from SIR 2015-5019 F (Sando et al., 2015b) was used to define the regional regression statistical confidence interval of plus/minus one standard error (FEMA 2016).

The weighted gage AEP peak flows estimates are less than the regional regression estimates but are within 1 standard error of the regional regression peak flow estimates.

Table 21 Study Reach Peak Flow Estimates (Systematic Data through 2011)

Station Identification number	Station Name	Drainage Area sq mi	Flow Records (year)	Period of record (water year)	Hydrologic region	Type of peak-flow frequency estimate[1]	Annual peak flow, in cfs, for indicated annual exceedance probability, in percent									
							66.7	50	42.9	20	10	4	2	1	0.5	0.2
12323250	SBC below Blacktail Creek at Butte, Montana	125	28	1984–2011	W	at-site	163	196	212	277	328	390	435	478	520	575
						regression	156	218	250	410	585	810	1,000	1,220	1,460	1,760
						weighted	162	196	212	280	335	405	461	518	579	663
12323600	SBC at Opportunity, Montana	343	23	1989–2011	W	at-site	222	299	338	532	718	988	1,210	1,460	1,730	2,120
						regression	400	547	622	992	1,390	1,890	2,320	2,790	3,300	3,940
						weighted	232	313	354	565	781	1,110	1,400	1,740	2,110	2,650

1. Source: SIR 2015- 5019-D (Sando et al., 2015c).

USGS: U.S. Geological Survey. sq mi: square miles. cfs: cubic feet per second. SBC: Silver Bow Creek.

Table 22 Variance Values for Regional Regression Weighted Analysis

Peak Flow Analysis Method	Regional Regression Weighted Variance									
	66.7% Annual Chance	50% Annual Chance	42.9% Annual Chance	20% Annual Chance	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.5% Annual Chance	0.2% Annual Chance
	1.5-year	2-year	2.33-year	5-year	10-year	25-year	50-year	100-year	200-year	500-year
Gage Analysis[1] 12323250	0.0012	0.0011	0.0012	0.0015	0.002	0.0031	0.0044	0.0059	0.0078	0.0108
Gage Analysis[1] 12323600	0.0029	0.0029	0.003	0.0038	0.0053	0.0084	0.0116	0.0157	0.0206	0.0284
Regional Regression[2]	0.054	0.050	0.049	0.045	0.044	0.044	0.046	0.051	0.051	0.056

1. Source: PeakFQ.
2. Source: StreamStats, SIR2015-5019D (Sando et al., 2015c, Table 1-4.

Table 23 Study Reach Peak Flow Estimates (Congruent Data 1989 - 2017)

Station Identification number	Station Name	Drainage Area sq mi	Flow Records (year)	Period of record (water year)	Hydrologic region	Type of peak-flow frequency estimate[1]	Annual peak flow, in cfs, for indicated annual exceedance probability, in percent									
							66.7	50	42.9	20	10	4	2	1	0.5	0.2
12323250	SBC below Blacktail Creek at Butte, Montana	125	29	1989–2017	W	at-site	139	116	183	247	304	380	440	503	568	661
						regression	156	218	250	410	586	810	1,010	1,220	1,460	1,760
						weighted	139	118	184	251	313	400	473	554	644	774
12323600	SBC at Opportunity, Montana	343	29	1989–2017	W	at-site	209	274	307	473	635	873	1,077	1,303	1,553	1,928
						regression	400	547	621	991	1,390	1,890	2,320	2,790	3,300	3,940
						weighted	216	285	320	501	691	988	1,257	1,572	1,929	2,452

1. Bulletin 17C gage analysis

cfs: cubic feet per second. SBC: Silver Bow Creek.

Figure 13 1% AEP Peak Flow Regional Regression Results for Silver Bow Creek below Blacktail Creek at Butte, Montana

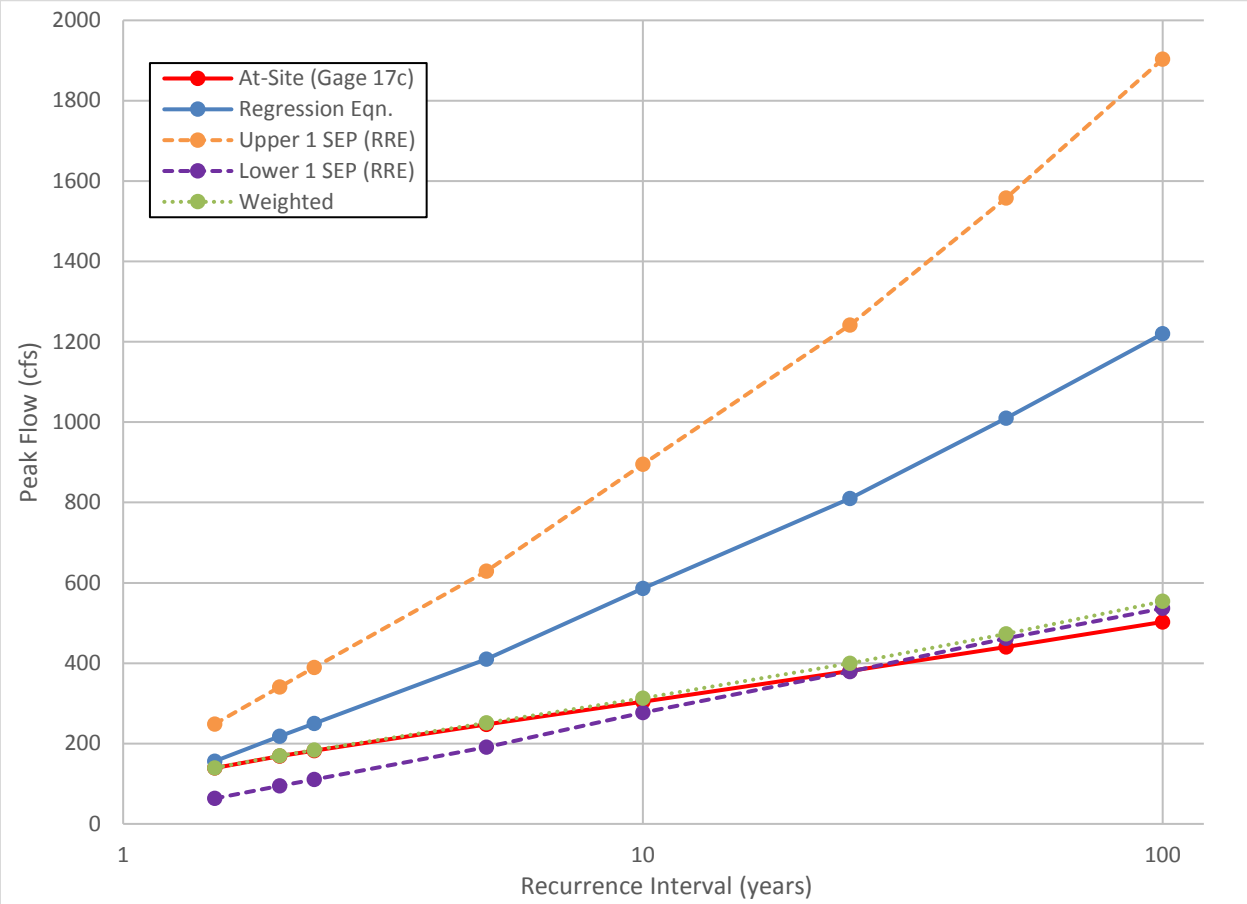
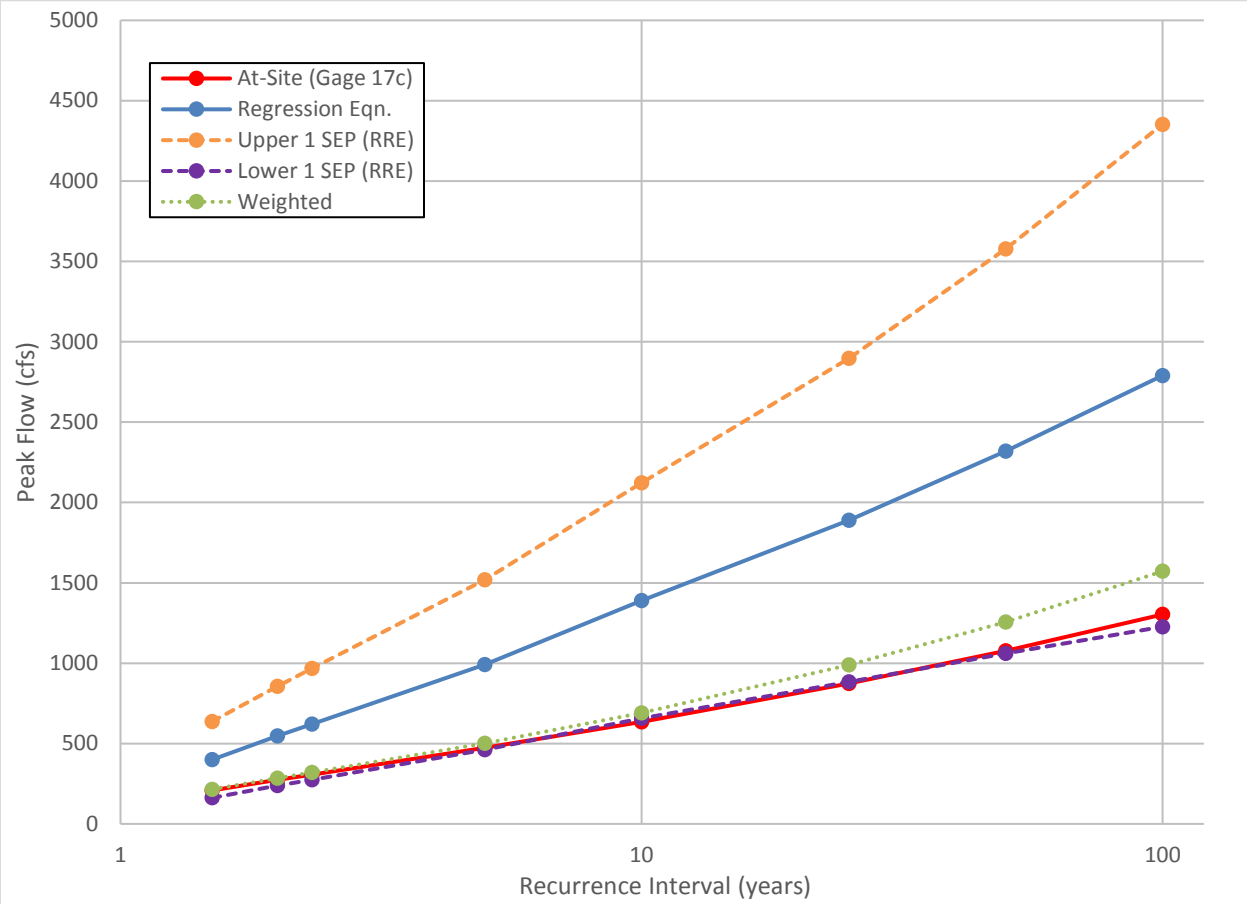


Figure 14 1% AEP Peak Flow Regional Regression Results for Silver Bow Creek at Opportunity, Montana



3.3.3 Two-Station Logarithmic Interpolation Method

Pioneer used the log interpolation method presented in SIR 2015-5019-F (Sando et al., 2015b) 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.

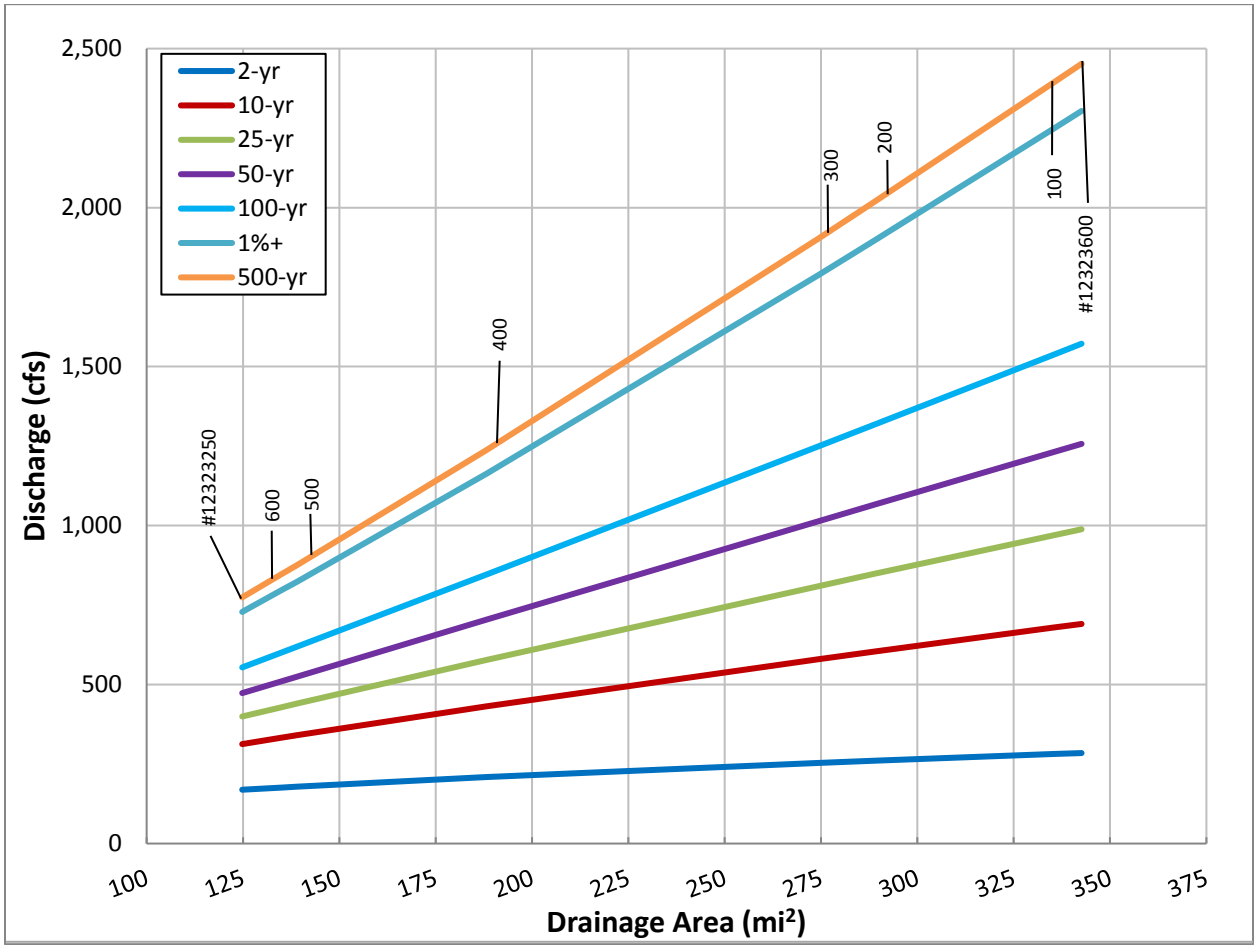
Table 24 shows the calculation results using the regional regression weighted gage estimates. Figure 15 plots the relationship between the calculated discharge estimates and correlating drainage area. Results indicate estimated flows at the ungaged flow nodes increase with increasing drainage area.

Table 24 Two-Station Log Interpolation Flow Node Peak Flow Estimates

Node/USGS Station ID	Location Description	Log Interpolation of RRE Weighted 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	
12323250	SBC below Blacktail Creek at Butte, MT	**169**	**313**	**400**	**473**	**554**	**774**	**729**
600	Rocker, MT	176	333	429	511	601	847	797
500	Sand Creek	179	341	440	526	620	876	824
400	Browns Gulch	209	432	578	704	847	1,237	1,164
300	McCleery Gulch	254	580	809	1,013	1,249	1,902	1,787
200	German Gulch	261	604	848	1,066	1,318	2,018	1,896
100	Silver Bow County Boundary	281	679	969	1,231	1,537	2,392	2,247
12323600	**SBC at Opportunity, MT**	**285**	**691**	**988**	**1,257**	**1,572**	**2,452**	**2,304**

USGS: U.S. Geological Survey. RRE: regional regression equation. cfs: cubic feet per second. SBC: Silver Bow Creek.

Figure 15 Silver Bow Creek Log Interpolation Gage Analysis Results



4 DISCUSSION

Pioneer conducted a peak discharge frequency analysis for the SBC study reach, which extends 17 miles upstream from the Deer Lodge/Silver Bow County Boundary. Information gathered from this analysis will be used to support the Butte-Silver Bow hydraulic analyses and floodplain mapping studies.

Previous flood studies on SBC are numerous. The most relevant earlier flood study was the SIR 2015-5019-C (Sando et al., 2015a). The Channel Stability Analysis and Conceptual Design Report SST OU Subarea 3 published in 2007 (Tetra Tech and AGI, 2007) was also an important study that included flood frequency analysis for the study reach as well as the design flows for the SST OU RA reconstructed channel and floodplain.

This hydrologic analysis developed flood frequency estimates for both gaged and ungaged sites. Peak flow estimates were calculated at 8 locations (flow nodes) within the watershed (2 gaged sites and 6 ungaged sites). The ungaged sites (flow nodes) were located at major tributaries, population centers, and at the end of study reaches.

Flood frequency estimates at the gaged sites were conducted using Bulletin #17C methodologies (England et al., 2018). Flood flow frequency estimates at ungaged flow nodes were conducted using regional regression methods and two-station logarithmic interpolation (Sando et al., 2015b). All the flow nodes were located at or within the 2 gaged sites, therefore the single station drainage area ratio method was not used in this study. The Peak flow 1%+ (plus) estimates were developed for all gaged and ungaged locations using standard FEMA methodologies.

Four USGS stream gaging stations exist within or near the study area. Two of these stream gaging stations, SBC at Opportunity, MT (12323600) and SBC below Blacktail Creek at Butte, MT (12323250), were used to estimate AEP peak flow values for the study area. The SBC below Blacktail Creek at Butte, MT gage is located at the upstream end of the study reach, and the SBC at Opportunity, MT gage is located 6.8 miles downstream of the study reach Butte-Silver Bow\Deer Lodge county boundary.

The 2 SBC stream gaging stations used in this study have non-congruent periods of record. Non-congruent periods of record can influence peak flow estimates between gaged sites within the drainage area and may introduce error to the peak flow frequency estimates. To eliminate the potential issues associated with non-congruent periods of record, flood frequency estimates were conducted using the congruent data set for 1989-2017 (29 years). The FEMA guidance document (FEMA, 2017) indicates that gage station records equal or exceeding 10 years in length are applicable to all types of studies. The gage period of record used in this study exceeds the FEMA minimum guidance by a factor of 2.9 and therefore is applicable to this flood study.

The SBC watershed in this study is considered unregulated. The basin parameters for the flow nodes evaluated in this study all fall within the range of basin and climatic characteristics used to develop the regional regression equations. Therefore, regional regression method peak flow estimates are applicable to this study.

The regional regression method estimates peak flows that are significantly greater than the weighted gage-based estimates. Regional regression peak flow estimates exceed the gage-based estimates used in the study by 220% at the SBC below Blacktail Creek at Butte, MT gage and 177% at the SBC at Opportunity, MT gage. The weighted gage-based estimates are within 1 standard error of the regional regression peak flow estimates.

Regional regression equations are based on comparisons of peak flows and basin characteristics for a given region (Sando et al., 2015b). As a result, regional regression equations are beneficial for estimating peak flows when gage data does not exist, or the period of record is too short to represent the historic climate. A minimum 10 years of gage data is recommended to perform gage peak flow analysis; the gages used in this analysis surpass that minimum.

Gage-based peak flow frequency estimates can be influenced by the climatic conditions that existed during the gage data collection period (gage period of record). To evaluate the climatic conditions of the gage period of record relative to longer term climatic conditions, Pioneer analyzed the study area historic precipitation.

Figure 16 and Figure 17 show the historic annual precipitation for Butte and Anaconda, Montana, respectively. The average precipitation during the study's gage period of record (1989-2017) was within 3% of the historical average. Therefore, the gage analysis performed in this study is considered representative of historical precipitation conditions.

The gage-based AEP estimates meet all the standard hydrologic flood frequency practice requirements including the following:

- A congruent period of record that exceeds the minimum FEMA guidance (by a factor 2.9).
- Gage period of record average precipitation values that are consistent with long-term basin average precipitation values.
- Estimates are weighted with regional regression peak flow estimates to account for climatic conditions outside of the study's gage period of record.
- Estimates fall within 1 standard error of the regional regression method peak flow estimates.

The gage data and the gage-based flood frequency estimating methods meet the hydrologic flood frequency standard practice criteria and guidance. Additionally, higher confidence is typically associated with flood frequency estimates that are based on measured stream flows, such as in the two-station logarithmic interpolation method. For these reasons, the regional regression method peak flow estimates were eliminated from further consideration.

It should be noted that hydrology developed for the SST OU RA designs used the regional regression methods to represent the 10% (10-year event) and lower AEP peak flows. At the time of the Subarea 3 Conceptual Design Report (Tetra Tech and AGI, 2007) the congruent period of record was 16 years (1989-2005). Due to the limited gage period of record only the 50% AEP flow (2-year event) was estimated using gage data. In 2018, the gage period of record for the same gages used in the Tetra Tech report were almost twice the period of record in 2007. Currently the 2 gages used in this study reach have 29 years of congruent flow records and therefore these 2018 gage-based AEP peak flow estimates are more accurate than the gage-based AEP estimates were in 2007.

Table 25 summarizes the recommended flood frequency discharge rates for the SBC study reach. Figure 18 shows the recommended 1% AEP discharge for each flow node location. The hydrologic analysis results provided in Table 25 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 [England et al., 2018], SIR 2015-5019-C [Sando et al., 2015a] and SIR 2015-5019-F [Sando et al., 2015b]) based on SBC basin characteristics. This hydrologic analysis conforms to FEMA standards for enhanced level studies, and the recommended flows of this analysis are deemed reliable and suitable for future floodplain studies and hydraulic analyses.

Figure 16 Butte Historical Annual Precipitation

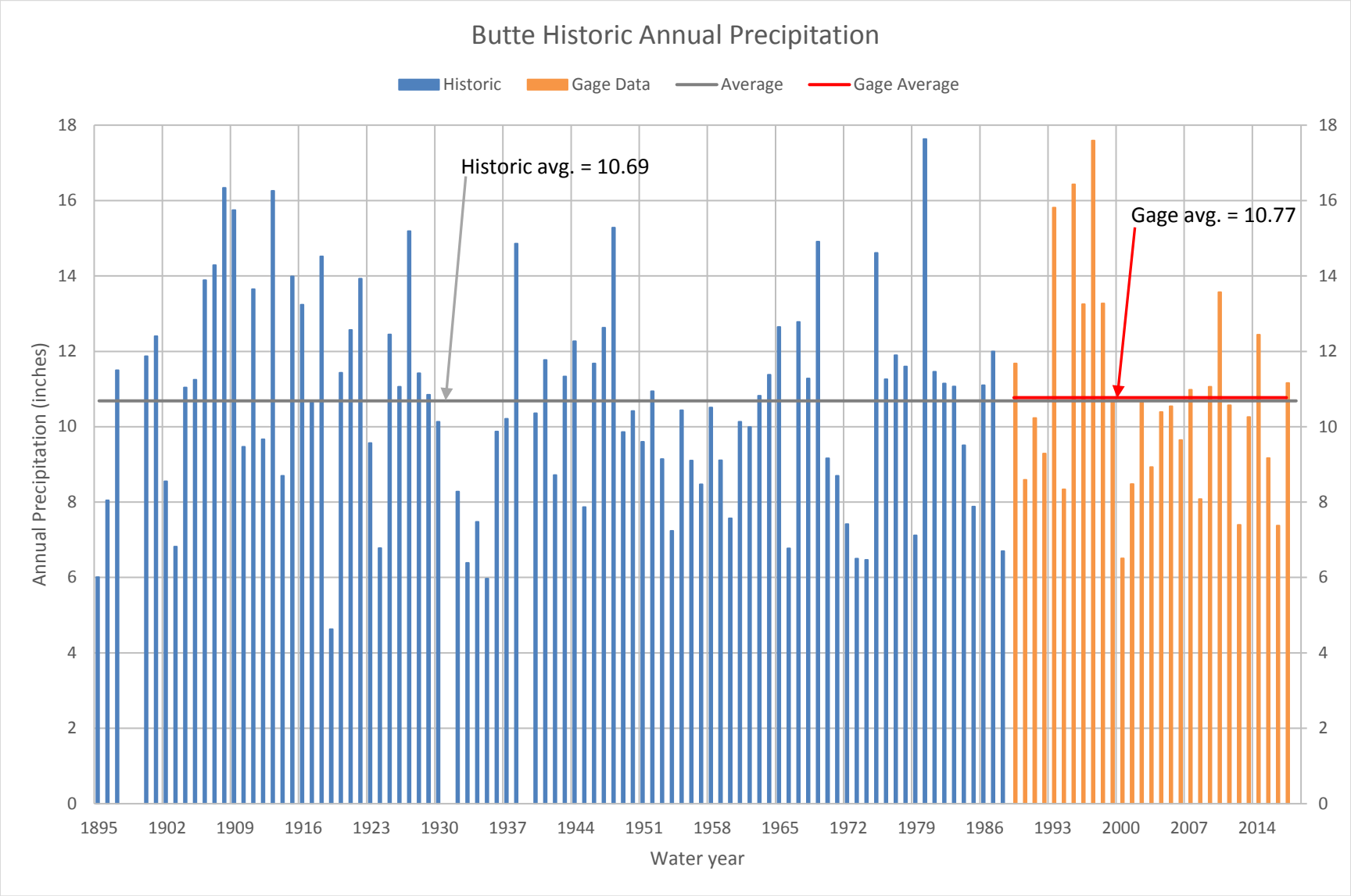


Figure 17 Anaconda Historical Annual Precipitation

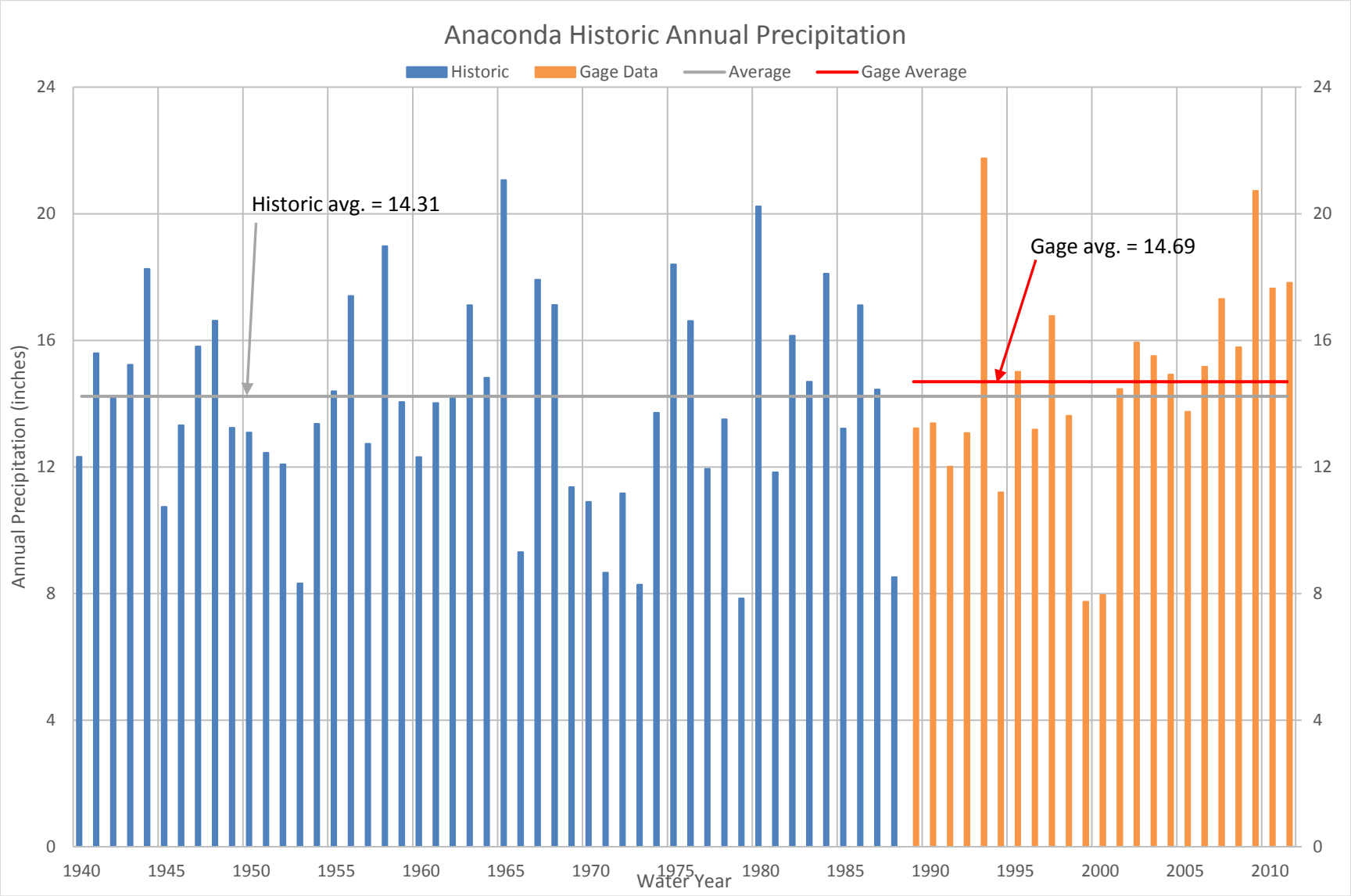
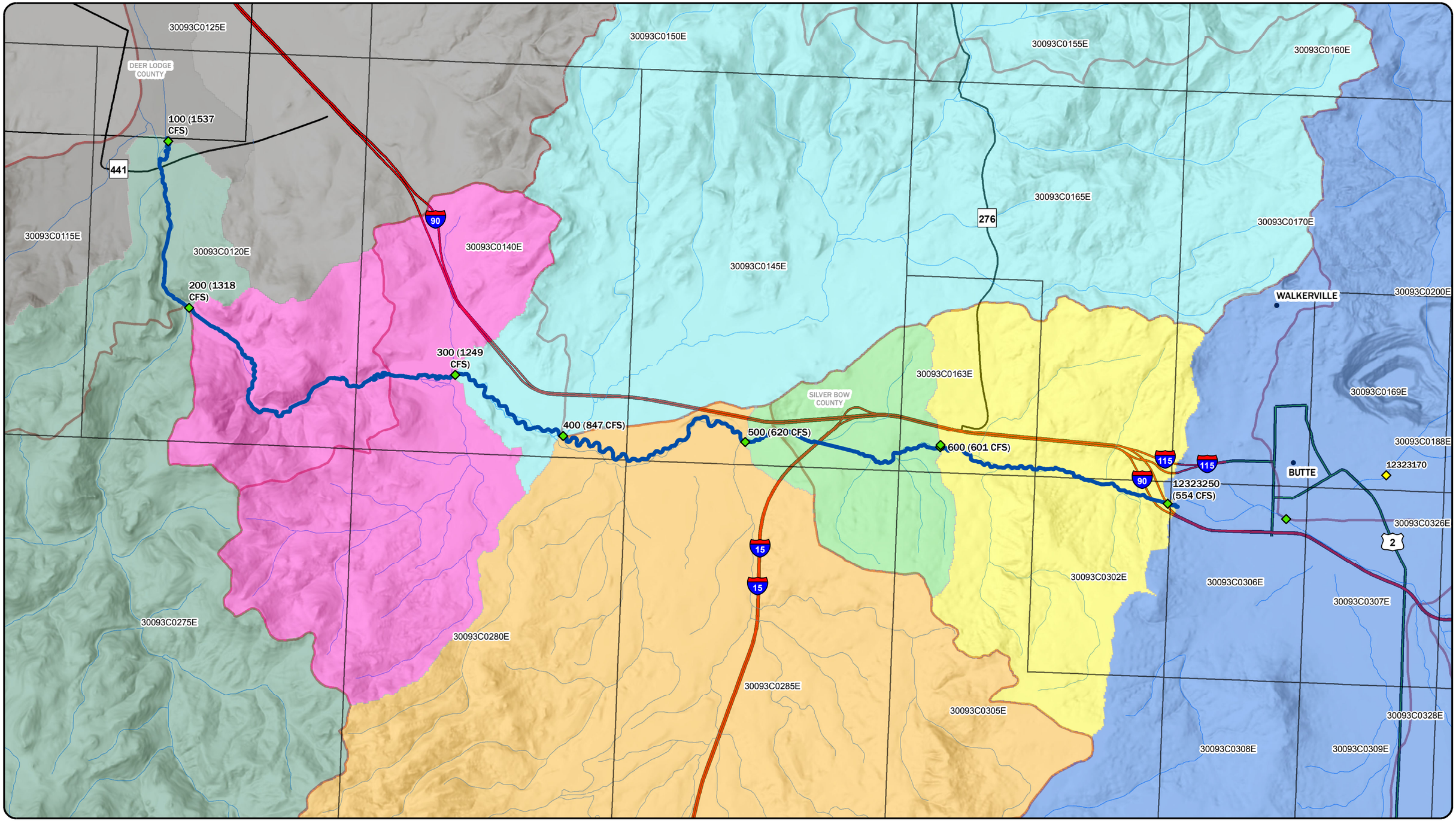


Table 25 Recommended Flood Discharge Estimates Using Two-Station Logarithmic Interpolation Methods

Node/USGS Station ID	Location Description	AEP 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	
12323250	SBC below Blacktail Creek at Butte, MT	**169**	**313**	**400**	**473**	**554**	**774**	**729**
600	Rocker, MT	176	333	429	511	601	847	797
500	Sand Creek	179	341	440	526	620	876	824
400	Browns Gulch	209	432	578	704	847	1,237	1,164
300	McCleery Gulch	254	580	809	1,013	1,249	1,902	1,787
200	German Gulch	261	604	848	1,066	1,318	2,018	1,896
100	Silver Bow County Boundary	281	679	969	1,231	1,537	2,392	2,247
12323600	SBC at Opportunity, MT	**285**	**691**	**988**	**1,257**	**1,572**	**2,452**	**2,304**

USGS: U.S. Geological Survey. cfs: cubic feet per second. SBC: Silver Bow Creek.



LEGEND

- INACTIVE USGS GAGES
- FLOW NODE (PEAK FLOW)
- SILVER BOW CREEK PROFILE BASELINE
- FIRM PANEL
- NHD HYDROGRAPHY
- HUC 12 BOUNDARIES
- MONTANA COUNTY BOUNDARIES
- NHS INTERSTATE
- NHS NON-INTERSTATE
- SECONDARY

FLOW CHANGE NODE
- 600
- 500
- 400
- 300
- 200
- 100
- 12323250

N

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

0 0.5 1 2
Miles

FIGURE 18

PIONEER TECHNICAL SERVICES, INC.

RECOMMENDED 1-PERCENT ANNUAL DISCHARGE FOR EACH LOCATION

DATE: 8/2/2018

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Appendix A: USGS Gage Flood Frequency Analysis

```
1
  Program PeakFq           U. S. GEOLOGICAL SURVEY             Seq.002.000
  Version 7.1         Annual peak flow frequency analysis      Run Date / Time
  3/14/2014                                                    06/05/2018 14:57

                        --- PROCESSING OPTIONS ---

                      Plot option         = None
                      Basin char output   = None
                      Print option        = Yes
                      Debug print         = No
                      Input peaks listing = Long
                      Input peaks format  = WATSTORE peak file

                      Input files used:
                         peaks (ascii)  -
C:\Users\jjupka\Desktop\watstore\SilverBowCr\12323250\12323250.TXT
                         specifications -
C:\Users\jjupka\Desktop\watstore\SilverBowCr\12323250\PKFQWPSF.TMP
                      Output file(s):
                         main - H:\DEQ\SSTOU NEW\2018\FEMA_PMR\HYDROLOGIC
ASSESSMENT\DATA\PEAKFQ\12323250\123232

1


  Program PeakFq           U. S. GEOLOGICAL SURVEY             Seq.001.001
  Version 7.1         Annual peak flow frequency analysis      Run Date / Time
  3/14/2014                                                    06/05/2018 14:57

        Station - 12323250  Silver Bow Cr bl Blacktail Cr at Butte MT


                     I N P U T   D A T A   S U M M A R Y

               Number of peaks in record            =       34
               Peaks not used in analysis           =        0
               Systematic peaks in analysis         =       34
               Historic peaks in analysis           =        0
               Beginning Year                       =     1984
               Ending Year                          =     2017
               Historical Period Length             =       34
               Generalized skew                     =   -0.091
                    Standard error                  =    0.550
                    Mean Square error               =    0.303
               Skew option                          =   WEIGHTED
               Gage base discharge                  =      0.0
               User supplied high outlier threshold =   --
               User supplied PILF (LO) criterion    =   --
               Plotting position parameter          =     0.00
               Type of analysis                            EMA
               PILF (LO) Test Method                       MGBT
               Perception Thresholds:
                    Begin     End       Low     High     Comment
                     1984    2017       0.0       INF     DEFAULT

               Interval Data                    =   None Specified


  *********  NOTICE  --  Preliminary machine computations.        *********
  *********  User responsible for assessment and interpretation.  *********
```

WCF002J-CALCS COMPLETED. RETURN CODE = 2
EMA002W-CONFIDENCE INTERVALS ARE NOT EXACT IF HISTORIC PERIOD > 0

Kendall's Tau Parameters

	TAU	P-VALUE	MEDIAN SLOPE	No. of PEAKS
SYSTEMATIC RECORD	-0.353	0.003	-3.700	34

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.002
Version 7.1 Annual peak flow frequency analysis Run Date / Time
3/14/2014 06/05/2018 14:57

Station - 12323250 Silver Bow Cr bl Blacktail Cr at Butte MT

ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

	LOGARITHMIC MEAN	LOGARITHMIC STANDARD DEVIATION	LOGARITHMIC SKEW
EMA W/O REG. INFO	2.2469	0.1885	0.031
EMA W/REG. INFO	2.2469	0.1885	-0.010

EMA ESTIMATE OF MSE OF SKEW W/O REG. INFO (AT-SITE) 0.1504
EMA ESTIMATE OF MSE OF SKEW W/SYSTEMATIC ONLY (AT-SITE) 0.1504

ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

ANNUAL EXCEEDANCE PROBABILITY	EMA W/ REG INFO ESTIMATE	EMA W/O REG INFO ESTIMATE	<------ FOR EMA ESTIMATES ------> VARIANCE OF EST.	68% CONFIDENCE INTERVALS LOWER	UPPER
0.9950	57.5	58.4	0.0068	45.0	67.9
0.9900	64.1	64.9	0.0052	51.9	74.2
0.9500	86.4	86.8	0.0025	75.1	96.1
0.9000	101.2	101.4	0.0018	90.3	111.1
0.8000	122.5	122.4	0.0014	111.7	133.2
0.6667	146.5	146.2	0.0012	134.9	158.6
0.5000	176.7	176.2	0.0011	163.3	191.1
0.4292	190.9	190.4	0.0012	176.5	206.7
0.2000	254.5	254.3	0.0015	234.2	279.0
0.1000	307.8	308.4	0.0020	280.6	344.4
0.0400	377.0	379.3	0.0031	337.5	436.7
0.0200	429.6	433.7	0.0044	378.4	512.8
0.0100	483.2	489.5	0.0059	417.9	595.3
0.0050	538.0	546.9	0.0078	456.3	685.1
0.0020	612.7	625.9	0.0108	505.8	816.3

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.003
Version 7.1 Annual peak flow frequency analysis Run Date / Time

Station - 12323250 Silver Bow Cr bl Blacktail Cr at Butte MT

I N P U T D A T A L I S T I N G

WATER YEAR	PEAK VALUE	PEAKFQ CODES	<--- Intervals ---> LOW	HIGH	REMARKS
1984	144.0				
1985	239.0				
1986	253.0				
1987	270.0				
1988	224.0				
1989	152.0				
1990	320.0				
1991	216.0				
1992	232.0				
1993	165.0				
1994	159.0				
1995	320.0				
1996	272.0				
1997	276.0				
1998	447.0				
1999	204.0				
2000	74.0				
2001	256.0				
2002	137.0				
2003	314.0				
2004	122.0				
2005	88.0				
2006	158.0				
2007	124.0				
2008	134.0				
2009	112.0				
2010	195.0				
2011	250.0				
2012	122.0				
2013	100.0				
2014	128.0				
2015	100.0				
2016	110.0				
2017	156.0				

Explanation of peak discharge qualification codes

PeakFQ CODE	NWIS CODE	DEFINITION
D	3	Dam failure, non-recurrent flow anomaly
G	8	Discharge greater than stated value
X	3+8	Both of the above
L	4	Discharge less than stated value
K	6 OR C	Known effect of regulation or urbanization
H	7	Historic peak

- Minus-flagged discharge -- Not used in computation
  -8888.0 -- No discharge value given
- Minus-flagged water year -- Historic peak used in computation

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.004
Version 7.1 Annual peak flow frequency analysis Run Date / Time
3/14/2014 06/05/2018 14:57

Station - 12323250 Silver Bow Cr bl Blacktail Cr at Butte MT

EMPIRICAL FREQUENCY CURVES -- HIRSCH-STEDINGER PLOTTING POSITIONS

WATER YEAR	RANKED DISCHARGE	EMA ESTIMATE	INTERVALS LOW	HIGH
1998	447.0	0.0286		
1990	320.0	0.0857		
1995	320.0	0.0571		
2003	314.0	0.1143		
1997	276.0	0.1429		
1996	272.0	0.1714		
1987	270.0	0.2000		
2001	256.0	0.2286		
1986	253.0	0.2571		
2011	250.0	0.2857		
1985	239.0	0.3143		
1992	232.0	0.3429		
1988	224.0	0.3714		
1991	216.0	0.4000		
1999	204.0	0.4286		
2010	195.0	0.4571		
1993	165.0	0.4857		
1994	159.0	0.5143		
2006	158.0	0.5429		
2017	156.0	0.5714		
1989	152.0	0.6000		
1984	144.0	0.6286		
2002	137.0	0.6571		
2008	134.0	0.6857		
2014	128.0	0.7143		
2007	124.0	0.7429		
2004	122.0	0.8000		
2012	122.0	0.7714		
2009	112.0	0.8286		
2016	110.0	0.8571		
2013	100.0	0.9143		
2015	100.0	0.8857		
2005	88.0	0.9429		
2000	74.0	0.9714		

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.005
Version 7.1 Annual peak flow frequency analysis Run Date / Time
3/14/2014 06/05/2018 14:57

Station - 12323250 Silver Bow Cr bl Blacktail Cr at Butte MT

EMA REPRESENTATION OF DATA

WATER YEAR	<----- OBSERVED-----> Q_LOWER	Q_UPPER	<-------- EMA -------> Q_LOWER	Q_UPPER	<-PERCEPTION THRESHOLDS-> LOWER	UPPER

1984	144.0	144.0	144.0	144.0	0.0	INF
1985	239.0	239.0	239.0	239.0	0.0	INF
1986	253.0	253.0	253.0	253.0	0.0	INF
1987	270.0	270.0	270.0	270.0	0.0	INF
1988	224.0	224.0	224.0	224.0	0.0	INF
1989	152.0	152.0	152.0	152.0	0.0	INF
1990	320.0	320.0	320.0	320.0	0.0	INF
1991	216.0	216.0	216.0	216.0	0.0	INF
1992	232.0	232.0	232.0	232.0	0.0	INF
1993	165.0	165.0	165.0	165.0	0.0	INF
1994	159.0	159.0	159.0	159.0	0.0	INF
1995	320.0	320.0	320.0	320.0	0.0	INF
1996	272.0	272.0	272.0	272.0	0.0	INF
1997	276.0	276.0	276.0	276.0	0.0	INF
1998	447.0	447.0	447.0	447.0	0.0	INF
1999	204.0	204.0	204.0	204.0	0.0	INF
2000	74.0	74.0	74.0	74.0	0.0	INF
2001	256.0	256.0	256.0	256.0	0.0	INF
2002	137.0	137.0	137.0	137.0	0.0	INF
2003	314.0	314.0	314.0	314.0	0.0	INF
2004	122.0	122.0	122.0	122.0	0.0	INF
2005	88.0	88.0	88.0	88.0	0.0	INF
2006	158.0	158.0	158.0	158.0	0.0	INF
2007	124.0	124.0	124.0	124.0	0.0	INF
2008	134.0	134.0	134.0	134.0	0.0	INF
2009	112.0	112.0	112.0	112.0	0.0	INF
2010	195.0	195.0	195.0	195.0	0.0	INF
2011	250.0	250.0	250.0	250.0	0.0	INF
2012	122.0	122.0	122.0	122.0	0.0	INF
2013	100.0	100.0	100.0	100.0	0.0	INF
2014	128.0	128.0	128.0	128.0	0.0	INF
2015	100.0	100.0	100.0	100.0	0.0	INF
2016	110.0	110.0	110.0	110.0	0.0	INF
2017	156.0	156.0	156.0	156.0	0.0	INF

1

```
 End PeakFQ analysis.
   Stations processed :       1
   Number of errors   :       0
   Stations skipped   :       0
   Station years      :      34
```

Data records may have been ignored for the stations listed below.
(Card type must be Y, Z, N, H, I, 2, 3, 4, or *.)
(2, 4, and * records are ignored.)

For the station below, the following records were ignored:

FINISHED PROCESSING STATION: 12323250 USGS Silver Bow Cr bl Blacktail Cr

For the station below, the following records were ignored:

FINISHED PROCESSING STATION:

```
1
  Program PeakFq           U. S. GEOLOGICAL SURVEY             Seq.002.000
  Version 7.1         Annual peak flow frequency analysis      Run Date / Time
  3/14/2014                                                    06/15/2018 09:37

                        --- PROCESSING OPTIONS ---

                      Plot option         = None
                      Basin char output   = None
                      Print option        = Yes
                      Debug print         = No
                      Input peaks listing = Long
                      Input peaks format  = WATSTORE peak file

                      Input files used:
                         peaks (ascii)  -
C:\Users\jjupka\Desktop\watstore\SilverBowCr\12323250\12323250-29YRS.TXT
                         specifications -
C:\Users\jjupka\Desktop\watstore\SilverBowCr\12323250\PKFQWPSF.TMP
                      Output file(s):
                         main - H:\DEQ\SSTOU NEW\2018\FEMA_PMR\HYDROLOGIC
ASSESSMENT\DATA\PEAKFQ\12323250\29YEAR

1


  Program PeakFq           U. S. GEOLOGICAL SURVEY             Seq.001.001
  Version 7.1         Annual peak flow frequency analysis      Run Date / Time
  3/14/2014                                                    06/15/2018 09:37

         Station - 12323250  Silver Bow Cr bl Blacktail Cr at Butte MT


                     I N P U T   D A T A   S U M M A R Y

                Number of peaks in record            =       29
                Peaks not used in analysis           =        0
                Systematic peaks in analysis         =       29
                Historic peaks in analysis           =        0
                Beginning Year                       =     1989
                Ending Year                          =     2017
                Historical Period Length             =       29
                Generalized skew                     =   -0.091
                     Standard error                  =    0.550
                     Mean Square error               =    0.303
                Skew option                          =   WEIGHTED
                Gage base discharge                  =      0.0
                User supplied high outlier threshold =   --
                User supplied PILF (LO) criterion    =   --
                Plotting position parameter          =     0.00
                Type of analysis                           EMA
                PILF (LO) Test Method                     MGBT
                Perception Thresholds:
                     Begin     End       Low     High     Comment
                      1989    2017       0.0       INF     DEFAULT

                Interval Data                    =   None Specified


  *********  NOTICE  --  Preliminary machine computations.        *********
  *********  User responsible for assessment and interpretation.  *********
```

WCF002J-CALCS COMPLETED. RETURN CODE = 2
EMA002W-CONFIDENCE INTERVALS ARE NOT EXACT IF HISTORIC PERIOD > 0

Kendall's Tau Parameters

	TAU	P-VALUE	MEDIAN SLOPE	No. of PEAKS
SYSTEMATIC RECORD	-0.372	0.005	-3.955	29

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.002
Version 7.1 Annual peak flow frequency analysis Run Date / Time
3/14/2014 06/15/2018 09:37

Station - 12323250 Silver Bow Cr bl Blacktail Cr at Butte MT

ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

	LOGARITHMIC MEAN	LOGARITHMIC STANDARD DEVIATION	LOGARITHMIC SKEW
EMA W/O REG. INFO	2.2301	0.1955	0.245
EMA W/REG. INFO	2.2301	0.1955	0.114

EMA ESTIMATE OF MSE OF SKEW W/O REG. INFO (AT-SITE) 0.1925
EMA ESTIMATE OF MSE OF SKEW W/SYSTEMATIC ONLY (AT-SITE) 0.1925

ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

ANNUAL EXCEEDANCE PROBABILITY	EMA W/ REG INFO ESTIMATE	EMA W/O REG INFO ESTIMATE	<------ FOR EMA ESTIMATES ------> VARIANCE OF EST.	68% CONFIDENCE INTERVALS LOWER	UPPER
0.9950	55.9	59.1	0.0078	43.5	66.4
0.9900	61.9	64.7	0.0060	49.8	72.1
0.9500	82.2	83.7	0.0030	71.0	92.0
0.9000	95.9	96.6	0.0022	85.0	106.0
0.8000	116.0	115.8	0.0017	105.0	127.1
0.6667	139.0	137.9	0.0015	126.9	151.7
0.5000	168.4	166.8	0.0014	154.3	184.1
0.4292	182.5	180.8	0.0015	167.2	199.9
0.2000	247.4	246.6	0.0019	224.9	275.9
0.1000	304.0	305.7	0.0026	273.0	347.8
0.0400	380.2	387.5	0.0041	334.0	453.9
0.0200	440.1	453.8	0.0057	379.3	545.1
0.0100	502.7	524.6	0.0077	424.2	647.4
0.0050	568.4	600.5	0.0101	469.2	762.3
0.0020	660.7	709.8	0.0139	528.7	936.5

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.003
Version 7.1 Annual peak flow frequency analysis Run Date / Time

Station - 12323250 Silver Bow Cr bl Blacktail Cr at Butte MT

I N P U T D A T A L I S T I N G

WATER YEAR	PEAK VALUE	PEAKFQ CODES	<--- Intervals ---> LOW	HIGH	REMARKS
1989	152.0				
1990	320.0				
1991	216.0				
1992	232.0				
1993	165.0				
1994	159.0				
1995	320.0				
1996	272.0				
1997	276.0				
1998	447.0				
1999	204.0				
2000	74.0				
2001	256.0				
2002	137.0				
2003	314.0				
2004	122.0				
2005	88.0				
2006	158.0				
2007	124.0				
2008	134.0				
2009	112.0				
2010	195.0				
2011	250.0				
2012	122.0				
2013	100.0				
2014	128.0				
2015	100.0				
2016	110.0				
2017	156.0				

Explanation of peak discharge qualification codes

PeakFQ CODE	NWIS CODE	DEFINITION
D	3	Dam failure, non-recurrent flow anomaly
G	8	Discharge greater than stated value
X	3+8	Both of the above
L	4	Discharge less than stated value
K	6 OR C	Known effect of regulation or urbanization
H	7	Historic peak

- Minus-flagged discharge -- Not used in computation
  -8888.0 -- No discharge value given
- Minus-flagged water year -- Historic peak used in computation

1

Version 7.1 Annual peak flow frequency analysis Run Date / Time
3/14/2014 06/15/2018 09:37

Station - 12323250 Silver Bow Cr bl Blacktail Cr at Butte MT

EMPIRICAL FREQUENCY CURVES -- HIRSCH-STEDINGER PLOTTING POSITIONS

WATER YEAR	RANKED DISCHARGE	EMA ESTIMATE	INTERVALS LOW	HIGH
1998	447.0	0.0333		
1990	320.0	0.1000		
1995	320.0	0.0667		
2003	314.0	0.1333		
1997	276.0	0.1667		
1996	272.0	0.2000		
2001	256.0	0.2333		
2011	250.0	0.2667		
1992	232.0	0.3000		
1991	216.0	0.3333		
1999	204.0	0.3667		
2010	195.0	0.4000		
1993	165.0	0.4333		
1994	159.0	0.4667		
2006	158.0	0.5000		
2017	156.0	0.5333		
1989	152.0	0.5667		
2002	137.0	0.6000		
2008	134.0	0.6333		
2014	128.0	0.6667		
2007	124.0	0.7000		
2004	122.0	0.7667		
2012	122.0	0.7333		
2009	112.0	0.8000		
2016	110.0	0.8333		
2013	100.0	0.9000		
2015	100.0	0.8667		
2005	88.0	0.9333		
2000	74.0	0.9667		

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.005
Version 7.1 Annual peak flow frequency analysis Run Date / Time
3/14/2014 06/15/2018 09:37

Station - 12323250 Silver Bow Cr bl Blacktail Cr at Butte MT

EMA REPRESENTATION OF DATA

WATER	<----- OBSERVED	----->	<-------- EMA	------->	<-PERCEPTION THRESHOLDS->	
YEAR	Q_LOWER	Q_UPPER	Q_LOWER	Q_UPPER	LOWER	UPPER
1989	152.0	152.0	152.0	152.0	0.0	INF
1990	320.0	320.0	320.0	320.0	0.0	INF
1991	216.0	216.0	216.0	216.0	0.0	INF
1992	232.0	232.0	232.0	232.0	0.0	INF
1993	165.0	165.0	165.0	165.0	0.0	INF
1994	159.0	159.0	159.0	159.0	0.0	INF
1995	320.0	320.0	320.0	320.0	0.0	INF
1996	272.0	272.0	272.0	272.0	0.0	INF
1997	276.0	276.0	276.0	276.0	0.0	INF
1998	447.0	447.0	447.0	447.0	0.0	INF

```
   1999      204.0      204.0      204.0      204.0          0.0        INF
   2000       74.0       74.0       74.0       74.0          0.0        INF
   2001      256.0      256.0      256.0      256.0          0.0        INF
   2002      137.0      137.0      137.0      137.0          0.0        INF
   2003      314.0      314.0      314.0      314.0          0.0        INF
   2004      122.0      122.0      122.0      122.0          0.0        INF
   2005       88.0       88.0       88.0       88.0          0.0        INF
   2006      158.0      158.0      158.0      158.0          0.0        INF
   2007      124.0      124.0      124.0      124.0          0.0        INF
   2008      134.0      134.0      134.0      134.0          0.0        INF
   2009      112.0      112.0      112.0      112.0          0.0        INF
   2010      195.0      195.0      195.0      195.0          0.0        INF
   2011      250.0      250.0      250.0      250.0          0.0        INF
   2012      122.0      122.0      122.0      122.0          0.0        INF
   2013      100.0      100.0      100.0      100.0          0.0        INF
   2014      128.0      128.0      128.0      128.0          0.0        INF
   2015      100.0      100.0      100.0      100.0          0.0        INF
   2016      110.0      110.0      110.0      110.0          0.0        INF
   2017      156.0      156.0      156.0      156.0          0.0        INF
1


 End PeakFQ analysis.
   Stations processed :       1
   Number of errors   :       0
   Stations skipped   :       0
   Station years      :      29


Data records may have been ignored for the stations listed below.
(Card type must be Y, Z, N, H, I, 2, 3, 4,  or *.)
(2, 4, and * records are ignored.)

 For the station below, the following records were ignored:

 FINISHED PROCESSING STATION:  12323250       USGS Silver Bow Cr bl Blacktail Cr


 For the station below, the following records were ignored:

 FINISHED PROCESSING STATION:
```

```
1
  Program PeakFq           U. S. GEOLOGICAL SURVEY             Seq.002.000
  Version 7.1         Annual peak flow frequency analysis      Run Date / Time
  3/14/2014                                                    06/05/2018 14:59

                         --- PROCESSING OPTIONS ---

                      Plot option         = None
                      Basin char output   = None
                      Print option        = Yes
                      Debug print         = No
                      Input peaks listing = Long
                      Input peaks format  = WATSTORE peak file

                      Input files used:
                         peaks (ascii)  -
C:\Users\jjupka\Desktop\watstore\SilverBowCr\12323600\12323600.TXT
                         specifications -
C:\Users\jjupka\Desktop\watstore\SilverBowCr\12323600\PKFQWPSF.TMP
                      Output file(s):
                         main - H:\DEQ\SSTOU NEW\2018\FEMA_PMR\HYDROLOGIC
ASSESSMENT\DATA\PEAKFQ\12323600\123236

1


  Program PeakFq           U. S. GEOLOGICAL SURVEY             Seq.001.001
  Version 7.1         Annual peak flow frequency analysis      Run Date / Time
  3/14/2014                                                    06/05/2018 14:59

            Station - 12323600  Silver Bow Creek at Opportunity MT


                 I N P U T   D A T A   S U M M A R Y

               Number of peaks in record           =       29
               Peaks not used in analysis          =        0
               Systematic peaks in analysis        =       29
               Historic peaks in analysis          =        0
               Beginning Year                      =     1989
               Ending Year                         =     2017
               Historical Period Length            =       29
               Generalized skew                    =   -0.114
                    Standard error                 =    0.550
                    Mean Square error              =    0.303
               Skew option                         =   WEIGHTED
               Gage base discharge                 =      0.0
               User supplied high outlier threshold =   --
               User supplied PILF (LO) criterion   =   --
               Plotting position parameter         =     0.00
               Type of analysis                          EMA
               PILF (LO) Test Method                    MGBT
               Perception Thresholds:
                    Begin     End       Low     High     Comment
                     1989    2017       0.0       INF     DEFAULT

               Interval Data                    =   None Specified


  *********  NOTICE  --  Preliminary machine computations.        *********
  *********  User responsible for assessment and interpretation.  *********
```

WCF002J-CALCS COMPLETED. RETURN CODE = 2
EMA002W-CONFIDENCE INTERVALS ARE NOT EXACT IF HISTORIC PERIOD > 0

Kendall's Tau Parameters

	TAU	P-VALUE	MEDIAN SLOPE	No. of PEAKS
SYSTEMATIC RECORD	-0.108	0.420	-3.091	29

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.002
Version 7.1 Annual peak flow frequency analysis Run Date / Time
3/14/2014 06/05/2018 14:59

Station - 12323600 Silver Bow Creek at Opportunity MT

ANNUAL FREQUENCY CURVE PARAMETERS -- LOG-PEARSON TYPE III

	LOGARITHMIC MEAN	STANDARD DEVIATION	SKEW
EMA W/O REG. INFO	2.4436	0.2774	0.283
EMA W/REG. INFO	2.4436	0.2774	0.127

EMA ESTIMATE OF MSE OF SKEW W/O REG. INFO (AT-SITE) 0.1959
EMA ESTIMATE OF MSE OF SKEW W/SYSTEMATIC ONLY (AT-SITE) 0.1959

ANNUAL FREQUENCY CURVE -- DISCHARGES AT SELECTED EXCEEDANCE PROBABILITIES

ANNUAL EXCEEDANCE PROBABILITY	EMA W/ REG INFO ESTIMATE	EMA W/O REG INFO ESTIMATE	<------ FOR EMA ESTIMATES ------> VARIANCE OF EST.	68% CONFIDENCE INTERVALS LOWER	UPPER
0.9950	57.8	63.5	0.0155	40.6	73.7
0.9900	66.7	71.9	0.0119	49.1	82.7
0.9500	99.4	102.5	0.0059	80.8	116.5
0.9000	123.6	125.2	0.0043	104.3	142.3
0.8000	161.6	161.1	0.0033	140.3	183.8
0.6667	208.6	206.0	0.0029	183.5	236.2
0.5000	274.0	269.5	0.0029	241.9	310.8
0.4292	307.1	302.1	0.0030	271.1	349.4
0.2000	473.3	470.4	0.0038	413.3	552.6
0.1000	634.8	640.4	0.0053	544.4	769.1
0.0400	873.3	902.0	0.0084	726.1	1125.0
0.0200	1077.	1134.	0.0116	870.8	1463.0
0.0100	1303.	1400.	0.0157	1022.0	1871.0
0.0050	1553.	1705.	0.0206	1181.0	2365.0
0.0020	1928.	2177.	0.0284	1402.0	3177.0

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.003
Version 7.1 Annual peak flow frequency analysis Run Date / Time

Station - 12323600 Silver Bow Creek at Opportunity MT

I N P U T D A T A L I S T I N G

WATER YEAR	PEAK VALUE	PEAKFQ CODES	<--- Intervals ---> LOW	HIGH	REMARKS
1989	654.0				
1990	373.0				
1991	257.0				
1992	228.0				
1993	194.0				
1994	209.0				
1995	479.0				
1996	1300.0				
1997	648.0				
1998	435.0				
1999	265.0				
2000	79.0				
2001	88.0				
2002	144.0				
2003	517.0				
2004	139.0				
2005	211.0				
2006	254.0				
2007	205.0				
2008	331.0				
2009	304.0				
2010	497.0				
2011	772.0				
2012	159.0				
2013	146.0				
2014	290.0				
2015	249.0				
2016	176.0				
2017	301.0				

Explanation of peak discharge qualification codes

PeakFQ CODE	NWIS CODE	DEFINITION
D	3	Dam failure, non-recurrent flow anomaly
G	8	Discharge greater than stated value
X	3+8	Both of the above
L	4	Discharge less than stated value
K	6 OR C	Known effect of regulation or urbanization
H	7	Historic peak

- Minus-flagged discharge -- Not used in computation
  -8888.0 -- No discharge value given
- Minus-flagged water year -- Historic peak used in computation

1

Version 7.1 Annual peak flow frequency analysis Run Date / Time
3/14/2014 06/05/2018 14:59

Station - 12323600 Silver Bow Creek at Opportunity MT

EMPIRICAL FREQUENCY CURVES -- HIRSCH-STEDINGER PLOTTING POSITIONS

WATER YEAR	RANKED DISCHARGE	EMA ESTIMATE	INTERVALS LOW	HIGH
1996	1300.0	0.0333		
2011	772.0	0.0667		
1989	654.0	0.1000		
1997	648.0	0.1333		
2003	517.0	0.1667		
2010	497.0	0.2000		
1995	479.0	0.2333		
1998	435.0	0.2667		
1990	373.0	0.3000		
2008	331.0	0.3333		
2009	304.0	0.3667		
2017	301.0	0.4000		
2014	290.0	0.4333		
1999	265.0	0.4667		
1991	257.0	0.5000		
2006	254.0	0.5333		
2015	249.0	0.5667		
1992	228.0	0.6000		
2005	211.0	0.6333		
1994	209.0	0.6667		
2007	205.0	0.7000		
1993	194.0	0.7333		
2016	176.0	0.7667		
2012	159.0	0.8000		
2013	146.0	0.8333		
2002	144.0	0.8667		
2004	139.0	0.9000		
2001	88.0	0.9333		
2000	79.0	0.9667		

1

Program PeakFq U. S. GEOLOGICAL SURVEY Seq.001.005
Version 7.1 Annual peak flow frequency analysis Run Date / Time
3/14/2014 06/05/2018 14:59

Station - 12323600 Silver Bow Creek at Opportunity MT

EMA REPRESENTATION OF DATA

WATER YEAR	<----- OBSERVED-----> Q_LOWER	Q_UPPER	<-------- EMA -------> Q_LOWER	Q_UPPER	<-PERCEPTION THRESHOLDS-> LOWER	UPPER
1989	654.0	654.0	654.0	654.0	0.0	INF
1990	373.0	373.0	373.0	373.0	0.0	INF
1991	257.0	257.0	257.0	257.0	0.0	INF
1992	228.0	228.0	228.0	228.0	0.0	INF
1993	194.0	194.0	194.0	194.0	0.0	INF
1994	209.0	209.0	209.0	209.0	0.0	INF
1995	479.0	479.0	479.0	479.0	0.0	INF
1996	1300.0	1300.0	1300.0	1300.0	0.0	INF
1997	648.0	648.0	648.0	648.0	0.0	INF
1998	435.0	435.0	435.0	435.0	0.0	INF

1999	265.0	265.0	265.0	265.0	0.0	INF
2000	79.0	79.0	79.0	79.0	0.0	INF
2001	88.0	88.0	88.0	88.0	0.0	INF
2002	144.0	144.0	144.0	144.0	0.0	INF
2003	517.0	517.0	517.0	517.0	0.0	INF
2004	139.0	139.0	139.0	139.0	0.0	INF
2005	211.0	211.0	211.0	211.0	0.0	INF
2006	254.0	254.0	254.0	254.0	0.0	INF
2007	205.0	205.0	205.0	205.0	0.0	INF
2008	331.0	331.0	331.0	331.0	0.0	INF
2009	304.0	304.0	304.0	304.0	0.0	INF
2010	497.0	497.0	497.0	497.0	0.0	INF
2011	772.0	772.0	772.0	772.0	0.0	INF
2012	159.0	159.0	159.0	159.0	0.0	INF
2013	146.0	146.0	146.0	146.0	0.0	INF
2014	290.0	290.0	290.0	290.0	0.0	INF
2015	249.0	249.0	249.0	249.0	0.0	INF
2016	176.0	176.0	176.0	176.0	0.0	INF
2017	301.0	301.0	301.0	301.0	0.0	INF

1

```
 End PeakFQ analysis.
   Stations processed :       1
   Number of errors   :       0
   Stations skipped   :       0
   Station years      :      29

Data records may have been ignored for the stations listed below.
(Card type must be Y, Z, N, H, I, 2, 3, 4,  or *.)
(2, 4, and * records are ignored.)

 For the station below, the following records were ignored:

 FINISHED PROCESSING STATION:  12323600       USGS Silver Bow Creek at Opportuni


 For the station below, the following records were ignored:

 FINISHED PROCESSING STATION:
```

Appendix B: Logarithmic Interpolation, Regional Regression and Weighted Calculations

Streamstats West Regression Calculations													
							West Region Regression						
							Estimated Discharge (cfs)						
							50% Annual Chance	10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance	1% +
Node/USGS Station ID	Location Description	County	Study Reach River Station	Basin Area (mi^2)	F (%)	P (in)	2-year	10-year	25-year	50-year	100-year	500-year	100-year
12323250	Silver Bow Cr. Bl Blacktail Cr. at Butte, MT*	Silver Bow	16.9	124.7	50.8	16.74	218	586	810	1,010	1,220	1,760	1,903
12323600	Silver Bow Creek at Opportunity, MT*	Silver Bow	NA	342.6	48.8	16.42	547	1,390	1,890	2,320	2,790	3,940	4,352

1. 3% or less of total area is in the StreamStats Southwest Region. Values are based on West Results.

Regression equation for indicated Q_{AEP}	*SEP*, in percent
West hydrologic region[2]	
$Q_{66.7} = 0.047\ A^{0.943}\ P^{2.44}\ (F+1)^{-0.840}$	59.4
$Q_{50} = 0.131\ A^{0.920}\ P^{2.24}\ (F+1)^{-0.845}$	56.5
$Q_{42.9} = 0.199\ A^{0.910}\ P^{2.16}\ (F+1)^{-0.847}$	55.7
$Q_{20} = 0.906\ A^{0.876}\ P^{1.88}\ (F+1)^{-0.864}$	53.4
$Q_{10} = 2.44\ A^{0.853}\ P^{1.71}\ (F+1)^{-0.875}$	52.8
$Q_{4} = 6.61\ A^{0.831}\ P^{1.53}\ (F+1)^{-0.890}$	53.2
$Q_{2} = 12.2\ A^{0.818}\ P^{1.42}\ (F+1)^{-0.896}$	54.2
$Q_{1} = 21.5\ A^{0.806}\ P^{1.32}\ (F+1)^{-0.904}$	56.0
$Q_{0.5} = 35.5\ A^{0.796}\ P^{1.23}\ (F+1)^{-0.910}$	58.0
$Q_{0.2} = 63.5\ A^{0.783}\ P^{1.12}\ (F+1)^{-0.915}$	61.4

Node/USGS Station ID	Location Description	Peak Flood Frequency Method	Weighted Regional Regression 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 +
12323250	Silver Bow Cr. Bl Blacktail Cr. at Butte, MT	Bulletin 17c - through 2017	168	304	380	440	503	661	647
		Regional Regression Equation	218	586	810	1,010	1,220	1,760	1,903
		RRE Weighted	**169**	**313**	**400**	**473**	**554**	**774**	**729**
12323600	Silver Bow Creek at Opportunity, MT	Bulletin 17c - through 2017	274	635	873	1,077	1,303	1,928	1,871
		Regional Regression Equation	547	1,390	1,890	2,320	2,790	3,940	4,352
		RRE Weighted	**285**	**691**	**988**	**1,257**	**1,572**	**2,452**	**2,304**

Peak FQ (Bulletin 17C/EMA) Variances		
AEP (%)	Gage #	
	12323250	12323600
50	0.0011	0.0029
10	0.002	0.0053
4	0.0031	0.0084
2	0.0044	0.0116
1	0.0059	0.0157
0.2	0.0108	0.0284

Weighting Method

As stated in the section Flood Distribution, the Pearson Type III distribution with log transformation of the peak-flow data should be the base method for the analysis of annual series data. Thus, the peak-flow statistic Q_i (such as the 0.01 AEP) is transformed using base-10 logarithms:

$$X_i = \log_{10}(Q_i) \tag{9–1}$$

where Q_i is the estimated peak-flow statistic at site i, and X_i is the log-transformed variable. All subsequent operations are performed on the transformed variable X_i. The weighted estimate is calculated using variances as

$$X_{weighted,i} = \frac{X_{site,i} \times V_{reg,i} + X_{reg,i} \times V_{site,i}}{V_{site,i} + V_{reg,i}} \tag{9–2}$$

where all X and V variables are in $\log_{10}$ units, $X_{weighted,i}$ is the weighted estimate for site i, $X_{site,i}$ is the at-site estimate at site i, $X_{reg,i}$ is the regional estimate at site i, $V_{site,i}$ is the variance of the at-site estimate at site i, and $V_{reg,i}$ is the variance of the regional estimate at site i.

As described in appendix 7, the Expected Moments Algorithm (EMA) provides a direct fit of the log-Pearson Type III distribution, which includes an estimate of the variance $V_{site,i}$ corresponding to each computed AEP.

Regression equation for indicated Q_{AEP}	Number of streamflow-gaging stations (n)[1]	σ_δ^2, in log units
West hydrologic region[2]		
$Q_{66.7} = 0.047\, A^{0.943}\, P^{2.44}\, (F+1)^{-0.840}$	113	0.054
$Q_{50} = 0.131\, A^{0.920}\, P^{2.24}\, (F+1)^{-0.845}$	113	0.050
$Q_{42.9} = 0.199\, A^{0.910}\, P^{2.16}\, (F+1)^{-0.847}$	113	0.049
$Q_{20} = 0.906\, A^{0.876}\, P^{1.88}\, (F+1)^{-0.864}$	113	0.045
$Q_{10} = 2.44\, A^{0.853}\, P^{1.71}\, (F+1)^{-0.875}$	113	0.044
$Q_{4} = 6.61\, A^{0.831}\, P^{1.53}\, (F+1)^{-0.890}$	113	0.044
$Q_{2} = 12.2\, A^{0.818}\, P^{1.42}\, (F+1)^{-0.896}$	113	0.046
$Q_{1} = 21.5\, A^{0.806}\, P^{1.32}\, (F+1)^{-0.904}$	113	0.048
$Q_{0.5} = 35.5\, A^{0.796}\, P^{1.23}\, (F+1)^{-0.910}$	113	0.051
$Q_{0.2} = 63.5\, A^{0.783}\, P^{1.12}\, (F+1)^{-0.915}$	113	0.056

Node/USGS Station ID	Location Description	County	Study Reach River Station (miles)	Incremental Basin Area (mi^2)	GIS Cumulative 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 +
12323250	**Silver Bow Cr. Bl Blacktail Cr. at Butte, MT***	**Silver Bow**	**17**	**0**	**125**	**125**	**169**	**313**	**400**	**473**	**554**	**774**	**729**
600	Rocker, MT	Silver Bow	14.1	10	135	135	176	333	429	511	601	847	797
500	Sand Creek	Silver Bow	11.6	4	139	139	179	341	440	526	620	876	824
400	Browns Gulch	Silver Bow	8.6	49	188	188	209	432	578	704	847	1,237	1,164
300	McCleery Gulch	Silver Bow	6.8	86	274	274	254	580	809	1,013	1,249	1,902	1,787
200	German Gulch	Silver Bow	2.3	15	289	289	261	604	848	1,066	1,318	2,018	1,896
100	Silver Bow County Boundary	Silver Bow	0	46	335	335	281	679	969	1,231	1,537	2,392	2,247
12323600	**Silver Bow Creek at Opportunity, MT***	**Silver Bow**	**NA**	7	**343**	**343**	**285**	**691**	**988**	**1,257**	**1,572**	**2,452**	**2,304**

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

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

where

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

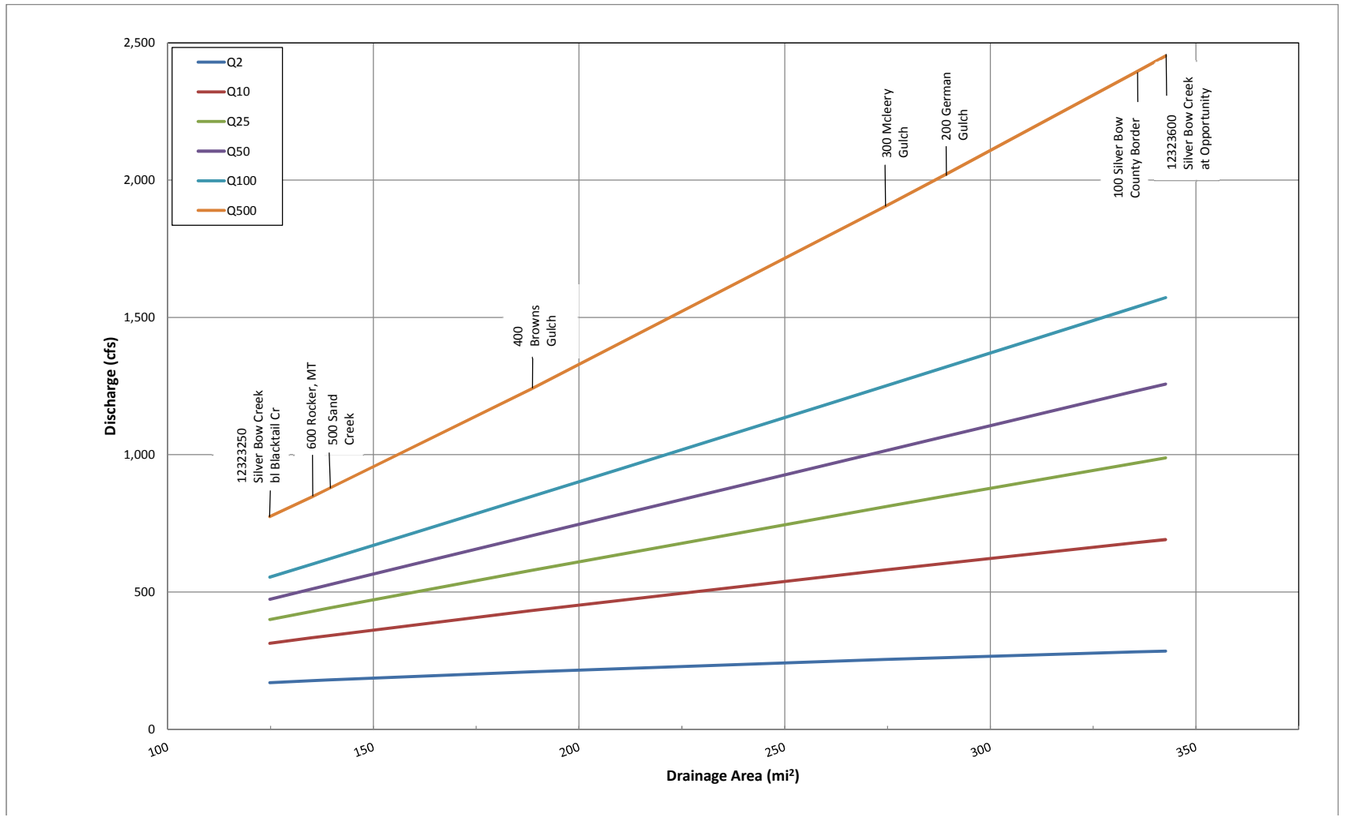
$Q_{AEP,G1}$ is the AEP-percent peak flow for the upstream gaging station $G1$, in cubic feet per second;

$Q_{AEP,G2}$ 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.



Appendix C: Digital Data and Calculation Files