Madison River Watershed
Hydrologic Analysis
Gallatin and Madison Counties, MT

May 2018

Michael Baker INTERNATIONAL

Document History

Document Location

Location

Revision History

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01	05/30/2018	Initial Submittal	R. Anderson

Client Distribution

Name	Title/Organization	Location

Cover Photograph:

Interstate 90 crossing Madison River near Three Forks, MT, looking east. Madison River flowing right to left (south to north). Union Pacific Railroad crossing and pedestrian/bike path crossing in same vicinity.

Cover Photograph Credit:

Celinda Adair, provided by DNRC.

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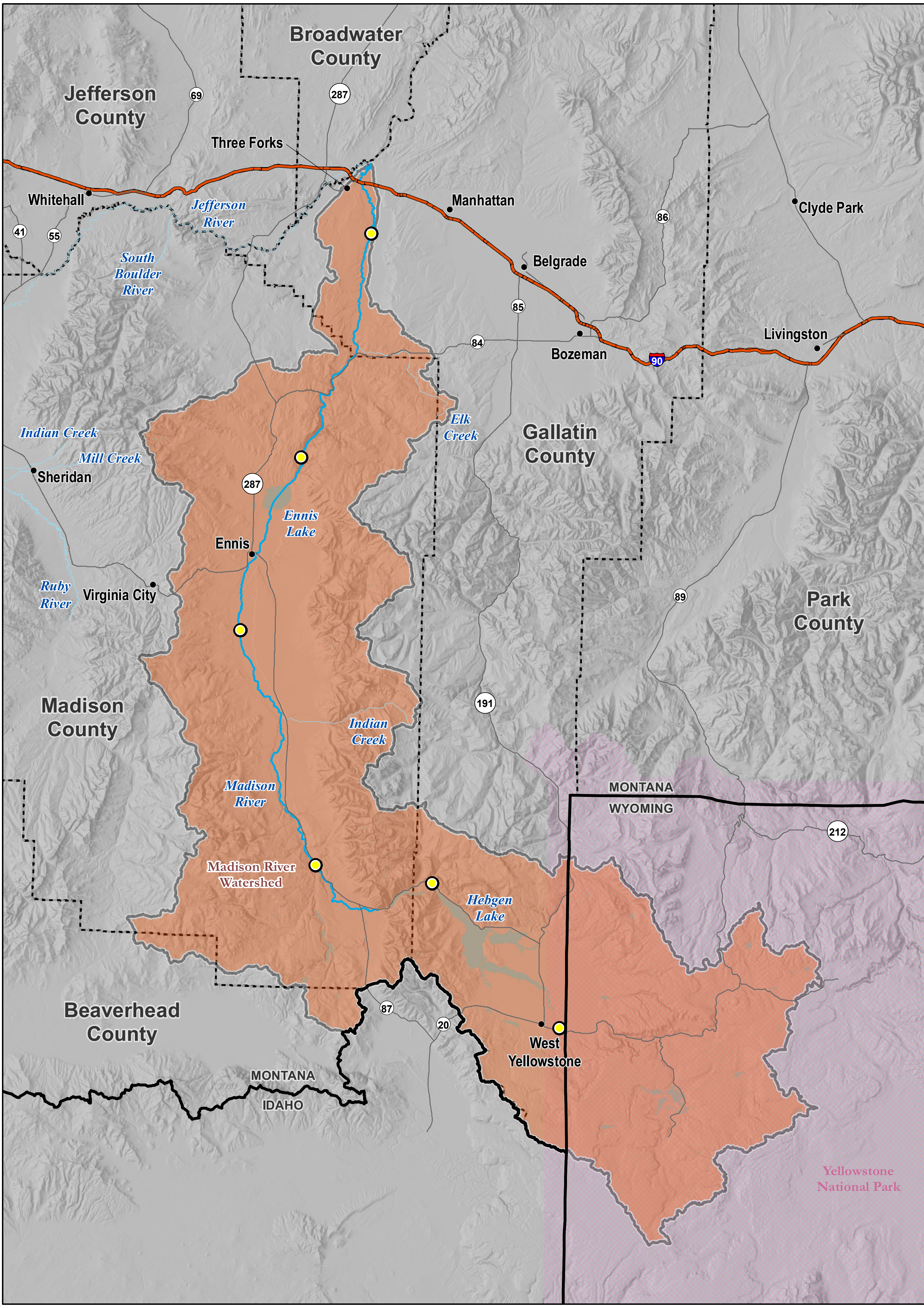
1. Executive Summary

Hydrologic analyses have been performed at USGS gaged and ungaged sites along the Madison River in Gallatin and Madison Counties, Montana. Select stream gages on the Madison River were analyzed using at-station and record extension methodologies described in Bulletin 17C. The peak discharge flood-frequency analyses determined the peak discharges for the 10%, 4%, 2%, 1% and 0.2% Annual Exceedance Probability flood events. Additionally, peak discharges were determined for a standard error of prediction above the 1% Annual Exceedance Probability event to demonstrate a level of uncertainty in the computed discharge values (the 1% Plus discharge). The USGS gaging stations at Three Forks, below Ennis Lake, near Cameron, at Kirby Ranch near Cameron, below Hebgen Lake, and near West Yellowstone, MT were included in the analyses. The Madison River analyses used up to 57 peak flow events in the Maintenance of Variance Extension, Type 3 record extension methodology.

This study revises the peak flow values previously reported in the Flood Insurance Study for the Madison River near Three Forks, MT in Gallatin County. The revised peak flow value is less than previously reported and is a result of a substantially longer period of record used in the analyses and more robust statistical analysis methods. This study incorporates peak flow data through 2016 and revises previous analyses performed in recent USGS flood frequency peak-flow analyses performed on USGS gaging stations with flow data through 2011. Along with the additional years of flow data, an updated record extension methodology was utilized at most gaging stations in this study. As a result, the calculated flood-frequency peak flow values generally vary a small amount from the analyses on the 2011 flow data. There were no systemic trends to the revised values, as the updated flows include both increases and decreases.

Intermediate flow change locations were identified based on watershed characteristics to account for the features within the watershed that result in the changes in flow as the river flows downstream through the watershed. The flow nodes were located at significant tributaries and other substantial increases in drainage area which can account for flow increases along the river. In addition to the six USGS gaging stations, three flow change locations are included on the Madison River. Linear interpolation methods based on the logarithm of contributing drainage area were utilized to determine the flow values for locations that are between two gages on the same river. For the flow node at the confluence of the Madison and Jefferson Rivers, a one-gage transfer equation was utilized to determine flow values at this location.

The resulting flow values at the gaged sites, ungaged site, and intermediate flow change locations are provided in summary information prepared as part of this study. The flow values were determined using methods that meet FEMA guidance and standards and are reliable for use in future flood risk products.



LEGEND

- Towns
- Counties
- Interstate
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- Study Reach
- USGS Gauge
- Madison River Watershed

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Madison River Watershed Study Area

FIGURE 1

DATA FRAME PROPERTIES:
Coordinate System: NAD 1983 StatePlane Montana FIPS 2500 Feet Intl
Projection: Lambert Conformal Conic
Datum: North American 1983
Units: Foot

Miles 0 2 4 8

Map Date: 5/30/2018

2. Introduction

Under contract to the State of Montana's Department of Natural Resources and Conservation (DNRC), Michael Baker International (Baker) has been tasked with preparing a Hydrologic Analysis Report for the Madison River within Gallatin and Madison Counties, Montana (Figure 1). The purpose of the hydrologic analyses is to provide new and updated hydrologic information that will be subsequently used in floodplain mapping activities within the Madison River watershed. The State of Montana is a Cooperating Technical Partner (CTP) with the US Department of Homeland Security (DHS) Federal Emergency Management Agency (FEMA), and this work is performed under Mapping Activity Statement (MAS) Number 2017-04, Jefferson River Watershed, Phase I.

This hydrologic analysis for the Madison River watershed includes the Madison River from its confluence with the Jefferson River near Three Forks, MT upstream to the uppermost stream gage on the Madison River near West Yellowstone, MT (Figure 1). Hydrologic analyses for the Madison River was performed by updating the peak flow analyses at gaged locations by the USGS. This study does not include tributaries to the Madison River.

2.1. Background Information and Existing Flood Hazards

As a participant in FEMA's CTP program, The State of Montana works in collaboration with FEMA to identify flood hazards and communicate flood risk to communities throughout the state, and to assist with administration of the National Flood Insurance Program (NFIP). In this role, the State also engages with communities to provide technical and community outreach resources related to implementation of the NFIP, the Montana Floodplain and Floodway Management Act (1971), and the Montana Code Annotated. Annually, the State identifies and prioritizes specific study and mapping projects and applies to FEMA for funding to implement these projects and other related program activities. The hydrologic evaluation of the Madison River is one element of a project identified and prioritized for the Jefferson River Watershed Phase I study. The ultimate goal of the study is to provide new and updated flood hazard risk information to the communities within the Jefferson River and Madison River watersheds.

Existing flood hazard information within the Madison River watershed is quite limited given the broad extent and considerable flood risk posed by the Madison River. Flood hazard information has been published by FEMA on a Flood Insurance Rate Map (FIRM) for Gallatin County, which includes the area around the City of Three Forks and unincorporated portions Gallatin County along the Madison River. Portions of the Madison River upstream and downstream of Three Forks within Gallatin County are currently mapped as Zone A on the effective FIRMs, while approximately 2.2 miles of the river immediately adjacent to Three Forks is mapped as Zone AE with floodway. Detailed (Zone AE) mapping extends approximately 1.2 miles upstream of the Madison River crossing at Interstate 90. Approximate (Zone A) mapping extends an additional four miles on the Madison River above the end of the detailed mapping area. Beyond that, the Madison River in Gallatin County is un-mapped. Further upstream, with one exception, the Madison River in Madison County is un-mapped as well. The exception is tied to a detailed study performed on Moores Creek in the Town of Ennis (performed in 2006, listed effective in 2011), which includes information on the Madison River within the town limits going back to previous approximate studies on Moores Creek presented on 1974 Federal Insurance Administration Flood Hazard Boundary Map and included on a 1984 FEMA Flood Hazard Boundary Map and 1986 FIRM. The most recent (2011) effective mapping incorporates a detailed study area along Moores Creek, which flows through the Town of Ennis immediately west of the Madison River. The 2011 detailed maps of Moores Creek include the portions of the previous Approximate mapping of the Madison River floodplain within the Town of Ennis limits and shown as Zone A. At the upper extents of the Madison River in Montana, the Madison River passes through a small portion of Gallatin County again at Earthquake and Hebgen Lakes prior to reaching the border of Wyoming and Yellowstone National Park near West Yellowstone, Montana. All of these headwater areas in Gallatin County are un-mapped with no effective flood hazard mapping that covers the Madison River. No effective floodplain mapping exists for the remaining portions of Madison County within the Madison River watershed study area, including the Beaverhead River, Ruby River, South Boulder River, Indian Creek, and Mill Creek.

2.2. Basin Description

The Madison River watershed drains a substantial portion of southwest Montana and includes portions of northwest Wyoming in Yellowstone National Park. Along with the Jefferson and Gallatin Rivers, the Madison River is one of the three headwater tributaries that forms the Missouri River near Three Forks, MT. The Madison River begins at the confluence of the Gibbon and Fire Hole Rivers in Yellowstone National Park, WY, approximately 13 miles upstream of West Yellowstone. The tributaries to the Madison River drain the continental divide in the southern portion of the watershed (Firehole River), as well as the Gravelly Range and Madison Range along the western and eastern portions of the watershed, respectively. The Madison River watershed at USGS gaging station near Three Forks, MT (USGS 06042500) drains approximately 2,516 mi^2.

Along the extents of the study area defined by a profile baseline developed for this hydrologic analysis (near the outlet of Earthquake Lake by the Madison County – Gallatin County line to the confluence with the Jefferson River), the character of the Madison River varies considerably. Near the outlet of Earthquake Lake, the Madison River leaves a narrow, confined canyon formed by the Henrys Lake Mountains and Madison Range and flows into a broader valley characterized by extensive terraces on both sides of the river that confine the Madison River from near the Earthquake Lake outlet to near Ennis (approximately 35 miles). The terraces limit the lateral movement of the Madison River through this reach, which is largely single-thread, relatively straight, and has a steeper gradient than reaches of the Madison River near Ennis and Three Forks.

Approximately nine miles above the Town of Ennis, the Madison River floodplain begins to widen, the Madison River transitions from a single thread channel to a multi-thread channel with an increasing prevalence of flow splits through the floodplain, along with the presence of seeps and springs flowing as spring creek channels fed by ground water sources. While the Town of Ennis sits largely on higher ground above the Madison River floodplain, the eastern boundary of Ennis lies adjacent to the Madison River and floodplain. Approximately five miles downstream of Ennis, the Madison River flows into Ennis Lake, a 3,850 acre impoundment formed by Madison Dam, which contains approximately 42,000 acre-ft of storage. Madison Dam was initially constructed in 1901, is currently owned by NorthWestern Energy and is operated as a hydro-electric facility. Madison Dam discharges into Beartrap Canyon, an approximately 10 mile reach of the Madison River characterized by steep canyon walls, higher gradient single-thread river, with coarse substrate including boulder-strewn rapids and minimal floodplain in overbank areas.

Exiting Beartrap Canyon, the Madison River is still relatively confined by valley features that extend to the river banks and maintain the single-thread character of the river and limiting overbank floodplain areas. The gradient is less steep below Beartrap Canyon and this reach begins the transition back to a lower gradient river with broad floodplain. The Madison River floodplain begins to broaden out approximately 15 miles above the Interstate 90 Madison River crossing. Once the river flattens out in this reach, multiple channel threads begin to form as the Madison River planform transitions to an anastomosed pattern. A review of aerial photography indicates the Madison River historically has meandered back and forth across the valley, but currently the Madison River is generally located along the western area of the valley in this reach down to Three Forks. Approximately 11 miles upstream from the Interstate 90 crossing, a levee embankment has been constructed along the right overbank area of the Madison River, limiting overbank flows and lateral migration from access much of the historic floodplain to the east. Approximately one mile upstream of the Interstate 90 cross over the Madison River, a levee embankment has been constructed along the left (west) overbank to limit potential flooding of Three Forks from the Madison River. Both the left and right levee features extend along the Madison River approximately ¾ of a mile north of the Interstate 90 crossing to limit flooding into Old Town Three Forks to the west and adjacent farm and ranch land to the east. North of Interstate 90, the Madison River continues as a lower gradient, multi-thread channel with significant floodplain in both the left and right overbank areas (albeit limited by the levees) down to the confluence with the Jefferson River.

Interstate 90 is a major feature that crosses the Madison River floodplain and blocks most of the overbank flowpaths. Madison River flows are limited to the main channel crossing of the Interstate and another smaller crossing a little over ½ mile east of the main channel crossing, immediately to the east of the levee in the right floodplain. In addition to the Interstate 90 roadway embankment, the Union Pacific Railroad, Intestate 90 Frontage road, and pedestrian/bicycle path all parallel Interstate 90 across the Madison River floodplain and also limit overbank flows from south to north at this location.

The broad floodplains in the lowest reach of the Madison River (above and below Interstate 90) appear to be inundated during relatively high flows that overtop the streambanks and continue as shallow overland flow. The floodplains have strong connectivity with the Madison River through the shallow ground water table present during the spring and early summer peak flows.

Much of the land use adjacent to the Madison River and floodplain around Three Forks and Ennis are classified as agricultural (farming and ranching), while land use in the Madison River reaches are upland and support grazing or are forested public lands. While several small farming communities are present along the Madison River, the setting is almost entirely rural, with Three Forks having the highest population (approximately 2,000 (US Census Bureau 2016 projected)) followed by Ennis (approximately 900). US Highway 287, State Highway 84, Madison Road, and Interstate 90 are the major roadways present along portions of the Madison River. These roadways, as well as a number of county roads, city streets, private drives, farm/ranch accesses, and the Montana Rail Link railroad have bridges that cross the Madison River.

A number of small irrigation ditches draw water from the Madison River in the reach between Interstate 90 upstream to where the floodplain narrows towards Beartrap Canyon to irrigate farm land within and immediately adjacent to the historic Madison River floodplain.

Several small irrigation systems divert water from the Madison River in the reach between Interstate 90 upstream to where the floodplain narrows towards Beartrap Canyon, but these appear to be relatively minor diversions and generally deliver water to farms and ranches within, or very near, the Madison River floodplain. In addition to Ennis Lake, Earthquake Lake and Hebgen Lake (reservoir) are the only significant impoundments on the Madison River. Hebgen Lake is impounded by Hebgen Dam, completed in 1914 by Montana Power Company. Hebgen Dam is approximately 85 feet tall and provides approximately 325,000 acre-feet storage in Hebgen Lake. Hebgen Dame is operated as a hydro-electric facility by NorthWestern Energy. Earthquake Lake was formed as a result of a landslide triggered by the August 1959 magnitude 7.5 earthquake along the Madison Fault near Hebgen Lake. The US Army Corps of Engineers have performed various projects to improve stabilization of the debris that forms Earthquake Lake. As a result of a natural geologic event, there are no flow control mechanisms out of Earthquake Lake, with stabilization efforts focused primarily on the outlet of Earthquake Lake. Concern about erosion through and downstream from the Earthquake Lake splillway resulted in operational limitations on flows into Earthquake Lake (Hebgen Dam outlet) to limit Madison River flows below Earthquake Lake at USGS Gage 06038800 (Madison River at Kirby Ranch near Cameron, MT) to 3,500 cfs. However, flood events of 1993, 1996, and 1997 exceeded this threshold.

As noted above, much of the land along the Madison River and its tributaries is in private ownership; primarily as farms, ranches, and the businesses and residents of the communities along the rivers. Throughout the remainder of the watershed, however, most of the land ownership is public land - managed primarily by the US Forest Service, Bureau of Land Management, and State of Montana.

The Madison River watershed elevation ranges from just over 4,000 feet above MSL (NGVD29) at the confluence with the Jefferson River, to approximately 4,160 feet at USGS gaging station 06042500 (Madison River near Three Forks MT), and over 11,000 feet in the watershed's mountain peaks. The mean basin elevation is 7,115 feet, and 76% of the basin is at an elevation above 6,000 ft. Approximately 41% of the watershed is forested. Annual precipitation varies widely across the watershed, with up to 50 inches per year in the high mountains and as low as 12 inches per year at the Madison River valley floor. Based on data collected using USGS StreamStats (McCarthy et al. 2016), mean annual precipitation averaged across the watershed is 28.7 inches per year. Temperatures vary widely across the watershed as well, with wintertime low temperatures frequently dropping well below zero degrees Fahrenheit, and summertime high temperatures average more than 80°F in the watershed's lower elevations (Montana Climate Office).

2.3. Flood History

2.3.1. Madison River

Consistent with many river systems in the Rocky Mountain region, peak flows on the Madison River and tributaries typically are a function of annual snowmelt and generally occur in the late spring or early summer. As an example, of the 57 years of peak flow records at USGS 06041000 Madison River below Ennis Lake, near McAllister, MT, all the annual peak flow events exceeding the 50% Annual Exceedance Probability (AEP) (4,760 cfs) occur in May or June. This dominance of spring/summer snowmelt on the annual peak flow record is reflected by other stream gages in watersheds within the region. In addition to flooding from snowmelt, ice jam flooding can be a significant source of localized flooding along the Madison River. The most commonly reported areas of flooding due to ice jamming on the Madison River are in the Ennis area and near Three Forks.

In addition to the USGS stream gage near Three Forks (06041000), there are flow data for the Madison River from other stream gages in the watershed within the study area. Figure 2 shows the individual sub-watersheds in the Madison River watershed, and indicates the location of the stream gages within the Madison River watershed project area. Figures 3 through 8 graphically present the peak flow data for the gages used in the statistical analyses, including the period of record at each gage site and the additional years included in those analyses that employed record extension. Table 1 lists peak flow information for the aforementioned gages as well as the largest recorded flood events from the gage record. Note that some stream gages included in Table 1 were not part of the stream gage analyses included in this study.

Based on the stream gage analyses performed by USGS using available gaging data (see Section 4.0 Hydrologic Analyses and Results) and record extension methods, the largest floods recorded on the Madison River in the Three Forks area were in 1970 (9,750 cfs), 1971 (8,910 cfs), 1996 (8,140 cfs), and 1997 (8,060 cfs). Based on the flood frequency analyses described in Section 4.0, the estimated recurrence interval of these flood events is on the order of approaching a 100-year flood in 1970, about a 50-year flood for the 1971 flood, and between a 10- and 25-year flood for the 1996 and 1997 floods. For the Madison River below Ennis Lake, the largest flood events occurred in many of the same years, including 1970 (9,550 cfs), 1971 (8,730 cfs), 1996 (7,980 cfs), and 1997 (7,910 cfs), as well as 1995 (7,360 cfs). Based on updated flood-frequency results, the 1970 flood was between a 50- and 100-year flood event, while the 1971 event was between the 25- and 50-year flood event. The other flood events were between the 10- and 25-year flood events. Near Cameron (above Ennis Lake and the Town of Ennis), analyses of the gaged data and record extension for the site indicate the five largest peaks occurred in the same years as the Madison River gage below Ennis Lake (1970, 1971, 1996, 1997, and 1995). Similarly, the peak flows at the Ennis Lake gage for these years lie within the range of 7,130 to 8,830 cfs, corresponding 10- to 100-year flood events at this gage. Further up the watershed at Kirby Ranch near Cameron, peak flows are significantly lower, with data synthesized through the record extension methodology in years 1970 and 1971 having peak flows of 6,150 and 5,560, respectively. These two events correspond to just above a 100-year event and between a 25- and 50-year flood event. The next three largest flow events were measured peaks at the gage in years 1993 (5,030 cfs), 1986 (5,000 cfs), and 1996 (4,840 cfs). These events are between 10- and 25-year flood events.

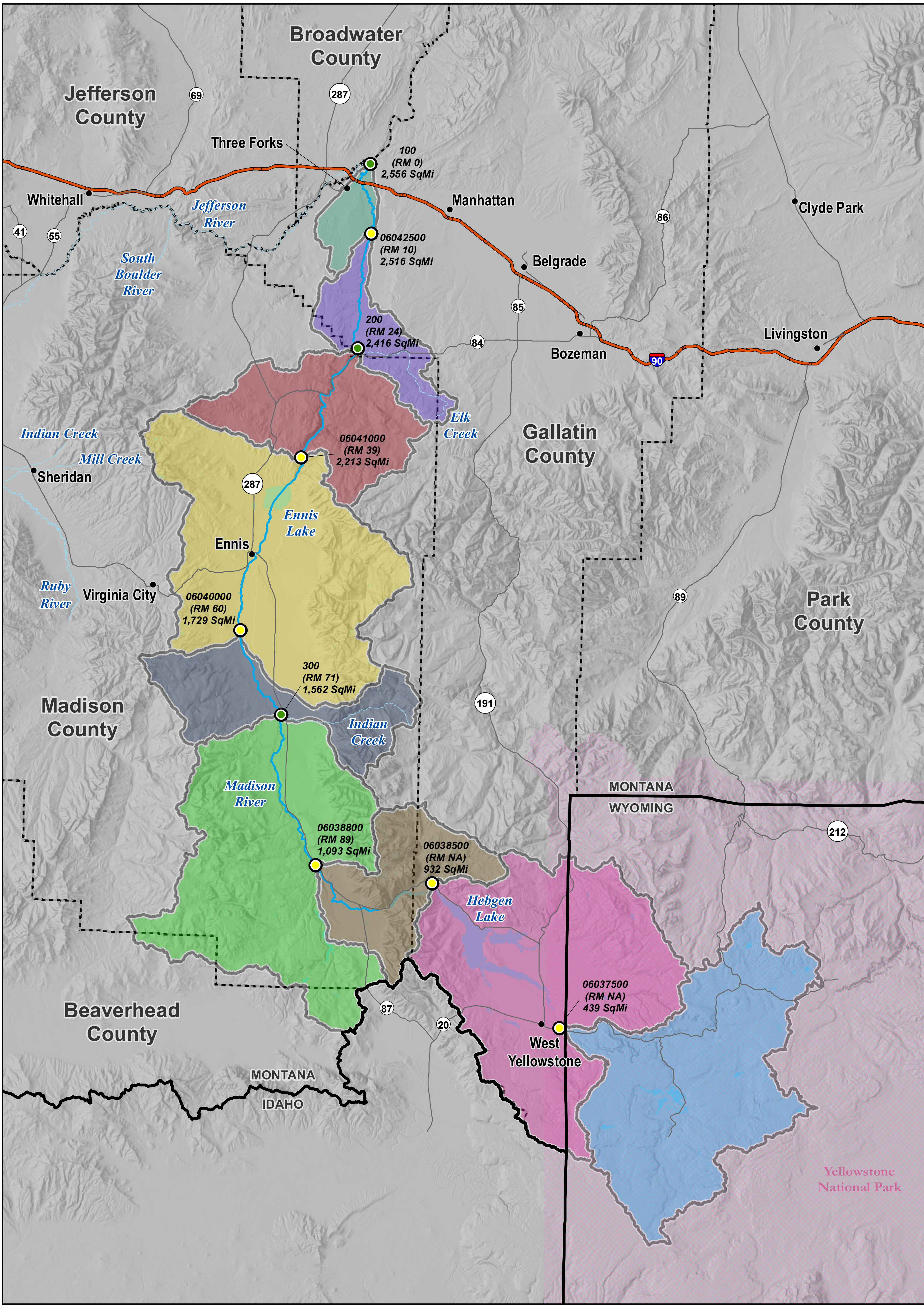
Two gages were analyzed by USGS above the Madison County – Gallatin County line above Earthquake Lake. The first gage is located between Hebgen Lake and Earthquake Lake (USGS 06038500). The largest flow events reported by USGS using gage analysis and record extension methods occurred in 1970, 1993, 1959 (November), and 1996. The corresponding flows were 5,170 cfs, 3,970 cfs, 3,880 cfs, and 3,880 cfs, respectively. The record extension method excludes the August peak flow event recorded on the gage, which was recorded when a severe earthquake struck the area near the gage station. The 1970 event was approximately a 100-year event, while the other peak flow events were approximately 25-year flood events. The final gage analyzed is the USGS gage above West Yellowstone, MT (USGS 06037500). This gage is just outside of Yellowstone National Park, WY, and not far from the origin of the Madison River (confluence of the Gibbon and Firehole Rivers). Peak flows at this site occurred in years 1996, 1997, 2011, 1986, and 1993. Corresponding peak flows are 2,820 cfs, 2,630 cfs, 2,520 cfs, 2,340 cfs, and 2,300 cfs, respectively. These events correspond to around a 100-year event (1996 and 1997), a 50-year event (2011), and 25-year event (1986 and 1993).

Available photo documentation of flood events within the Madison River watershed are included in Appendix A.

Table 1: Peak flow data for select gages in the Madison River watershed.

Madison River						
Station Name	Madison River near Three Forks		Madison River bl Cherry Cr nr Norris MT		Madison River bl Ennis Lake nr McAllister MT	
Station Number	06042500		06042000		06041000	
Period of Peak Flow Data	1894–1950		1898-1905		1939 - 2017	
Number of Peak Flow Records	16		8		79	
Largest Recorded Events	Date	Peak Flow (cfs)	Date	Peak Flow (cfs)	Date	Peak Flow (cfs)
	6/19/1896	8,175	6/16/1899	10,300	6/12/1970	9,550
	6/2/1943	7,840	5/19/1901	8,325	6/28/1971	8,730
	6/2/1894	6,980	6/18/1898	8,000	6/10/1996	7,980
	6/10/1942	6,650	5/25/1904	6,740	6/6/1997	7,910
	6/11/1947	6,540	6/10/1903	6,150	6/2/1943	7,750
Madison River						
Station Name	Madison River ab powerplant nr McAllister MT		Madison River near Cameron MT		Madison River at Kirby Ranch nr Cameron MT	
Station Number	06040800		06040000		06038800	
Period of Peak Flow Data	2002 - 2017		1952 - 2017		1959 - 2017	
Number of Peak Flow Records	16		21		36	
Largest Recorded Events	Date	Peak Flow (cfs)	Date	Peak Flow (cfs)	Date	Peak Flow (cfs)
	6/24/2011	5,940	6/11/1970	8,830	5/31/1993	5,030
	5/29/2014	4,330	6/7/1952	6,670	6/6/1986	5,000
	6/12/2010	4,220	6/24/2011	6,600	6/7/1996	4,840
	6/23/2008	4,170	5/28/1969	6,220	10/23/1959	4,710
	6/5/2006	4,000	6/2/1956	5,980	6/6/1997	4,700

Madison River						
Station Name	Madison River bl Hebgen Lake nr Grayling MT		Madison River near West Yellowstone, MT			
Station Number	06038500		06037500			
Period of Peak Flow Data	1940 - 2017		1914 - 2017			
Number of Peak Flow Records	77		91			
Largest Recorded Events	Date	Peak Flow (cfs)	Date	Peak Flow (cfs)		
	8/17/1959	10,200*	5/18/1996	2,820		
	6/10/1970	5,170	5/18/1997	2,630		
	6/3/1943	5,090	6/8/2011	2,520		
	5/27/1993	3,970	5/31/1986	2,340		
	11/5/1959	3,880	5/22/1993	2,300		
***Peak affected by severe earthquake at Hebgen Lake Dam**						



LEGEND

- Towns
- Counties
- Study Reach
- Flow Change Location
- USGS Gauge

Flow Change Basins

- 100
- 06042500
- 200
- 06041000
- 06040000
- 300
- 06038800
- 06038500
- 06037500

MONTANA DNRC

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DATA FRAME PROPERTIES:
Coordinate System: NAD 1983 StatePlane Montana FIPS 2500 Feet Intl
Projection: Lambert Conformal Conic
Datum: North American 1983
Units: Foot

0 2 4 8 Miles

N

Madison River Flow Change Basins

FIGURE 2

Map Date: 5/30/2018

Figure 3: USGS 06042500 Madison River near Three Forks MT.

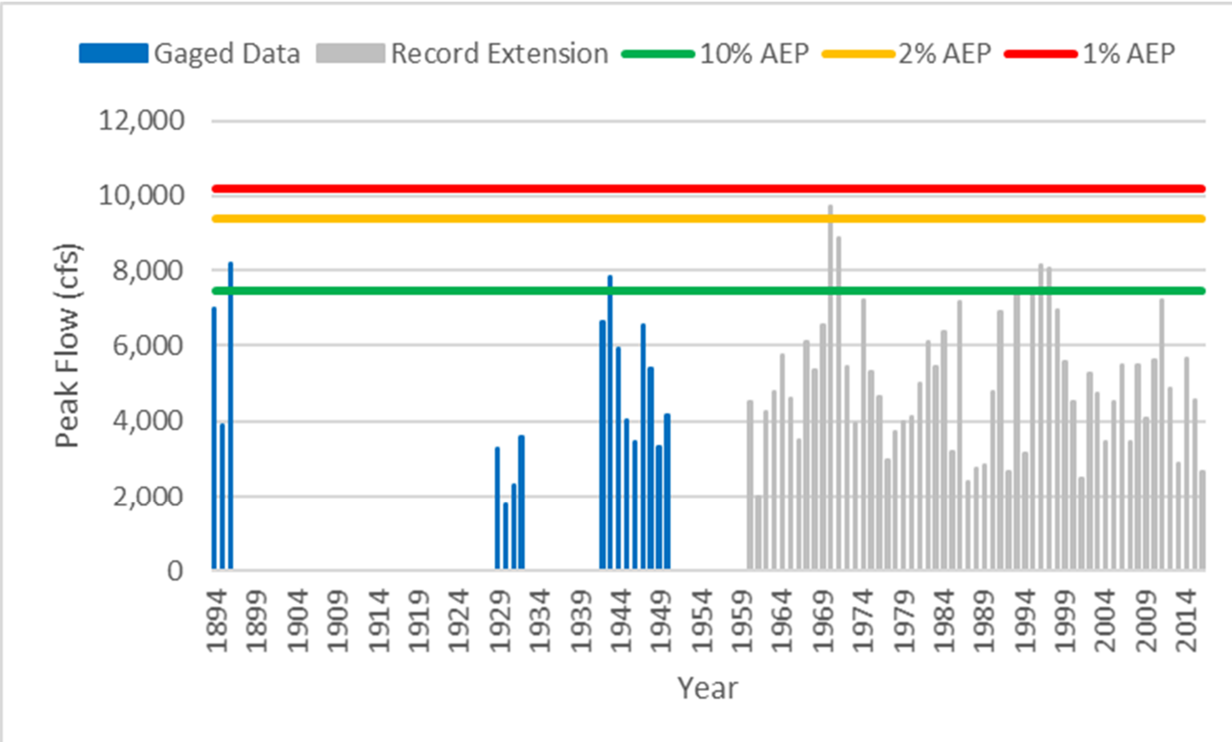


Figure 4: USGS 06041000 Madison River below Ennis Lake near McAllister MT.

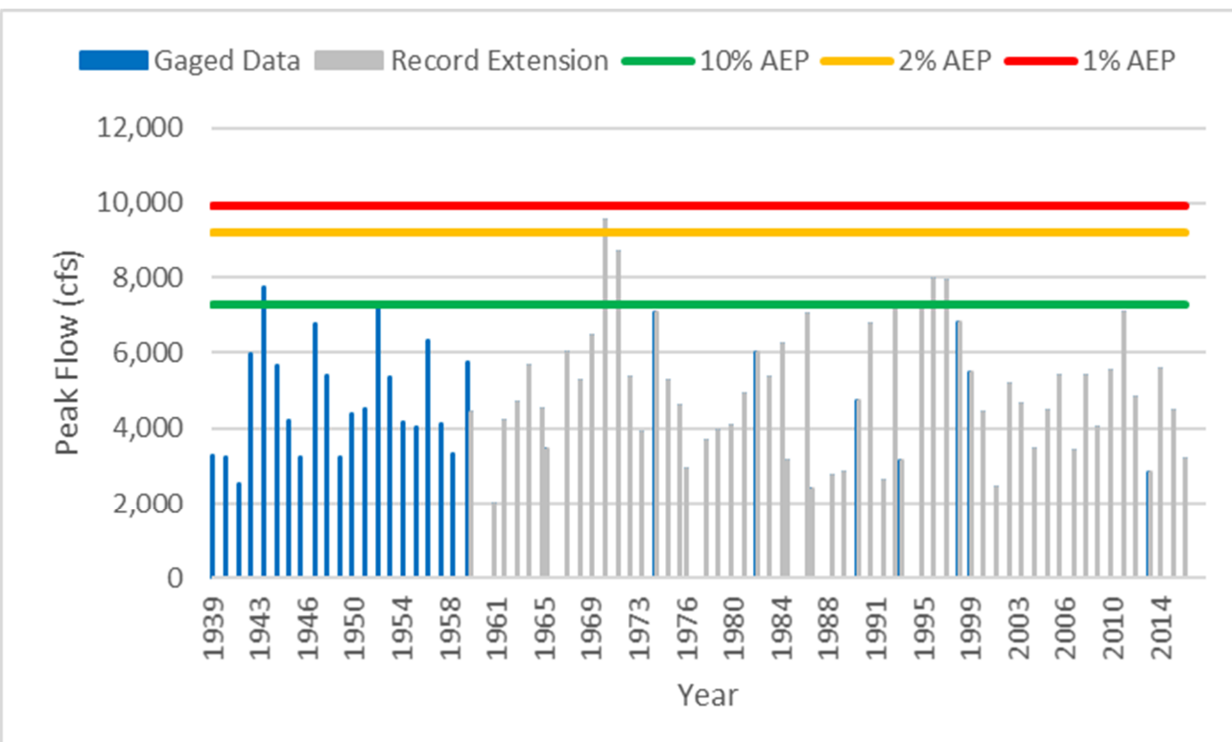


Figure 5: USGS 06040000 Madison River near Cameron MT.

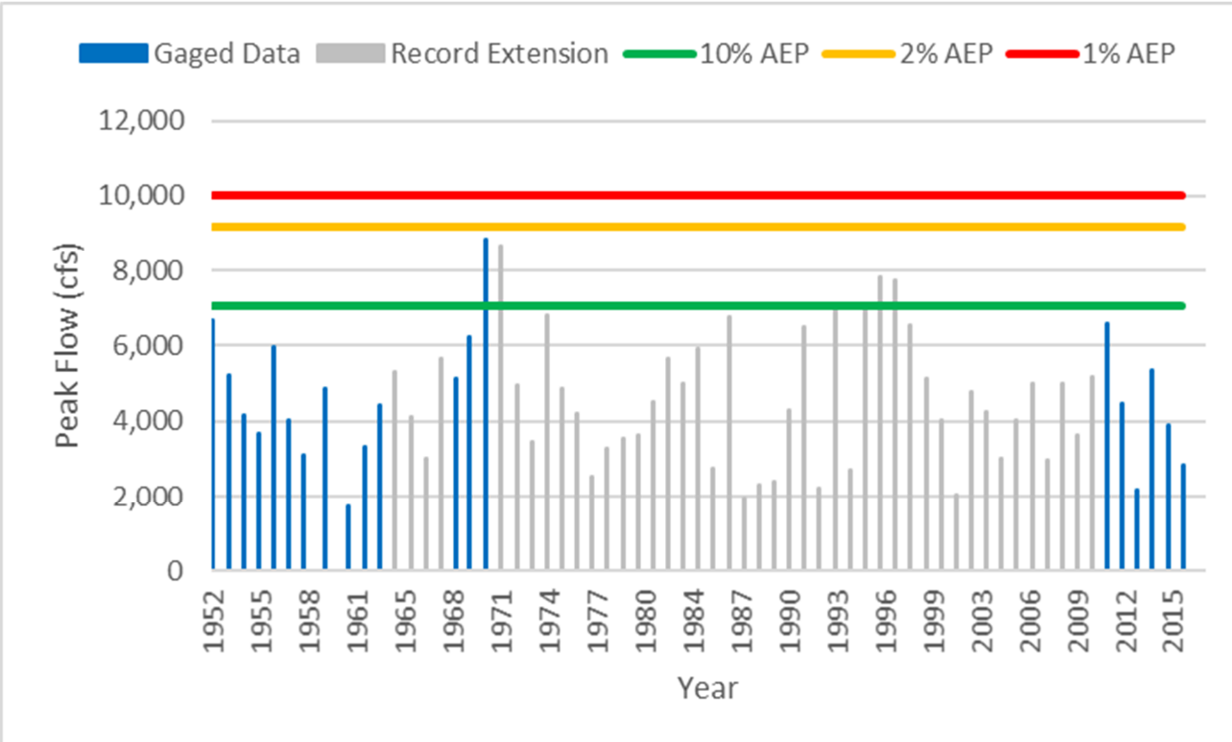


Figure 6: USGS 06038800 Madison River at Kirby Ranch near Cameron MT.

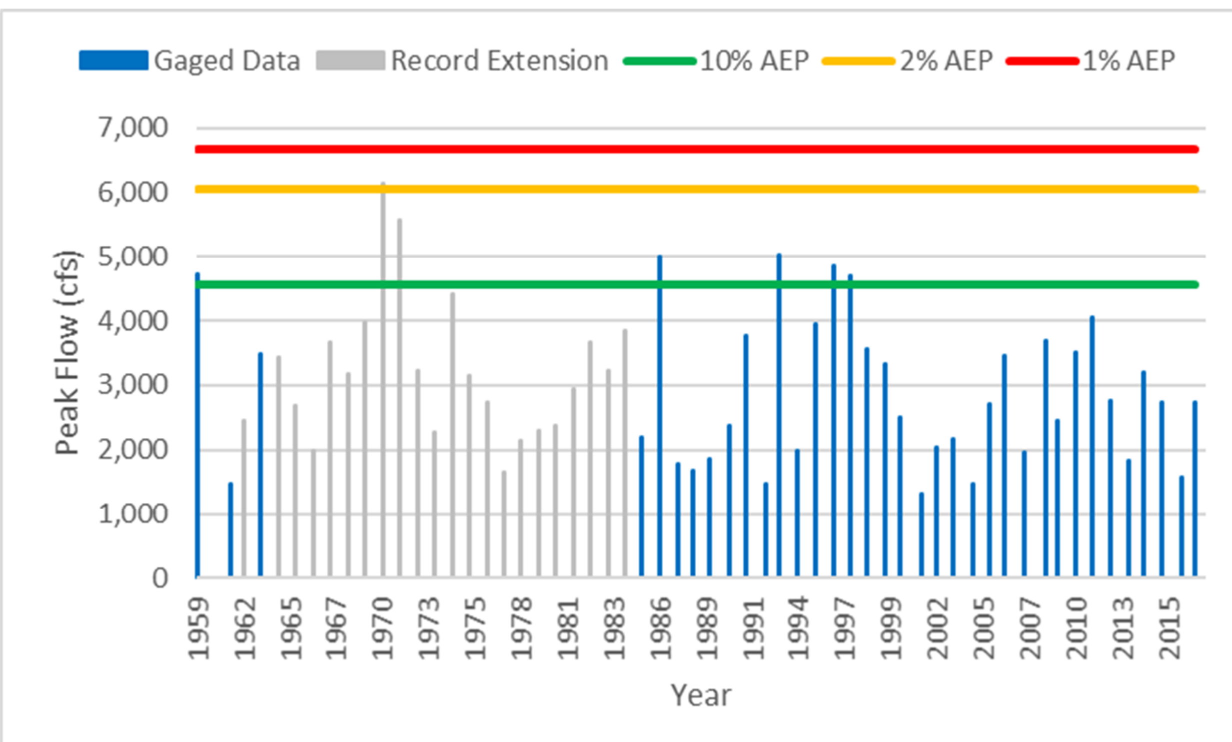


Figure 7: USGS 06038500 Madison River below Hebgen Lake near Grayling MT.

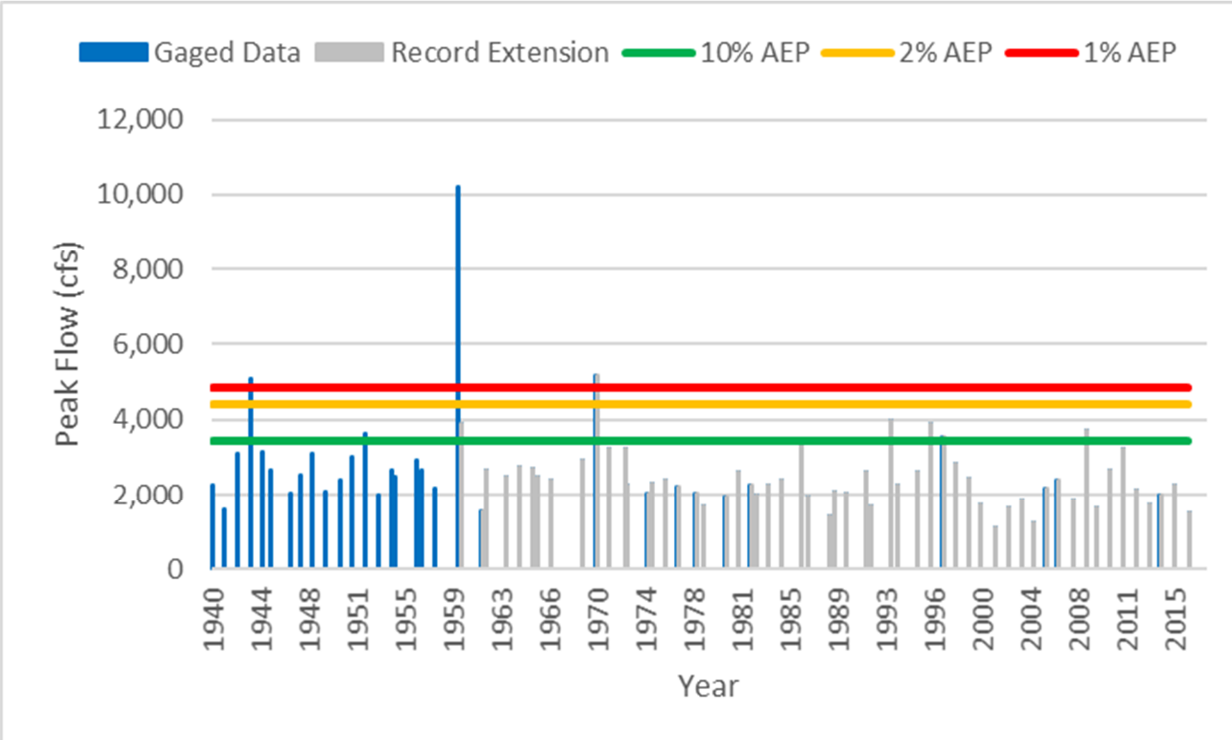
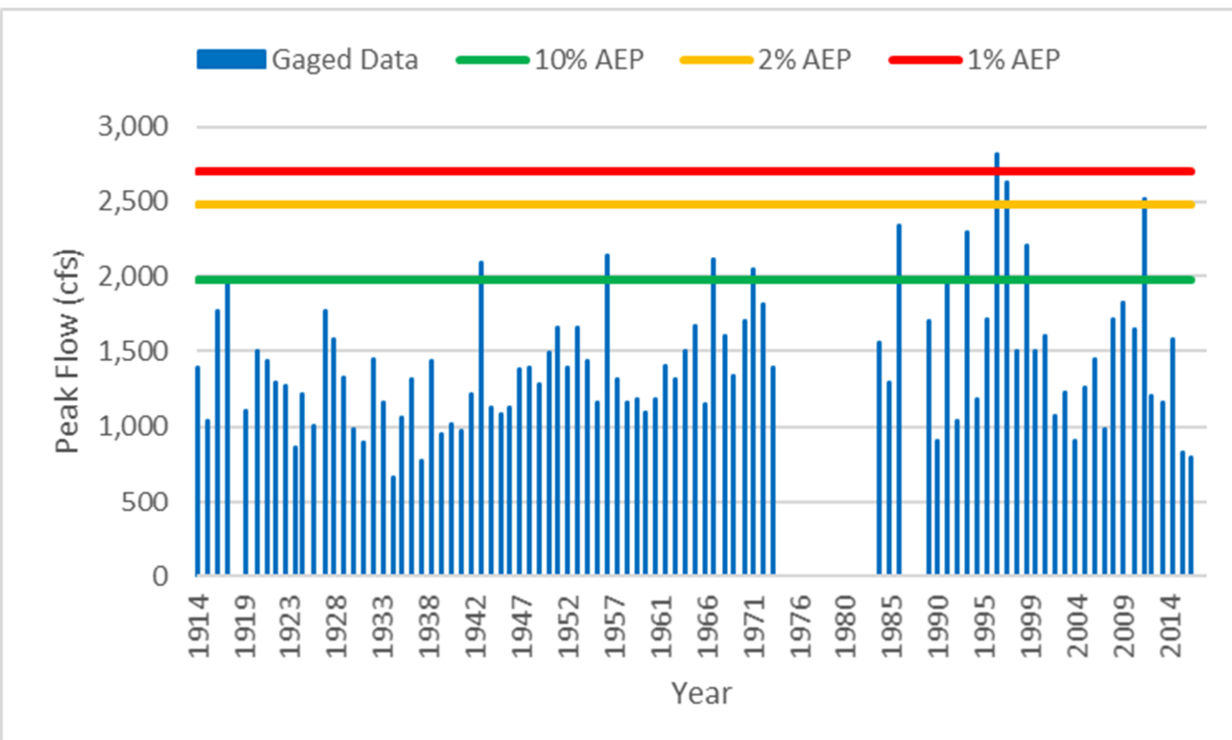


Figure 8: USGS 06037500 Madison River near West Yellowstone MT.



3. Previous Studies

Previous studies for the Madison River within this study area are very limited. Various sources of information are tied to previous FEMA flood insurance studies and data compiled by the USGS for stream gages within the watershed. A summary of the existing studies and documents are provided in the following sections.

3.1. Gallatin County, Montana and Incorporated Areas Flood Insurance Study

A Flood Insurance Study (FIS) for Gallatin County, Montana and Incorporated Areas was published effective by FEMA on September 2, 2011 (FEMA 2011). An updated version of this FIS was issued preliminary on February 16, 2018 for studies outside of the Jefferson and Madison River watersheds. Both versions describe the flooding sources and hydrologic analyses for the City of Three Forks and the portion of the Madison River within Gallatin County. The FIS notes that prior to construction of the Madison River dike in 1920, flooding was frequent (nearly every year) in parts of the Madison River valley floor. However, upon completion of the Madison River dike these nearly annual flooding events ceased.

Ice jamming appears to provide the greatest flood risk to Three Forks and surrounding areas. The FIS notes that a 1949 ice jam flood resulted in rebuilding and raising the dikes. The east dike is higher than the west dike, which tends to direct overtopping flows over the west dike and into the vicinity of the Interstate 90 and railroad bridge. However, ice jamming at these crossings may back water up into the City of Three Forks. In addition to the 1949 ice jam event, ice jams were noted in 1972, 1975, and 1978 which backed up water near developed areas of Three Forks. The FIS notes that the dikes should not be considered reliable flood control features and may require additional upgrades or maintenance. The FIS references previous hydrologic analyses performed for the City of Three Forks, including an NRCS study from 1979 and a re-study completed in 2004 by Van Mullem Engineering.

The 2004 Van Mullem Engineering hydrologic analyses were performed for a Letter of Map Revision (LOMR, No. 05-08-A579P) in the City of Three Forks, issued by FEMA June 29, 2006. Van Mullem performed a peak discharge frequency analysis following USGS Bulletin 17B methods for a nearby USGS gage (Madison River below Ennis Lake (06041000)) with 50 years of record and compared that gage's flow record with the Madison River at Three Forks gage (06042500; 16 years of flow record) and found there was no significant difference between the peak flows of the two gages. Using Log-Pearson Type III distribution methodologies following Bulletin 17B, Van Mullem estimated a 1% AEP discharge of 10,100 cfs (Van Mullem 2003), a reduction of nearly 2,000 cfs from the NRCS 1979 estimated discharge of 12,000 cfs.

Peak discharge relationships for the Madison River near the Town of Three Forks were based on regional regression equations developed using peak discharge data for selected frequencies and drainage area data from 19 selected USGS stream gages in the surrounding area. Two gages on the Madison River were included in the analysis (06041000 Madison River below Ennis Lake near McAllister and 06042500 Madison River near Three Forks). The source data for the gage analyses are USGS Compilation of

Records of Surface Waters of the US through September 30, 1950; 1950 – 1960 in Missouri River Basin above Sioux City, IA; and 1961 – 1975 Water Resources Data for Montana.

The results of the hydrologic analyses reported in the FIS are provided in Table 3.

3.2. Flood Insurance Study, Town of Ennis, Madison County, MT

Detailed hydrologic and hydraulic analyses and associated mapping were performed for Moores Creek within the limits of the Town of Ennis (effective June 2011). The study revises approximate limits with more detailed information to better describe the flood risk along Moores Creek within Ennis. While this FIS is specific the Moores Creek flooding source, the resulting mapping retained mapping approximate (Zone A) floodplain delineations along the Madison River within the town limits. Reviewing historic information, the Madison River floodplain mapping are part of Flood Hazard Boundary Map produced for the Federal Insurance Administration in 1974, with subsequent updates as FEMA Flood Hazard Boundary Maps and Flood Insurance Rates Maps in 1984 and 1986, respectively. The Ennis FIS notes that no FIS was prepared for the previous mapping efforts, and a search for historic documentation yielded no additional documentation.

4. Hydrologic Analyses and Results

Hydrologic analyses performed in this study identify the peak flow discharge estimates for flood events corresponding to the 10%, 4%, 2%, 1%, 0.2%, and 1% 'plus' AEP events at specific locations within the Madison River watershed. The locations for these calculations define flow change locations throughout the watershed and generally correspond to stream gage locations, the confluence with significant tributaries in the watershed, local communities, and other locations where the flood frequency characteristics are likely to change (e.g. at dams and reservoirs). The analyses performed to determine peak flow characteristics at these locations include USGS stream gage analyses and flow determination using methods at ungaged stream locations.

The USGS operates a number of stream gages on the Madison River, and the stream gage analyses were performed on select gages on the Madison River. Given the large distances between stream gage locations on the Madison River, intermediate flow change locations have been identified that recognize the contribution of other tributaries and increases in drainage area along these rivers between gaged sites. Peak flow estimates at these intermediate flow change locations were performed using flow determination methods at ungaged stream locations.

Nine flow change locations have been identified on the Madison River (Figure 2). Six of these are at USGS gaging sites:

- USGS 06042500 Madison River near Three Forks, MT
- USGS 06041000 Madison River below Ennis Lake, near McAllister, MT
- USGS 06040000 Madison River near Cameron, MT
- USGS 06038800 Madison River at Kirby Ranch, near Cameron, MT
- USGS 06038500 Madison River below Hebgen Lake, near Grayling, MT
- USGS 06037500 Madison River near West Yellowstone, MT

The remaining three flow change locations on the Madison River are associated with tributaries or significant changes in the contributing drainage area.

4.1. USGS Stream Gage Analyses

Historically, the USGS has operated ten stream gages on the Madison River, with eight of these within the reach of Madison River from the confluence with the Jefferson River upstream to the Madison County – Gallatin County line. The remaining two gages are in Gallatin County upstream of Earthquake Lake, one between Earthquake Lake and the other above West Yellowstone, MT. Of the ten gages, four gages are inactive and one gage began recording flow data in 2002. As part of USGS scope of work for performing stream gage analyses, the USGS identified five stream gages as having been previously reported in USGS reports and listed those gages as being included in this revised flood-frequency analysis:

- USGS 06042500 Madison River near Three Forks, MT
- USGS 06041000 Madison River below Ennis Lake, near McAllister, MT
- USGS 06040000 Madison River near Cameron, MT
- USGS 06038800 Madison River at Kirby Ranch, near Cameron, MT
- USGS 06038500 Madison River below Hebgen Lake, near Grayling, MT

The USGS notes that three of the gages are between Hebgen Lake and Ennis Lake (USGS 06038500, 06038800, and 06040000), two others are downstream from Ennis Lake (USGS 06042500 and 06041000), and that all five gages were grouped together for record extension analyses under the 2015 data release of stream gages through Year 2011 (Sando et al. 2018a). For the analyses, the MOVE.3 (Maintenance of Variance Extension Type III) record extension statistical method was applied to three gaging station sites (USGS 06042500, 06041000, 06038800) to create an analysis that extends the record to 57 peak flow events for the Base Period of the gage and flow records for years 1960 to 2016. This extended the records from 16 years, 20 years, and 35 years to 57 years for USGS gages 06042500, 06040000, and 06038800, respectively. Even though data are available at some locations prior to 1960, the 1959 Madison Earthquake created Earthquake Lake and management of releases from Hebgen Dam have been limited to minimize the risk of erosion of the Earthquake Lake outlet and downstream areas. The stream gage downstream of Hebgen Dam (USGS 06038500) has 56 years of peak flow data from 1960 to 1967 and 1969 to 2016, thus record extension at this gage is not required and peak flow analyses were performed on the peak flow data for the site following the Madison Earthquake. An additional gage (USGS 06037500 Madison River near West Yellowstone, MT) was included in the analysis based on the availability of flow data at this gage and to bring all appropriate gages on the Madison River into the analysis. The West Yellowstone gage is furthest upstream and unaffected by the Madison Earthquake nor other flow regulating impoundments. Thus, gage analysis for USGS 06037500 was performed on the 90 years of peak flow data that are available at this site between 1914 to 2016.

Table 2 lists USGS stream gages and gage information for the Madison River gages that are used in this study.

Under an agreement with Montana DNRC, the USGS performed peak-flow frequency analyses for selected gages on the Madison River. The analyses were specific to the study area included in this report and is documented in a standalone USGS data release (McCarthy, et al. 2018). With the exception of the Madison River gages near West Yellowstone and below Hebgen Dam, flood frequency estimates at the remaining stations (those with short records, affected by flow regulation, or with large drainage areas (typically larger than 2,750 mi^2)) were analyzed using the mixed-station record extension methodology, MOVE.3. Details of how USGS applied the MOVE.3 analysis to synthesize peak flow data are provided in detail in Chapter D of Montana StreamStats (Sando, et al. 2018a) and summarized below. The MOVE.3 methodology is based on correlation of concurrent peak-flow records for the target station (station with incomplete flow records) with one or more index stations (stations with peak flow records for one or more of the missing years of the target station). The procedure evaluates the strength of the relationship between peak discharges at target and index stations for the same year and adjusts the peaks for the index stations to fit the characteristics of the target station for the missing year data. Documentation regarding the application of the mixed-station MOVE.3 procedure is provided in the USGS data release (McCarthy, et al. 2018). Analyses for the Madison River gage at Hebgen Dam and the gage near West Yellowstone were performed using at-station peak flow data following procedures described Bulletin 17C "Guidelines for Determining Flood Flow Frequency" (England et al., 2017).

Table 2: USGS stream gages and gage information used in this study.

Gage Station Number	Station Name	Drainage Area (mi^2)	Peak-flow analysis type	Water Years of Peak Flows Used in Analysis[1]	Number of Peak Flows Used in Analysis[1]	River Station (mile)
Madison River						
06042500	Madison River near Three Forks, Montana	2,516	MOVE.3	1960–2016 (1894–96, 1929–32, 1942–50)	57 (16)	10.6
06041000	Madison River below Ennis Lake, near McAllister, Montana	2,213	At-site	1960–2016	57	39.2
06040000	Madison River near Cameron, Montana	1,729	MOVE.3	1960–2016 (1952–58, 1960–63, 1968–70, 2011–16)	57 (20)	60.2
06038800	Madison River at Kirby Ranch, near Cameron, Montana	1,093	MOVE.3	1960–2016 (1960–61, 1963, 1985–2016)	57 (35)	89.8
06038500	Madison River below Hebgen Lake, near Grayling, Montana	932	At-site	1960–67, 1969–2016	56	NA
06037500	Madison River near West Yellowstone, Montana	439	At-site	1914–17, 1919–73, 1984–86, 1989–2016	90	NA

[1] Numbers in parenthesis represent peak flow events and corresponding years without applying MOVE.3 analysis

As noted above, this study updates the peak-flood frequency analyses published by USGS in 2015, which analyzed stream gages with flow records through water year 2011. A comparison of the results of this study with the 2015 study are presented in Table 3.

Figure 9 provides the calculated flow values based on the AEP event as a function of basin area for the Madison River. There are six gaging stations used in this analysis on the Madison River. The peak flows indicate the expected response of increasing peak flows at gages as the drainage area increases down the watershed.

Figure 9: Flood Events based on Annual Exceedance Probability for Madison River flow gages evaluated by this study.

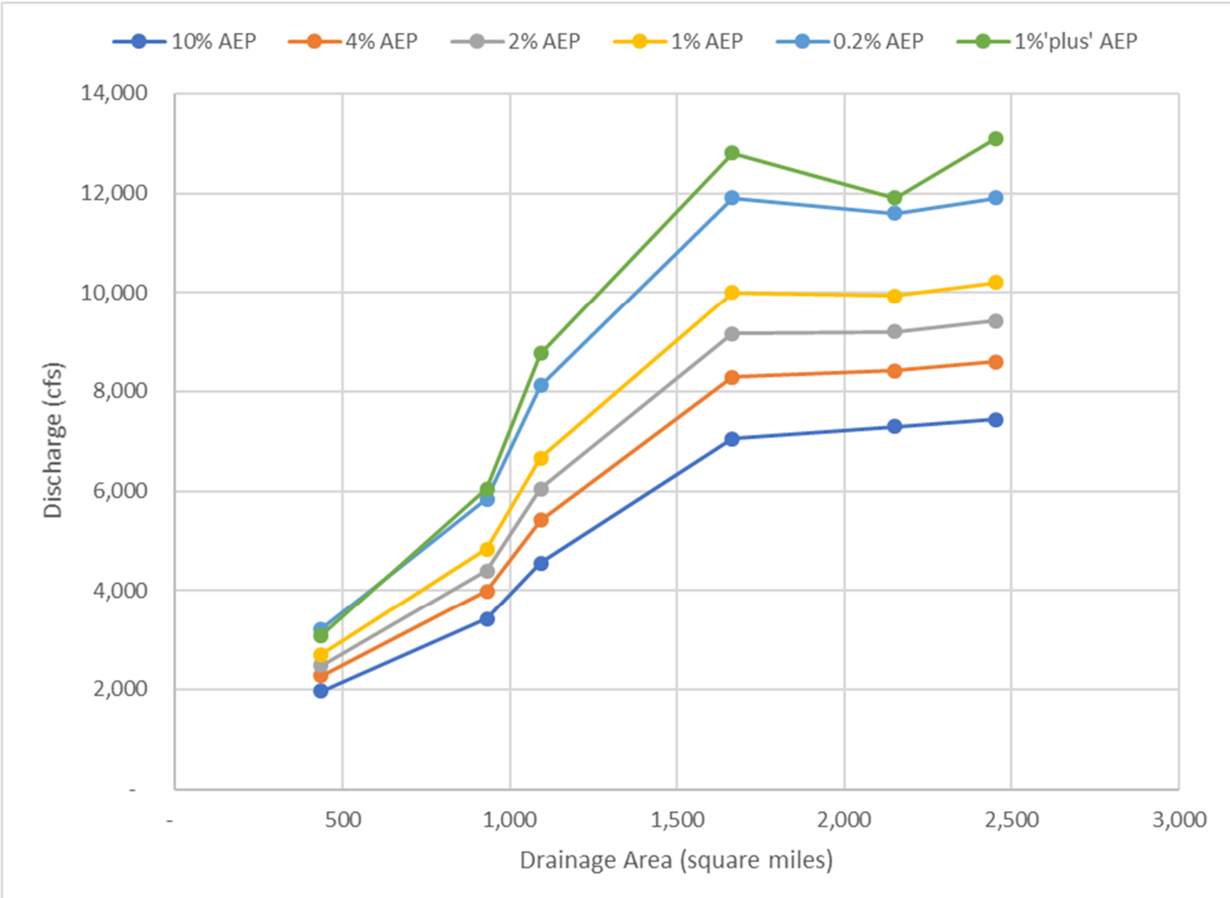


Table 3: Peak discharge comparison 2016 data analysis compared to 2015 study results on data through 2011.

Station Number	Station Name	Peak Discharge (cfs) for Annual Exceedance Probability (%) Flows									
		10%		4%		2%		1%		0.2%	
		2011	2016	2011	2016	2011	2016	2011	2016	2011	2016
Madison River											
06042500	Madison River near Three Forks, MT	7,370	7,440	8,510	8,600	9,310	9,420	10,100	10,200	11,700	11,900
	2011 FIS (Spring Runoff)	8,000		(*1)		10,800		12,000		14,900	
	2011 FIS (Winter Runoff)	2,660		(*1)		3,295		3,550		4,135	
06041000	Madison River below Ennis Lake, near McAllister, Montana	7,230	7,290	8,330	8,420	9,100	9,200	9,830	9,940	11,400	11,600
06040000	Madison River near Cameron, Montana	6,930	7,050	8,010	8,290	8,770	9,160	9,480	10,000	11,00	11,900
06038800	Madison River at Kirby Ranch, near Cameron, Montana	4,630	4,550	5,500	5,410	6,140	6,040	6,800	6,660	8,350	8,120
06038500	Madison River below Hebgen Lake, near Grayling, Montana	3,540	3,420	4,080	3,980	4,470	6,070	4,860	4,830	5,750	5,840
06037500	Madison River near West Yellowstone, Montana	2,080	1,970	2,410	2,270	2,650	2,480	2,890	2,700	3,470	3,210

*1 FIS (2011) data not available

4.1.1. 1% Plus Peak Flow Estimates

As previously discussed, FEMA flood risk products employ a method for determining peak discharge estimates for a standard error of prediction above the 1% AEP, known as the 1% Plus discharge. The purpose of the 1% plus analysis is to highlight uncertainty within the hydrologic model and potential underestimations in the resulting modeled flood elevations by using the upper confidence limits (84%) to compute higher flood discharge (FEMA 2012). Baker staff reviewed supplemental information provided by USGS (Sando, pers. comm. 2018) and incorporated the 1% plus results for the Madison River gages listed in Table 4. Table 4 lists the 1% plus AEP peak flow values calculated for the stream gages utilized in this study.

4.2. Flow Change Node Locations

The hydrologic data prepared in this report is intended to describe the general hydrologic conditions within the Madison River watershed areas of interest. One of the uses of the data from this study is to describe flood risk for the communities within the Madison River watershed, which involves developing hydraulic models based on these hydrologic data and stream channel and floodplain characteristics to develop predicted water surface elevations through the study area. These water surface elevations are then applied to topographic data to develop floodplain boundaries, inundation maps, depth grids, and other useful mapping products. However, over the approximately 100 miles of the Madison River, peak flow data have only been determined at locations controlled by USGS gaging station locations. There are locations along the Madison River where substantial distance (and corresponding contributing drainage area) between these gages exist. As a result, intermediate flow change locations are required at locations along the Madison River to better describe the flow conditions along these rivers at locations without stream gages. Table 4 lists the flow change locations along each of the study reach and indicates whether the location is a stream gage location or is included as an intermediate flow change location. By definition, the intermediate flow change locations are ungaged sites, and methods described in the “Gage Transfer to Ungaged Sites” (Sando et al. 2018b) were used to estimate peak-flow frequencies at these locations.

To perform the gage transfer to ungaged sites, sub-basins were defined at the flow change locations along the watershed. These sub-basins include the intermediate flow change locations as well as the gage locations where flow changes are defined. As part of defining the sub-basins, the contributing drainage area for the sub-basin was determined through a geoprocessing tool in ArcGIS which is based upon the NHDPlus version 2 data. The source data for delineation was US 30m National Elevation Dataset (NED) and the sub-basin points were defined at the USGS gage location or intermediate flow change location established by reviewing the overall Madison River watershed characteristics. It was determined that additional flow change locations were necessary at the confluence of the Madison River with the Jefferson River, at a location immediately upstream of Elk Creek, and immediately upstream of Indian Creek. The automatic watershed delineation was checked for accuracy and manually adjusted as necessary. It should be noted that the delineated watershed areas for this study vary slightly from those reported by USGS at the gage station. The modified values are included in the analyses, calculations, and results reported in this study.

Table 4: Gage and flow node locations and recommended Annual Exceedance Probability flows.

Pour Point ID	Station / Node Number	Station/Node Name	Drainage Area[1] (square miles)	Peak Discharge (cfs) for Annual Exceedance Probability (%) Flows					
				10%	4%	2%	1%	0.2%	1% Plus
Madison River									
25	100	Madison River Confluence with Jefferson River	2,556	7,529	8,694	9,517	10,298	12,000	13,226
26	06042500	Madison River near Three Forks, MT	2,516	7,440	8,600	9,420	10,200	11,900	13,100
28	200	Madison River above Elk Creek	2,416	7,392	8,543	9,350	10,117	11,804	12,708
30	06041000	Madison River below Ennis Lake, near McAllister, Montana	2,213	7,290	8,420	9,200	9,940	11,600	11,900
32	06040000	Madison River near Cameron, Montana	1,729	7,050	8,290	9,160	10,000	11,900	12,800
33	300	Madison River above Indian Creek	1,562	6,398	7,542	8,353	9,139	10,934	11,769
35	06038800	Madison River at Kirby Ranch, near Cameron, Montana	1,093	4,550	5,410	6,040	6,660	8,120	8,760
36	06038500	Madison River below Hebgen Lake, near Grayling, Montana	932	3,420	3,980	4,400	4,830	5,840	6,050
50	06037500	Madison River near West Yellowstone, Montana	439	1,970	2,270	2,480	2,700	3,210	3,090

[1] Drainage area based on delineation of watershed using ESRI ArcGIS with manual correction if necessary

4.3. Gage Transfer to Ungaged Sites

To provide a better representation of the flow distribution through the Madison River study corridor, intermediate flow change locations have been identified to represent the influences of tributaries and other watershed features on the flow distribution along the Madison River. These flow changes correspond to inputs from the Elk Creek and Indian Creek watersheds. Since a significant portion of the Madison River watershed lies below the USGS gaging station at Three Forks (06042500) down to the confluence with the Jefferson River, an additional pour point was located at the confluence to determine the peak flow estimates for the area between the lowest Madison River USGS gage and the confluence with the Jefferson River.

Montana StreamStats Chapter F (Sando et al. 2018b) provides gage transfer methodologies to estimate peak flow characteristics at ungaged locations that are either a) near a stream gage station (Equation 1); or b) between stream gaging stations (Equation 2).

4.3.1. Estimating Peak-Flow Frequencies at an Ungaged Site on a Gaged Stream

USGS SIR 20155019 Chapter F (Sando et al. 2018b) provides the methodology for estimating the peak-flow frequency when an ungaged site is close to a gaging station on the same river. The drainage-area ratio adjustment methodology is provided in Chapter F and is included below. This method was utilized to estimate the peak-flow frequencies on the Madison River below the USGS gaging station at Three Forks (06042500). As noted in SIR 20155019, this method is appropriate for ungaged sites on large streams where regression equations are not applicable (e.g. drainage area out of the range of applicability), and results may not be reliable if the ratio of drainage areas (DA_U/DA_G) is outside the range of 0.5 to 1.5. Application of this methodology for the ungaged site on the Madison River met these criteria. Results are summarized in Table 4.

Equation 1:

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

Where:

$Q_{AEP,U}$	is the AEP-percent peak flow for ungaged site *U*, in cubic feet per second;
$Q_{AEP,G}$	is the AEP-percent peak flow for gaging station *G*, in cubic feet per second;
DA_U	is the drainage area at ungaged site *U*, in square miles;
DA_G	is the drainage area at gaging station *G*, in square miles;
exp_{AEP}	is the regression coefficient for an OLS regression relating the log of the AEP-percent peak flow to the log of the drainage area within each location (SIR 20155019 Chapter F, Table 5).

At ungaged sites located between two gaging stations on the same river, Chapter F provides a methodology to estimate peak-flow frequencies using linear interpolation of the logarithms of peak-flow frequencies at two bounding gages using the logarithm of the drainage areas as the basis for the interpolation. The flow change locations between gaging stations on the Madison River utilize this methodology and are at site numbers 200 (Madison River above Elk Creek) and 300 (Madison River above Indian Creek). The SIR cautions that this method may produce unreliable results if the two gaging stations have different peak flow characteristics caused by substantially different periods of records. The MOVE.3 analysis performed by USGS (Sando and McCarthy 2018) minimizes the potential for this cause of unreliability given the record extension methodology. Results are presented in Table 4.

Equation 2:

$$logQ_{AEP,U} = logQ_{AEP,G1} + \left[\frac{(logQ_{AEP,G2} - logQ_{AEP,G1})}{(logDA_{G2} - logDA_{G1})}\right](logDA_U - logDA_{G1})$$

where:

$Q_{AEP,U}$ is the AEP-percent peak flow at ungaged site *U*, in cubic feet per second;
$Q_{AEP,G1}$ 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 *G2*, in square miles;
DA_{G1} is the drainage area at the upstream gaging station *G1*, in square miles; and
D_{AU} is the drainage area at ungaged site *U*, in square miles.

4.4. Ice Jam Analysis

Ice jams are a documented flood risk along the Madison River. While ice jamming can occur at any location along the Madison River, Ennis and Three Forks are the most frequent areas where ice jamming has been a concern. This may be in large part due to the fact that they are the two most significant communities along the Madison River.

Of the USGS gaging stations along the Madison River, only two have ice jam stage data in the USGS National Water Information System (NWIS). At the gaging station near Three Forks (USGS 06042500), there are four ice jam stages available within the 16 year period of record for this gage. The ice jam data at this gage are during years 1942 to 1950 and range in stage from 7.67 ft to 10.48 ft. The other gaging station with ice jam data is the Madison River near Cameron (USGS 06040000). For the 20 years of annual peak flow data available at this gage, there are four ice jam stages within the period of 1955 to 1962 ranging from 8.11 ft to 8.83 ft.

As part of the 2003-2004 map change in Three Forks, Van Mullem Engineering performed an ice jam analysis on the Madison River near Three Forks. Van Mullem developed a HEC-RAS model using an ice cover/thickness analysis approach. For hydrology, Van Mullem analyzed winter discharges at the USGS Madison River gage near Three Forks to establish a 1% AEP peak flow for wintertime flows and used that value in the hydraulic/ice jam analysis. Van Mullem utilized the four ice jam stage data to verify the hydraulic model results under floating type ice jam with specified ice thickness.

As part of this hydrologic analysis, Baker performed a preliminary ice jam analysis using the Three Forks (USGS 06042500) and Cameron (USGS 0604000) gaging stations. The annual ice jam stages were plotted on normal probability paper using Weibull plotting positions and the exceedance probabilities were adjusted by the fraction of years that ice jam floods occurred in the period of record, per FEMA guidance document on ice jam analyses. The 10% and 1% AEP ice jam stages for each gage were determined using the graphical frequency curves. These were compared against the 10% and 1% AEP open water stages to evaluate the potential flood risk due to ice jamming.

The results of the preliminary ice jam analysis is presented in Table 5. These results indicate that the ice jam stages at both gages under both recurrence intervals are higher than the associated open water stages for flows with the same recurrence intervals. These results are consistent with the Van Mullem ice jam analysis where Van Mullem reports the ice jam stages were 3 – 4 feet higher than open water stages. Additional details and supporting documentation of the analysis are presented in Appendix D.

Table 5: Results of preliminary ice jam analysis at the Three Forks and Cameron gages.

Station Number	Station Name	Stage (ft)			
		10% AEP		1% AEP	
		Ice Jam	Open Water	Ice Jam	Open Water
06042500	Madison River near Three Forks, MT	9.1	6.3	11.6	7.2
06040000	Madison River near Cameron, Montana	7.2	4.9	8.8	5.6

5. Summary/Discussion

The peak flow frequency analyses were performed for the Madison River primarily in Gallatin and Madison Counties. The peak flow frequency analyses were performed for the flows that correspond to the 10%, 4%, 2%, 1%, and 0.2% AEP flood events. In addition to these recurrence intervals, the 1%plus discharge value was determined at each flow node, which incorporates a standard error of prediction into the 1% AEP calculations. Figure 10 provides a summary of recommended 1% AEP flow values at all Madison River watershed flow nodes.

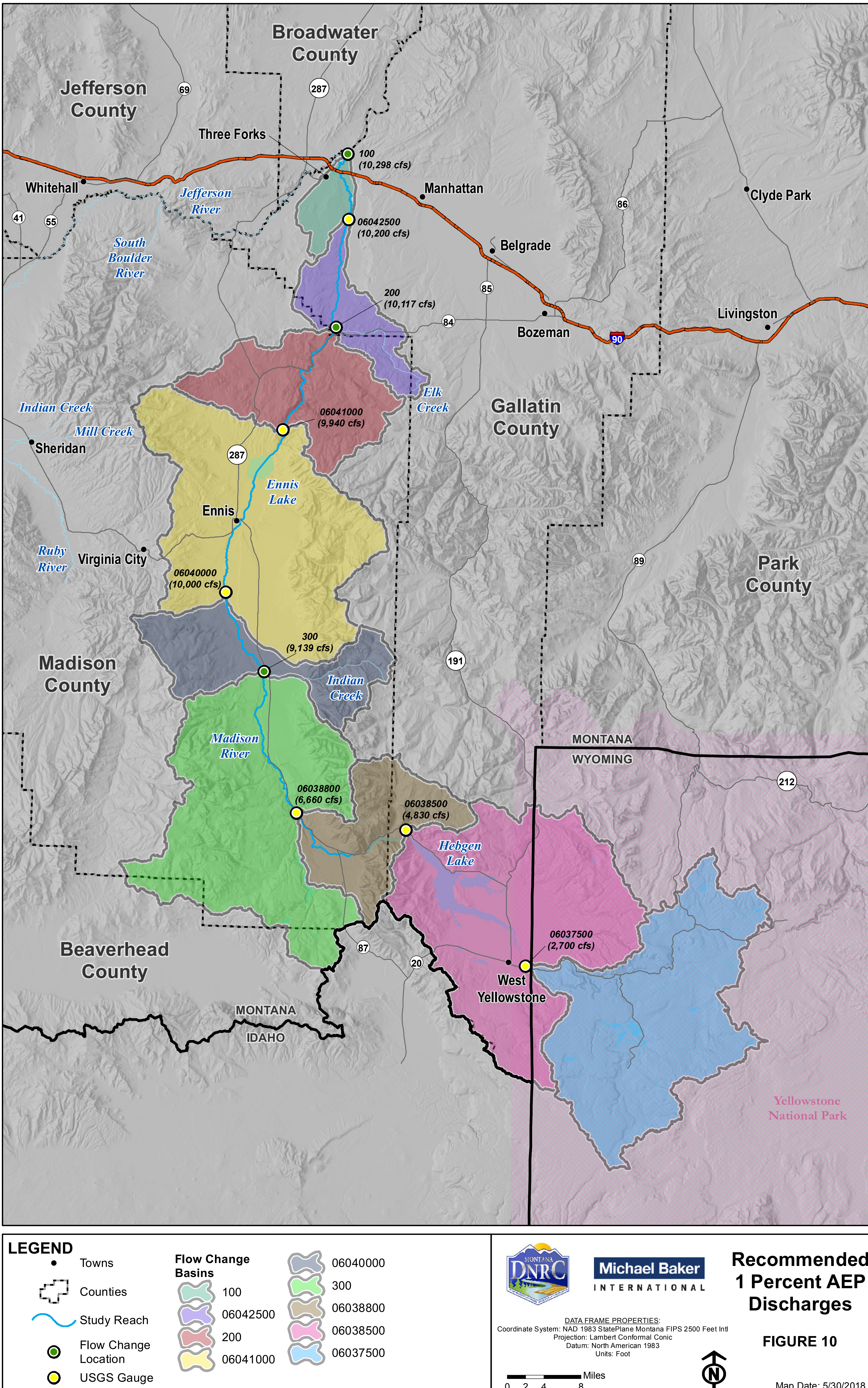
The peak flow frequency analyses were performed by the USGS on select USGS stream flow gages on the Madison River at the following stream gages:

- USGS 06042500 Madison River near Three Forks, MT
- USGS 06041000 Madison River below Ennis Lake, near McAllister, MT
- USGS 06040000 Madison River near Cameron, MT
- USGS 06038800 Madison River at Kirby Ranch, near Cameron, MT
- USGS 06038500 Madison River below Hebgen Lake, near Grayling, MT
- USGS 06037500 Madison River near West Yellowstone, MT

These analyses were performed on stream gage peak flow data through 2016, and update the flood-frequency analyses performed on these gages by the USGS in 2015, which used peak flow data through 2011.

For the Madison River at Three Forks, the 2016 analysis resulted in 100 cfs increase over the calculations on data through year 2011. This increase represents about a one-percent increase and falls within the standard error of prediction for the analysis, with the slight difference likely due to refinement in record extension methodologies between MOVE.3 (this study) and MOVE.1 (2015 study on data through 2011). In particular, the 2015 analyses defined the base period as water years 1939 to 2011 (73 years with peak flow records), while this study defined the base period as water years 1960 to 2016 with 57 peak flow records. The difference in revising the base period was recognition that following the 1959 Madison Earthquake, flows out of Hebgen Dam have been managed to limit releases from the dam such that flows are maintained less than 3,500 cfs at USGS 06038800 (Madison River at Kirby Ranch, near Cameron, MT). The analyses on data through 2016 result in significantly lower peak-flood values than those currently reported in the effective FIS (10,100 cfs using data to 2016 versus 12,000 cfs for the 1% AEP flood in the FIS). Significantly different approaches were utilized to estimate peak-flood frequency between the FIS and this analysis. The FIS used regional regression equations developed from 19 USGS stream gages in nearby watersheds (including two on the Madison River), while this analysis utilizes Bulletin 17C record extension methodologies for the stream gages in the study, which is determined to be a more robust statistical methodology that incorporates actual peak flow data at other gage locations on the Madison River. As with the analysis for the Three Forks gage, the other gaged locations in this analysis have comparable results, with the updated 2016 analysis agreeing relatively closely with the 2015 analysis on 2011 data. The largest difference is at the Madison River near Cameron gage where the 2016 analysis is 520 cfs greater than the previous analysis. The reasons listed above provide the most likely explanation for the difference.

Table 4 summarizes the results of the analyses performed for this study and provides the flow recommendations at select USGS gaging stations, intermediate flow change locations (pour points), and locations within ungaged watersheds.



Recommended 1 Percent AEP Discharges

FIGURE 10

6. References

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Appendix A.

Historic Flood Photos

Photo 1. Madison River (left) and Jefferson River (right) at Confluence. June 2011.

Photo 2. Madison River at Three Forks, MT. June 2011.

Photo 3. Madison River near Three Forks, MT. June 2011.

Photo 4. Madison River above Three Forks, MT. June 2011.

Photo 5. Madison River above Three Forks – near Cobblestone FAS. June 2011.

Photo 6. Madison River below Beartrap Canyon. June 2011.

Photo 7. Madison River, Beartrap Canyon, below Ennis Lake. June 2011.

Photo 8. Madison River at Ennis Lake Dam. June 2011.

Photo 9. Madison River below Three Forks, MT. June 2011.

Photo 10. Ice Jam near Ennis. January 2011.

Photo 11. Madison River at Ennis, MT and Hwy 287. February 2011.

Photo 12. Madison River Ice Jam at Ennis. February 2011.

Photo 13. Madison River Ice Jam at Ennis. January 2011.

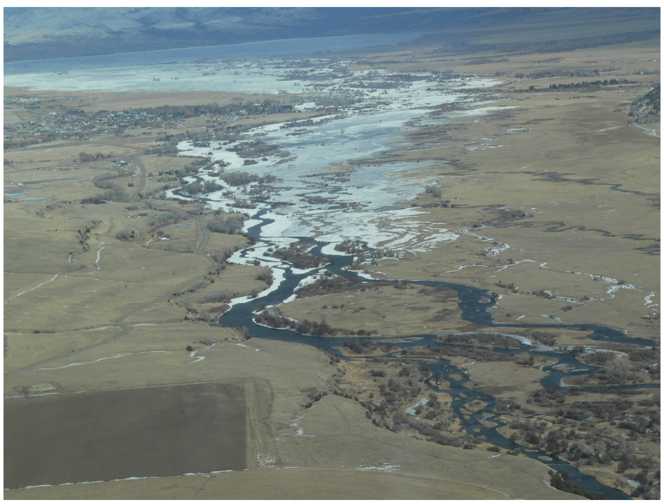

Photo 14. Madison River Ice Jam at Ennis, MT. February 2011.

Photo 15. Old Town flooding at Three Forks, MT. February 1972.

Photo 16. Old Town flooding at Three Forks, MT. February 1972.

Photo 17. Old Town flooding at Three Forks, MT. February 1972.

Photo 18. Breach in dike on Madison River near Three Forks. Flooded Old Town. February 1972.

Photo 19. Madison River lower end of dike below highway. February 1972.

Appendix B.

USGS Stream Gage Analyses

Table 1–1. Information on streamgages for which peak-flow frequency analyses are reported.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. NAD 83, North American Datum of 1983; --, not applicable; U, unregulated; ND, not determined; R, regulated]

Map number (fig. 1)	Streamgage identification number	Streamgage name	Latitude, in decimal degrees (NAD 83)	Longitude, in decimal degrees (NAD 83)	Type of streamgage[1]	Contributing drainage area, in square miles	Data combination[2]	Data correction[3]	Regulation status[4] as of 2014	Number of recorded peak flows	Water years of recorded peak flows	Number of unregulated peak-flow records	Water years of unregulated peak-flow records	Number of regulated peak-flow records	Water years of regulated peak-flow records	Percentage of drainage basin regulated by dams	Regulation status for reported at-site peak-flow frequency analyses
31	06018500	Beaverhead River near Twin Bridges, Montana	45.3834	-112.4528	CONT	3,618	--	--	R (MAJ–dam)	80	1936–44, 1946–2016	28	1936–64	52	1965–2016	65	R
33	06019500	Ruby River above reservoir, near Alder, Montana	45.1923	-112.1428	CONT	534	--	--	U	78	1939–2016	78	1939–2016	0	--	0	U
35	06020600	Ruby River below reservoir, near Alder, Montana	45.2419	-112.1112	CONT	595	--	--	R (MAJ–dam)	54	1963–2016	0	--	54	1963–2016	100	R
37	06021500	Ruby River at Laurin, Montana	45.3525	-112.1225	CONT	643	--	--	R (MAJ–dam)	14	1947–60	0	--	14	1947–60	92	R
37B	06022000	Ruby River below Ramshorn Creek, near Sheridan, Montana	45.4113	-112.2058	CONT	839	Yes	--	R (MAJ–dam)	26	1947–53, 1997–2011, 2013–16	0	--	26	1947–53, 1997–2011, 2013–16	71	R
38	06023000	Ruby River near Twin Bridges, Montana	45.5069	-112.3309	CONT	970	--	--	R (MAJ–dam)	25	1942–43, 1947–65, 1980–81, 2015–16	0	--	25	1942–43, 1947–65, 1980–81, 2015–16	62	R
48	06026500	Jefferson River near Twin Bridges, Montana	45.6133	-112.3294	CONT	7,616	Yes	--	R (MAJ–dam)	65	1911–16, 1921–39, 1942–43, 1958–72, 1994–2016	34	1911–16, 1921–39, 1942–43, 1958–64	31	1965–72, 1994–2016	40	R, Total
64	06036650	Jefferson River near Three Forks, Montana	45.8971	-111.5957	CONT	9,558	Yes	--	R (MAJ–dam)	80	1895, 1897–1905, 1939–69, 1975, 1979–2016	36	1895, 1897–1905, 1939–64	44	1965–69, 1975, 1979–2016	34	R, Total
69	06037500	Madison River near West Yellowstone, Montana	44.6571	-111.0680	CONT	435	--	--	U	90	1914–17, 1919–73, 1984–86, 1989–2016	90	1914–17, 1919–73, 1984–86, 1989–2016	0	--	0	U
70	06038500	Madison River below Hebgen Lake, near Grayling, Montana	44.8664	-111.3388	CONT	931	--	Yes	R (MAJ–dam)	75	1940–58, 1960–67, 1969–2016	19	1940–58	56	1960–67, 1969–2016	100	R
72	06038800	Madison River at Kirby Ranch, near Cameron, Montana	44.8887	-111.5809	CONT	1,092	--	--	R (MAJ–dam)	35	1960–61, 1963, 1985–2016	0	--	35	1960–61, 1963, 1985–2016	94	R
73	06040000	Madison River near Cameron, Montana	45.2331	-111.7516	CONT	1,665	--	--	R (MAJ–dam)	20	1952–58, 1960–63, 1968–70, 2011–16	0	--	20	1952–58, 1960–63, 1968–70, 2011–16	61	R
75	06041000	Madison River below Ennis Lake, near McAllister, Montana	45.4902	-111.6345	CONT	2,150	--	--	R (MAJ–dam)	77	1939–2016	0	--	77	1939–2015	98	R
76	06042500	Madison River near Three Forks, Montana	45.8236	-111.4997	CONT	2,453	--	--	R (MAJ–dam)	16	1894–96, 1929–32, 1942–50	3	1894–96	13	1929–32, 1942–50	87	R

[1]Abbreviations for type of streamgage are defined as follows:

CONT: continuous streamflow operations.

CSG: crest-stage gage operations.

In cases where both CONT and CSG are indicated for an individual streamgage, the historic operations of the streamgage have included periods of continuous streamflow operations and periods of crest-stage gage operations.

[2]Data combination refers to combining peak-flow records of two or more closely located streamgages on the same channel. Information on combining records of multiple streamgages is presented in table 1–2.

[3]Data correction refers to manual adjustment of specific peak-flow records to provide reliable frequency analyses. Information on manual correction of peak-flow records is presented in table 1–3.

[4]Abbreviations for regulation status are defined as follows:

U, unregulated, where the cumulative drainage area upstream from all dams is less than 20 percent of the drainage area of the streamgage.

R (MAJ–dam): major dam regulation, where a single upstream dam has a drainage area that exceeds 20 percent of the drainage area of the streamgage.

R (MAJ–canal): major diversion canal regulation, where a large diversion canal is known to be located on the channel upstream from the streamgage.

R (MIN–dams): minor dam regulation, where the cumulative drainage area of all upstream dams exceeds 20 percent of the drainage area of the streamgage, but no single upstream dam has a drainage area that exceeds 20 percent of the drainage area of the streamgage.

Total: the combined unregulated and regulated peak-flow records for streamgages with peak-flow records before and after the start of regulation, . The "Total" peak-flow frequency analysis is provided in cases where major regulation affects less than 50 percent of the drainage area of the streamgage and there is uncertainty in the effects of regulation on specific peak-flow characteristics. Also, the "Total" peak-flow frequency analysis is the only peak-flow frequency analysis provided in cases of minor dam regulation.

Table 1–4. Documentation regarding analytical procedures for peak-flow frequency analyses

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

Map number (fig. 1)	Streamgage identification number and analysis designation[1]	Streamgage name	Contributing drainage area, in square miles	Regulation status for analysis[2]	Type of peak-flow frequency analysis[3]	Number of peak flows used in the analysis	Water years of peak flows used in the analysis	Primary reason for deviation from standard Bulletin 17C procedures[4]	Log-distribution information for peak-flow data: Mean	Standard deviation	Skew type used in analysis	Station skew of the peak-flow data	Generalized skew	Source of generalized skew used in weighted skew determinations	Analysis skew used for the frequency analysis	PILF information: PILF threshold, cubic feet per second	Type of PILF threshold	Number of systematic peak flows equal to zero	Number of systematic peak flows less than PILF threshold	Frequency analysis incorporates historical information? (if yes, see Table 1-5 for additional information)
31	06018500.10	Beaverhead River near Twin Bridges, Montana	3,618	R (MAJ–dam)	At-site	52	1965–2016	--	2.840	0.215	Weighted	-0.056	-0.192	Bulletin 17B[5]	-0.083	--	MGBT	0	0	--
33	06019500.00	Ruby River above reservoir, near Alder, Montan	534	U	At-site	78	1939–2016	upper tail	2.989	0.158	Station	0.658	-0.205	--	0.658	537	Manual	0	1	Yes
35	06020600.10	Ruby River below reservoir, near Alder, Montan	595	R (MAJ–dam)	At-site	54	1963–2016	reg	2.964	0.182	Station	0.090	-0.188	--	0.090	--	MGBT	0	0	Yes
35	06020600.11	Ruby River below reservoir, near Alder, Montan	595	R (MAJ–dam)	MOVE.3	78	BP 1939–2016	reg	2.936	0.177	Station	0.237	-0.188	--	0.237	--	MGBT	0	0	Yes
37	06021500.10	Ruby River at Laurin, Montana	643	R (MAJ–dam)	At-site	14	1947–60	reg	2.551	0.261	Station	-0.285	-0.159	--	-0.285	--	MGBT	0	0	--
37	06021500.11	Ruby River at Laurin, Montana	643	R (MAJ–dam)	MOVE.3	78	BP 1939–2016	reg	2.584	0.347	Station	0.146	-0.159	--	0.146	--	MGBT	0	0	Yes
37B	06022000.10	Ruby River below Ramshorn Creek, near Sheridan, Montana	839	R (MAJ–dam)	At-site	26	1947–53, 1997–2011, 2013–16	--	2.701	0.304	Weighted	0.318	-0.154	Bulletin 17B[5]	0.047	--	MGBT	0	0	--
37B	06022000.11	Ruby River below Ramshorn Creek, near Sheridan, Montana	839	R (MAJ–dam)	MOVE.3	78	BP 1939–2016	--	2.722	0.309	Weighted	0.149	-0.154	Bulletin 17B[5]	0.099	--	MGBT	0	0	Yes
38	06023000.10	Ruby River near Twin Bridges, Montana	970	R (MAJ–dam)	At-site	25	1942–43, 1947–65, 1980–81, 2015–16	--	2.806	0.222	Weighted	-0.176	-0.148	Bulletin 17B[5]	-0.160	--	MGBT	0	0	--
38	06023000.11	Ruby River near Twin Bridges, Montana	970	R (MAJ–dam)	MOVE.3	78	BP 1939–2016	--	2.839	0.280	Weighted	0.195	-0.148	Bulletin 17B[5]	0.138	--	MGBT	0	0	Yes
48	06026500.10	Jefferson River near Twin Bridges, Montana	7,616	R (MAJ–dam)	At-site	31	1965–72, 1994–2016	--	3.930	0.149	Weighted	-0.516	-0.123	Bulletin 17B[5]	-0.241	7,530	MGBT	0	11	--
48	06026500.11	Jefferson River near Twin Bridges, Montana	7,616	R (MAJ–dam)	MOVE.3	52	BP 1965–2016	--	3.917	0.158	Weighted	-0.699	-0.123	Bulletin 17B[5]	-0.330	7,530	MGBT	0	20	--
48	06026500.20	Jefferson River near Twin Bridges, Montana	7,616	Total	At-site	65	1911–16, 1921–39, 1942–43, 1958–72, 1994–2016	--	3.896	0.197	Weighted	-1.004	-0.123	Bulletin 17B[5]	-0.420	6,050	MGBT	0	18	--
48	06026500.21	Jefferson River near Twin Bridges, Montana	7,616	Total	MOVE.3	111	BP 1895, 1897–1905, 1911–16, 1921–26, 1928–2016	--	3.906	0.180	Weighted	-0.611	-0.123	Bulletin 17B[5]	-0.379	6,820	MGBT	0	37	--
64	06036650.10	Jefferson River near Three Forks, Montana	9,558	R (MAJ–dam)	At-site	44	1965–69, 1975, 1979–2016	--	3.908	0.210	Weighted	-1.130	0.078	Bulletin 17B[5]	-0.205	7,220	MGBT	0	18	Yes
64	06036650.11	Jefferson River near Three Forks, Montana	9,558	R (MAJ–dam)	MOVE.3	52	BP 1965–2016	--	3.964	0.166	Weighted	-0.590	0.078	Bulletin 17B[5]	-0.178	8,430	MGBT	0	21	--
64	06036650.20	Jefferson River near Three Forks, Montana	9,558	Total	At-site	80	1895, 1897–1905, 1939–69, 1975, 1979–2016	--	3.919	0.205	Weighted	-0.981	0.078	Bulletin 17B[5]	-0.286	6,910	MGBT	0	28	Yes
64	06036650.21	Jefferson River near Three Forks, Montana	9,558	Total	MOVE.3	111	BP 1895, 1897–1905, 1911–16, 1921–26, 1928–2016	--	3.948	0.184	Weighted	-0.606	0.078	Bulletin 17B[5]	-0.283	7,610	MGBT	0	39	--
69	06037500.00	Madison River near West Yellowstone, Montana	435	U	At-site	90	1914–17, 1919–73, 1984–86, 1989–2016	--	3.134	0.124	Weighted	0.146	-0.145	Bulletin 17B[5]	0.103	--	MGBT	0	0	Yes
70	06038500.10	Madison River below Hebgen Lake, near Grayling, Montan	931	R (MAJ–dam)	At-site	56	1960–67, 1969–2016	reg	3.366	0.129	Station	0.184	-0.142	--	0.184	--	MGBT	0	0	--
72	06038800.10	Madison River at Kirby Ranch, near Cameron, Montan	1,092	R (MAJ–dam)	At-site	35	1960–61, 1963, 1985–2016	reg	3.426	0.175	Station	-0.013	-0.181	--	-0.013	--	MGBT	0	0	--
72	06038800.11	Madison River at Kirby Ranch, near Cameron, Montan	1,092	R (MAJ–dam)	MOVE.3	57	BP 1960–2016	reg	3.449	0.164	Station	-0.056	-0.181	--	-0.056	--	MGBT	0	0	--
73	06040000.10	Madison River near Cameron, Montana	1,665	R (MAJ–dam)	At-site	13	1960–63, 1968–70, 2011–16	--	3.625	0.197	Weighted	-0.521	-0.134	Bulletin 17B[5]	-0.215	--	MGBT	0	0	--
73	06040000.11	Madison River near Cameron, Montana	1,665	R (MAJ–dam)	MOVE.3	57	BP 1960–2016	--	3.631	0.174	Weighted	-0.312	-0.134	Bulletin 17B[5]	-0.274	--	MGBT	0	0	--
75	06041000.10	Madison River below Ennis Lake, near McAllister, Montan	2,150	R (MAJ–dam)	At-site	57	1960–2016	reg	3.670	0.154	Station	-0.274	-0.041	--	-0.274	--	MGBT	0	0	--
76	06042500.11	Madison River near Three Forks, Montan	2,453	R (MAJ–dam)	MOVE.3	57	BP 1960–2016	reg	3.675	0.158	Station	-0.286	0.072	--	-0.286	--	MGBT	0	0	--

[1]The streamgage identification number and analysis designation is defined by XXXXXXXX.AB,
where,
XXXXXXXX is the streamgage identification number;
A is the regulation status for the analysis period; and
B is the type of peak-flow frequency analysis.

Values of A (regulation status) are defined as:
A = 0, unregulated;
A = 1, regulated by major regulation; and
A =2, total; that is, the combined unregulated and regulated peak-flow records for streamgages with peak-flow records before and after the start of regulation (see footnote 2).

Values of B (type of peak-flow frequency analysis) are defined as:
B = 0, at-site peak-flow frequency analysis conducted on recorded data;
B = 1, peak-flow frequency analysis conducted on combined recorded and synthesized data; synthesized data from Maintenance of Variance Extension Type III (MOVE.3) record extension procedure;
B =2, peak-flow frequency analysis determined from regional regression equations (RREs); RRE frequency results not presented in this report; and
B = 3, at-site peak-flow frequency analysis weighted with results from RREs; distributional parameters not available for RRE weighted frequency analyses.

[2]Abbreviations for regulation status are defined as follows:
U, unregulated, where the cumulative drainage area upstream from all dams is less than 20 percent of the drainage area of the streamgage.
R (MAJ–dam): major dam regulation, where a single upstream dam has a drainage area that exceeds 20 percent of the drainage area of the streamgage.
R (MAJ–canal): major diversion canal regulation, where a large diversion canal is known to be located on the channel upstream from the streamgage.
R (MIN–dams): minor dam regulation, where the cumulative drainage area of all upstream dams exceeds 20 percent of the drainage area of the streamgage, but no single upstream dam has a drainage area that exceeds 20 percent of the drainage area of the streamgage.
Total: the combined unregulated and regulated peak-flow records for streamgages with peak-flow records before and after the start of regulation, . The "Total" peak-flow frequency analysis is provided in cases where major regulation affects less than 50 percent of the drainage area of the streamgage and there is uncertainty in the effects of regulation on specific peak-flow characteristics. Also, the "Total" peak-flow frequency analysis is the only peak-flow frequency analysis provided in cases of minor dam regulation.

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

[4]Standard Bulletin 17C (England and others, 2017) procedures are considered to be the use of the weighted skew and the use of the multiple Grubbs-Beck low-outlier test (MGBT) for identifying PILFs. In cases where either the station skew or a manual (analyst-selected) PILF threshold was used, the peak-flow frequency analysis was considered to deviate from standard Bulletin 17C procedures. The abbreviations for the reasons for deviation from standard Bulletin 17C procedures are defined as follows:
reg: the peak-flow records are affected by major dam or canal regulation;
upper tail: the probability plots of the peak-flow records deviate from typical patterns in the upper tail of the frequency curve, generally because of mixed population characteristics; and
lower tail: the probability plots of the peak-flow records deviate from typical patterns in the lower tail of the frequency curve at high annual exceedance probabilities (greater than about 50.0 percent).
[5]U.S. Interagency Advisory Council on Water Data, 1982, Guidelines for determining flood flow frequency: Hydrology Subcommittee, Bulletin 17B, appendixes 1–14, 28 p.

Table 1–6. Documentation regarding the Maintenance of Variance Extension Type III (MOVE.3) record extension procedure for selected streamgages.

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. --, not applicable]

Target streamgage for which peak flows were synthesized									Index streamgage(s) used for synthesis of peak flows								
Map number (fig. 1)	Streamgage identification number	Streamgage Name	Contributing drainage area, in square miles	Number of recorded peak flows	Water years of recorded peak flows	Number of years requiring synthesis of peak flows	Water years requiring synthesis of peak flows	Percentage of record synthesized	Streamgage identification number	Streamgage Name	Contributing drainage area, in square miles	Number of peak flows synthesized based on this streamgage	Number of concurrent recorded peak flows for target and index streamgages	Pearson correlation coefficient for concurrent peak flows for target and index streamgages	Weighted average Pearson correlation coefficient[1]	Estimated[2] standard error of MOVE.3 analysis, in percent	Effective record length for the synthesized peak flows, in years
Streamgages on the Ruby River—base period 1939–2016 (78 years)																	
35	06020600	Ruby River below reservoir, near Alder, Montana	595	54	1963–2016	24	1939–62	30.8	06019500	Ruby River above reservoir, near Alder, Montana	534	24	54	0.87	0.87	24.4	11.5
37	06021500	Ruby River at Laurin, Montana	643	14	1947–60	64	1939–46, 1961–2016	82.1	06019500	Ruby River above reservoir, near Alder, Montana	534	38	14	0.87	0.90	26.1	22.7
									06022000	Ruby River below Ramshorn Creek, near Sheridan, Montana	839	19	7	0.98			
									06023000	Ruby River near Twin Bridges, Montana	970	7	14	0.90			
37B	06022000	Ruby River below Ramshorn Creek, near Sheridan, Montana	839	26	1947–53, 1997–2011, 2013–16	52	1939–46, 1954–96, 2012	66.7	06019500	Ruby River above reservoir, near Alder, Montana	534	8	26	0.73	0.82	45.5	15.8
									06020600	Ruby River below reservoir, near Alder, Montana	595	30	19	0.77			
									06021500	Ruby River at Laurin, Montana	643	7	7	0.98			
									06023000	Ruby River near Twin Bridges, Montana	970	7	9	0.96			
38	06023000	Ruby River near Twin Bridges, Montana	970	25	1942–43, 1947–65, 1980–81, 2015–16	53	1939–41, 1944–46, 1966–79, 1982–2014	67.9	06019500	Ruby River above reservoir, near Alder, Montana	534	36	25	0.73	0.80	31.7	13.6
									06022000	Ruby River below Ramshorn Creek, near Sheridan, Montana	839	17	9	0.96			
Streamgages on the Jefferson River																	
Regulated base period 1965–2016 (52 years)																	
48	06026500	Jefferson River near Twin Bridges, Montana	7,616	65	1911–16, 1921–39, 1942–43, 1958–72, 1994–2016	21	1973–93	40.4	06025500	Big Hole River near Melrose, Montana	2,472	5	31	0.98	0.99	9.0	19.3
									06036650	Jefferson River near Three Forks, Montana	9,558	16	28	0.99			
64	06036650	Jefferson River near Three Forks, Montana	9,558	80	1895, 1897–1905, 1939–69, 1975, 1979–2016	8	1970–74, 1976–78	15.4	06025500	Big Hole River near Melrose, Montana	2,472	5	44	0.97	0.98	15.0	7.2
									06026500	Jefferson River near Twin Bridges, Montana	7,616	3	28	0.99			
Total base period 1895, 1897–1905, 1911–16, 1921–26, 1928–2016 (111 years)																	
48	06026500	Jefferson River near Twin Bridges, Montana	7,616	64	1911–16, 1921–26, 1928–39, 1942–43, 1958–72, 1994–2016	47	1895, 1897–1905, 1940–41, 1944–57, 1973–93	42.3	06025500	Big Hole River near Melrose, Montana	2,472	5	31	0.98	0.99	8.8	41.5
									06036650	Jefferson River near Three Forks, Montana	9,558	42	38	0.99			
64	06036650	Jefferson River near Three Forks, Montana	9,558	80	1895, 1897–1905, 1939–69, 1975, 1979–2016	31	1911–16, 1921–26, 1928–38, 1970–74, 1976–78	27.9	06025500	Big Hole River near Melrose, Montana	2,472	5	44	0.97	0.98	9.6	27.8
									06026500	Jefferson River near Twin Bridges, Montana	7,616	26	38	0.99			
Streamgages on the Madison River—base period 1960–2016 (57 years)																	
72	06038800	Madison River at Kirby Ranch, near Cameron, Montana	1,092	35	1960–61, 1963, 1985–2016	22	1962, 1964–84	38.6	06041000	Madison River below Ennis Lake, near McAllister, Montana	2,150	22	34	0.90	0.90	19.2	11.4
73	06040000	Madison River near Cameron, Montana	1,665	20	1952–58, 1960–63, 1968–70, 2011–16	44	1964–67, 1971–2010	77.2	06041000	Madison River below Ennis Lake, near McAllister, Montana	2,150	44	12	0.98	0.98	8.7	30.0
76	06042500	Madison River near Three Forks, Montana	2,453	16	1894–96, 1929–32, 1942–50	57	1960–2016	100.0	06038500	Madison River below Hebgen Lake, near Grayling, Montana	931	1	9	0.84	0.98	5.4	39.8
									06041000	Madison River below Ennis Lake, near McAllister, Montana	2,150	56	9	0.99			

[1]The weighted average Pearson correlation coefficient was determined by multiplying the number of peak flows synthesized based on an index streamgage times the Pearson correlation coefficent for the index streamgage for each index streamgage. The resultant products then were summed and divided by the total number of synthesized peak flows.

[2]A standard error was calculated based on an ordinary least squares (OLS) formulation of the analysis. That OLS standard error was adjusted to an estimated MOVE.3 formulation by multiplying times the following adjustment factor (Wilbert O. Thomas, Michael Baker International, written commun., November 2016):

$AF_{SE} = (2/[1+\rho])$^0.5,

where,

AF_{SE} is the adjustment factor; and

ρ is the weighted average Pearson correlation coefficient.

Table 1–7. Peak-flow frequency results.

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

Map number (fig. 1)	Streamgage identification number and analysis designation[1]	Streamgage name	Contributing drainage area, in square miles	Regulation status for analysis[2]	Type of peak-flow frequency analysis[3]	Number of peak flows used in the analysis	Water years of peak flows used in the analysis	Frequency analysis incorporates historical information? (if yes, see Table 1-5 for additional information)	Annual peak flow, in cubic feet per second, for indicated annual exceedance probability, in percent								
									50	42.9	20	10	4	2	1	0.5	0.2
31	06018500.10	Beaverhead River near Twin Bridges, Montana	3,618	R (MAJ–dam)	At-site	52	1965–2016	--	696	760	1,050	1,300	1,620	1,870	2,120	2,380	2,730
33	06019500.00	Ruby River above reservoir, near Alder, Montana	534	U	At-site	78	1939–2016	Yes	938	1,000	1,300	1,580	1,990	2,330	2,700	3,120	3,730
35	06020600.10	Ruby River below reservoir, near Alder, Montana	595	R (MAJ–dam)	At-site	54	1963–2016	Yes	916	987	1,310	1,580	1,950	2,230	2,520	2,820	3,230
35	06020600.11	Ruby River below reservoir, near Alder, Montana	595	R (MAJ–dam)	MOVE.3	78	BP 1939–2016	Yes	849	914	1,210	1,470	1,820	2,100	2,390	2,700	3,130
37	06021500.10	Ruby River at Laurin, Montana	643	R (MAJ–dam)	At-site	14	1947–60	--	366	407	594	754	960	1,120	1,270	1,430	1,640
37	06021500.11	Ruby River at Laurin, Montana	643	R (MAJ–dam)	MOVE.3	78	BP 1939–2016	Yes	376	434	746	1,080	1,610	2,100	2,670	3,340	4,400
37B	06022000.10	Ruby River below Ramshorn Creek, near Sheridan, Montana	839	R (MAJ–dam)	At-site	26	1947–53, 1997–2011, 2013–16	--	499	566	904	1,240	1,730	2,150	2,620	3,150	3,920
37B	06022000.11	Ruby River below Ramshorn Creek, near Sheridan, Montana	839	R (MAJ–dam)	MOVE.3	78	BP 1939–2016	Yes	522	592	956	1,320	1,880	2,360	2,900	3,520	4,450
38	06023000.10	Ruby River near Twin Bridges, Montana	970	R (MAJ–dam)	At-site	25	1942–43, 1947–65, 1980–81, 2015–16	--	648	710	987	1,220	1,520	1,750	1,980	2,210	2,520
38	06023000.11	Ruby River near Twin Bridges, Montana	970	R (MAJ–dam)	MOVE.3	78	BP 1939–2016	Yes	680	763	1,180	1,590	2,200	2,720	3,300	3,940	4,920
48	06026500.10	Jefferson River near Twin Bridges, Montana	7,616	R (MAJ–dam)	At-site	31	1965–72, 1994–2016	--	8,620	9,160	11,400	13,100	15,100	16,500	17,800	19,100	20,700
48	06026500.11	Jefferson River near Twin Bridges, Montana	7,616	R (MAJ–dam)	MOVE.3	52	BP 1965–2016	--	8,430	8,990	11,300	13,000	15,000	16,400	17,600	18,900	20,400
48	06026500.20	Jefferson River near Twin Bridges, Montana	7,616	Total	At-site	65	1911–16, 1921–39, 1942–43, 1958–72, 1994–2016	--	8,130	8,800	11,600	13,800	16,300	18,000	19,700	21,200	23,200
48	06026500.21	Jefferson River near Twin Bridges, Montana	7,616	Total	MOVE.3	111	BP 1895, 1897–1905, 1911–16, 1921–26, 1928–2016	--	8,260	8,880	11,500	13,400	15,700	17,300	18,800	20,200	22,000
64	06036650.10	Jefferson River near Three Forks, Montana	9,558	R (MAJ–dam)	At-site	44	1965–69, 1975, 1979–2016	Yes	8,220	8,960	12,200	14,900	18,200	20,700	23,200	25,600	28,900
64	06036650.11	Jefferson River near Three Forks, Montana	9,558	R (MAJ–dam)	MOVE.3	52	BP 1965–2016	--	9,300	9,950	12,700	14,900	17,500	19,400	21,300	23,100	25,400
64	06036650.20	Jefferson River near Three Forks, Montana	9,558	Total	At-site	80	1895, 1897–1905, 1939–69, 1975, 1979–2016	Yes	8,490	9,220	12,400	14,900	18,000	20,300	22,500	24,600	27,400
64	06036650.21	Jefferson River near Three Forks, Montana	9,558	Total	MOVE.3	111	BP 1895, 1897–1905, 1911–16, 1921–26, 1928–2016	--	9,040	9,750	12,700	15,000	17,800	19,800	21,700	23,600	26,000
69	06037500.00	Madison River near West Yellowstone, Montana	435	U	At-site	90	1914–17, 1919–73, 1984–86, 1989–2016	Yes	1,360	1,430	1,730	1,970	2,270	2,480	2,700	2,920	3,210
70	06038500.10	Madison River below Hebgen Lake, near Grayling, Montana	931	R (MAJ–dam)	At-site	56	1960–67, 1969–2016	--	2,300	2,430	2,980	3,420	3,980	4,400	4,830	5,260	5,840
72	06038800.10	Madison River at Kirby Ranch, near Cameron, Montana	1,092	R (MAJ–dam)	At-site	35	1960–61, 1963, 1985–2016	--	2,670	2,860	3,740	4,460	5,380	6,070	6,770	7,480	8,440
72	06038800.11	Madison River at Kirby Ranch, near Cameron, Montana	1,092	R (MAJ–dam)	MOVE.3	57	BP 1960–2016	--	2,820	3,020	3,870	4,550	5,410	6,040	6,660	7,290	8,120
73	06040000.10	Madison River near Cameron, Montana	1,665	R (MAJ–dam)	At-site	13	1960–63, 1968–70, 2011–16	--	4,290	4,650	6,200	7,460	9,010	10,100	11,300	12,400	13,800
73	06040000.11	Madison River near Cameron, Montana	1,665	R (MAJ–dam)	MOVE.3	57	BP 1960–2016	--	4,350	4,670	6,010	7,050	8,290	9,160	10,000	10,800	11,900
75	06041000.10	Madison River below Ennis Lake, near McAllister, Montana	2,150	R (MAJ–dam)	At-site	57	1960–2016	--	4,760	5,060	6,330	7,290	8,420	9,200	9,940	10,700	11,600
76	06042500.11	Madison River near Three Forks, Montana	2,453	R (MAJ–dam)	MOVE.3	57	BP 1960–2016	--	4,810	5,130	6,450	7,440	8,600	9,420	10,200	10,900	11,900

[1]The streamgage identification number and analysis designation is defined by XXXXXXXX.AB,
where,
XXXXXXXX is the streamgage identification number;
A is the regulation status for the analysis period; and
B is the type of peak-flow frequency analysis.

Values of A (regulation status) are defined as:
A = 0, unregulated;
A = 1, regulated by major regulation; and
A =2, total; that is, the combined unregulated and regulated peak-flow records for streamgages with peak-flow records before and after the start of regulation (see footnote 2).

Values of B (type of peak-flow frequency analysis) are defined as:
B = 0, at-site peak-flow frequency analysis conducted on recorded data;
B = 1, peak-flow frequency analysis conducted on combined recorded and synthesized data; synthesized data from Maintenance of Variance Extension Type III (MOVE.3) record extension procedure;
B =2, peak-flow frequency analysis determined from regional regression equations (RREs); RRE frequency results not presented in this report; and
B = 3, at-site peak-flow frequency analysis weighted with results from RREs; distributional parameters not available for RRE weighted frequency analyses.

06042500.11 Madison River near Three Forks, Montana
Analysis for regulated period of record
Analysis period of record, water years: 1960–2016
Peak-flow frequency analysis conducted on recorded and synthesized data

Table 1-1 Table 1-2 Table 1-3 Table 1-4 Table 1-5 Table 1-6 Table 1-7 Table 1-8

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. PILF; potentially influential low flow; MGBT, multiple Grubbs-Beck test]

Contributing drainage area, in square miles									Type of peak-flow frequency analysis
2,453									MOVE.3
Peak flow, in cubic feet per second, for indicated annual exceedance probability (bold values), in percent									
	50	**42.9**	**20**	**10**	**4**	**2**	**1.0**	**0.5**	**0.2**
	4,810	5,130	6,450	7,440	8,600	9,420	10,200	10,900	11,900
Upper and lower 90-percent confidence intervals, in cubic feet per second, for indicated annual exceedance probability, in percent									
	50	**42.9**	**20**	**10**	**4**	**2**	**1.0**	**0.5**	**0.2**
	5,500	5,860	7,420	8,870	11,000	12,700	14,400	16,300	19,100
	4,190	4,480	5,640	6,470	7,340	7,810	8,130	8,390	8,560

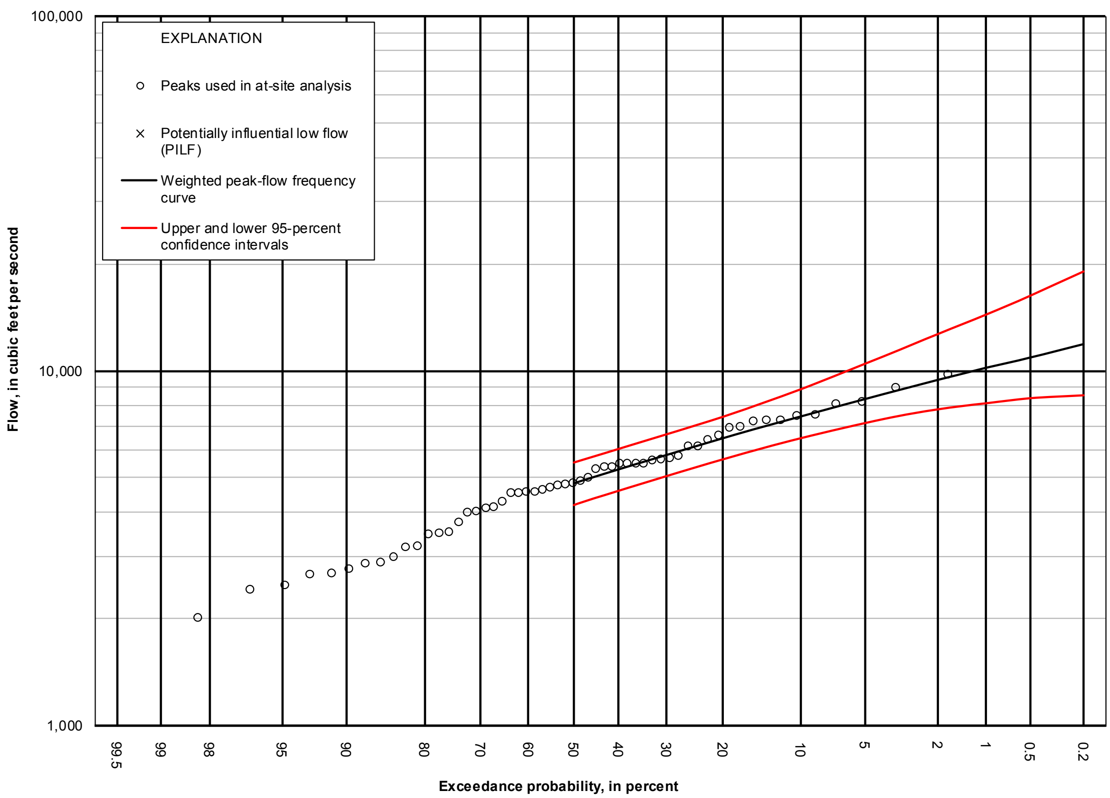

Figure 1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and HIrsch, 2002) and peak-flow frequency curve

[1]Peak flows with a value of zero are not plotted in figure 1 .

[2]In cases where the month, day, or both are not present in the date of a peak flow (as indicated by adjacent slash marks with no intervening values), the month, day, or both are unknown.

[3]Flood-frequency results not reported because of too many values less than the PILF threshold used in the at-site analysis.

[4]Definitions of peak-flow designations used in analysis include:

PT definition: The peak flow is used to define perception thresholds in ungaged historical periods;

Opportunistic: The peak flow was excluded from the analysis because it is outside of the systematic record and was of insufficient magnitude to determine nonexceedance during an ungaged period;

PILF: The peak flow was identified as a potentially influential low flow;

England, J.F. Jr., Cohn, T.A., Faber, B.A., Stedinger, J.R., Thomas Jr., W.O., Veilleux, A.G., Kiang, J.E., and Mason, R.R., 2017, Guidelines for Determining Flood Flow Frequency – Bulletin 17C: U.S. Geological Survey Techniques and Methods book 4, chap. B5, 167 p., https://dx.doi.org/10.3133/tm4–B5/, accessed October 2, 2017 at https://acwi.gov/hydrology/Frequency/b17c/bulletin17c-draft-for-soh-31Aug2017.pdf.

06042500.11 Madison River near Three Forks, Montana
Analysis for regulated period of record
Analysis period of record, water years: 1960–2016
Peak-flow frequency analysis conducted on recorded and synthesized data

Table 1-1 Table 1-2 Table 1-3 Table 1-4 Table 1-5 Table 1-6 Table 1-7 Table 1-8

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends.]

Peak-flow data[2]					Ranked (largest to smallest) peak-flow data[2]				
Water year	Date[3]	Peak flow, in cubic feet per second	Gage height, in feet	Peak-flow designation in analysis[4]	Water year	Date[3]	Peak flow, in cubic feet per second	Gage height, in feet	Peak-flow designation in analysis[4]
1960	//1960	4,510	--	Synthesized	1970	//1970	9,750	--	Synthesized
1961	//1961	2,010	--	Synthesized	1971	//1971	8,910	--	Synthesized
1962	//1962	4,250	--	Synthesized	1996	//1996	8,140	--	Synthesized
1963	//1963	4,780	--	Synthesized	1997	//1997	8,060	--	Synthesized
1964	//1964	5,750	--	Synthesized	1995	//1995	7,500	--	Synthesized
1965	//1965	4,600	--	Synthesized	1993	//1993	7,440	--	Synthesized
1966	//1966	3,490	--	Synthesized	2011	//2011	7,230	--	Synthesized
1967	//1967	6,100	--	Synthesized	1974	//1974	7,210	--	Synthesized
1968	//1968	5,340	--	Synthesized	1986	//1986	7,180	--	Synthesized
1969	//1969	6,570	--	Synthesized	1998	//1998	6,940	--	Synthesized
1970	//1970	9,750	--	Synthesized	1991	//1991	6,890	--	Synthesized
1971	//1971	8,910	--	Synthesized	1969	//1969	6,570	--	Synthesized
1972	//1972	5,440	--	Synthesized	1984	//1984	6,360	--	Synthesized
1973	//1973	3,960	--	Synthesized	1982	//1982	6,110	--	Synthesized
1974	//1974	7,210	--	Synthesized	1967	//1967	6,100	--	Synthesized
1975	//1975	5,330	--	Synthesized	1964	//1964	5,750	--	Synthesized
1976	//1976	4,670	--	Synthesized	2014	//2014	5,650	--	Synthesized
1977	//1977	2,970	--	Synthesized	2010	//2010	5,630	--	Synthesized
1978	//1978	3,740	--	Synthesized	1999	//1999	5,590	--	Synthesized
1979	//1979	4,010	--	Synthesized	2006	//2006	5,470	--	Synthesized
1980	//1980	4,120	--	Synthesized	2008	//2008	5,470	--	Synthesized
1981	//1981	4,990	--	Synthesized	1983	//1983	5,450	--	Synthesized
1982	//1982	6,110	--	Synthesized	1972	//1972	5,440	--	Synthesized
1983	//1983	5,450	--	Synthesized	1968	//1968	5,340	--	Synthesized
1984	//1984	6,360	--	Synthesized	1975	//1975	5,330	--	Synthesized
1985	//1985	3,190	--	Synthesized	2002	//2002	5,260	--	Synthesized
1986	//1986	7,180	--	Synthesized	1981	//1981	4,990	--	Synthesized
1987	//1987	2,400	--	Synthesized	2012	//2012	4,880	--	Synthesized
1988	//1988	2,760	--	Synthesized	1990	//1990	4,800	--	Synthesized
1989	//1989	2,860	--	Synthesized	1963	//1963	4,780	--	Synthesized
1990	//1990	4,800	--	Synthesized	2003	//2003	4,730	--	Synthesized
1991	//1991	6,890	--	Synthesized	1976	//1976	4,670	--	Synthesized
1992	//1992	2,660	--	Synthesized	1965	//1965	4,600	--	Synthesized
1993	//1993	7,440	--	Synthesized	2015	//2015	4,550	--	Synthesized
1994	//1994	3,170	--	Synthesized	2005	//2005	4,530	--	Synthesized
1995	//1995	7,500	--	Synthesized	1960	//1960	4,510	--	Synthesized
1996	//1996	8,140	--	Synthesized	2000	//2000	4,510	--	Synthesized
1997	//1997	8,060	--	Synthesized	1962	//1962	4,250	--	Synthesized
1998	//1998	6,940	--	Synthesized	1980	//1980	4,120	--	Synthesized
1999	//1999	5,590	--	Synthesized	2009	//2009	4,100	--	Synthesized
2000	//2000	4,510	--	Synthesized	1979	//1979	4,010	--	Synthesized
2001	//2001	2,480	--	Synthesized	1973	//1973	3,960	--	Synthesized
2002	//2002	5,260	--	Synthesized	1978	//1978	3,740	--	Synthesized
2003	//2003	4,730	--	Synthesized	1966	//1966	3,490	--	Synthesized
2004	//2004	3,480	--	Synthesized	2004	//2004	3,480	--	Synthesized
2005	//2005	4,530	--	Synthesized	2007	//2007	3,440	--	Synthesized
2006	//2006	5,470	--	Synthesized	1985	//1985	3,190	--	Synthesized
2007	//2007	3,440	--	Synthesized	1994	//1994	3,170	--	Synthesized
2008	//2008	5,470	--	Synthesized	1977	//1977	2,970	--	Synthesized
2009	//2009	4,100	--	Synthesized	2013	//2013	2,880	--	Synthesized
2010	//2010	5,630	--	Synthesized	1989	//1989	2,860	--	Synthesized
2011	//2011	7,230	--	Synthesized	1988	//1988	2,760	--	Synthesized
2012	//2012	4,880	--	Synthesized	2016	//2016	2,680	--	Synthesized
2013	//2013	2,880	--	Synthesized	1992	//1992	2,660	--	Synthesized
2014	//2014	5,650	--	Synthesized	2001	//2001	2,480	--	Synthesized
2015	//2015	4,550	--	Synthesized	1987	//1987	2,400	--	Synthesized
2016	//2016	2,680	--	Synthesized	1961	//1961	2,010	--	Synthesized

06041000.10 Madison River below Ennis Lake, near McAllister, Montana
Analysis for regulated period of record
Analysis period of record, water years: 1960–2016
At-site peak-flow frequency analysis conducted on recorded data

Table 1-1 Table 1-2 Table 1-3 Table 1-4 Table 1-5 Table 1-6 Table 1-7 Table 1-8

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. PILF; potentially influential low flow; MGBT, multiple Grubbs-Beck test]

Contributing drainage area, in square miles	Number of recorded peak flows used in the analysis	Skew type used in analysis	Type of PILF threshold[1]	PILF threshold, in cubic feet per second				Type of peak-flow frequency analysis
2,150	57	Station	MGBT	--				At-site
Peak flow, in cubic feet per second, for indicated annual exceedance probability (bold values), in percent								
	50	**42.9**	**20**	**10**	**4**	**2**	**1.0**	**0.5**	**0.2**
	4,760	5,060	6,330	7,290	8,420	9,200	9,940	10,700	11,600
Upper and lower 90-percent confidence intervals, in cubic feet per second, for indicated annual exceedance probability, in percent									
	50	**42.9**	**20**	**10**	**4**	**2**	**1.0**	**0.5**	**0.2**
	5,270	5,600	7,050	8,340	10,100	11,500	13,000	14,600	16,800
	4,300	4,580	5,740	6,580	7,480	8,010	8,440	8,780	9,150

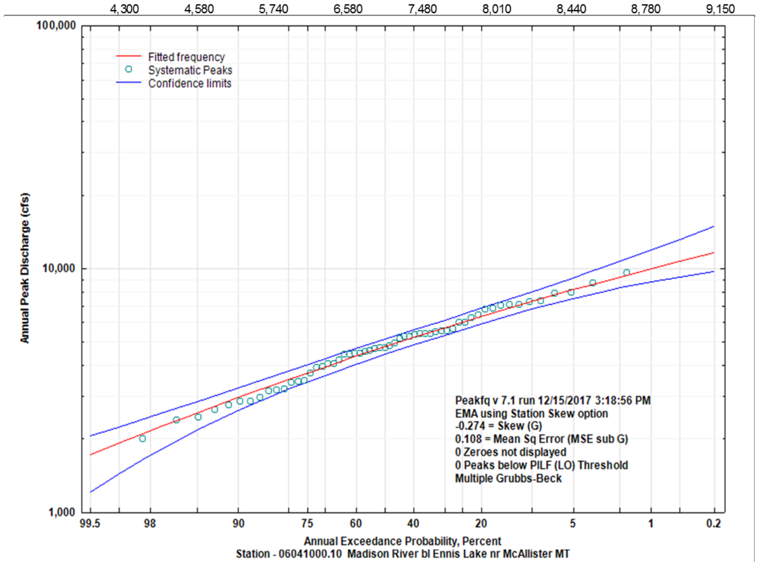

Figure 1. Annual peak flows (probability plotting positions) and peak-flow frequency curve.

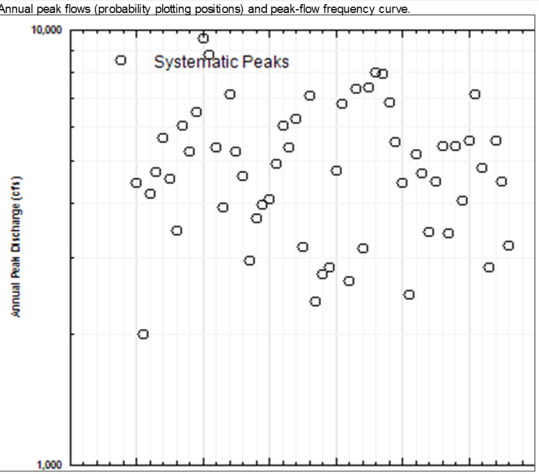

Figure 2. Annual peak flows and perception thresholds.

[1]Definitions of types of PILF thresholds include:
MGBT: PILF threshold calculated by using the multiple Grubbs-Beck Test as specifed in Bulletin 17C (England and others, 2016);
Manual: PILF threshold based on a systematic peak flow selected by the peak-flow frequency analyst.

[2]Peak-flow data with a value of zero are not plotted in figures 1 or 2.
[3]In cases where the month, day, or both are not present in the date of a peak flow (as indicated by adjacent slash marks with no intervening values), the month, day, or both are unknown.
[4]Definitions of peak-flow designations used in analysis include:
PT definition: The peak flow is used to define perception thresholds in ungaged historical periods;
Opportunistic: The peak flow was excluded from the analysis because it is outside of the systematic record and was of insufficient magnitude to determine nonexceedance during an ungaged period;
PILF: The peak flow was identified as a potentially influential low flow;
Synthesized: The peak flow was synthesized using Maintenance of Variance Extension Type III record extension.

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06041000.10 Madison River below Ennis Lake, near McAllister, Montana
Analysis for regulated period of record
Analysis period of record, water years: 1960–2016
At-site peak-flow frequency analysis conducted on recorded data

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[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends.]

Peak-flow data[2]					Ranked (largest to smallest) peak-flow data[2]				
Water year	Date[3]	Peak flow, in cubic feet per second	Gage height, in feet	Peak-flow designation in analysis[4]	Water year	Date[3]	Peak flow, in cubic feet per second	Gage height, in feet	Peak-flow designation in analysis[4]
1960	10/25/1959	4,450	5.25		1970	06/12/1970	9,550	8.01	
1961	09/19/1961	2,000	2.87		1971	06/28/1971	8,730	7.92	
1962	06/21/1962	4,200	4.95		1996	06/10/1996	7,980	7.60	
1963	06/16/1963	4,710	5.41		1997	06/06/1997	7,910	7.42	
1964	06/28/1964	5,660	6.19		1995	06/16/1995	7,360	7.11	
1965	06/13/1965	4,540	5.27		1993	05/29/1993	7,300	7.23	
1966	10/19/1965	3,450	4.32		2011	06/24/2011	7,100	7.00	
1967	06/23/1967	6,000	6.45		1974	06/17/1974	7,080	7.04	
1968	06/21/1968	5,260	5.75		1986	06/06/1986	7,050	7.11	
1969	05/28/1969	6,460	6.70		1998	06/27/1998	6,820	6.83	
1970	06/12/1970	9,550	8.01		1991	06/06/1991	6,770	6.93	
1971	06/28/1971	8,730	7.92		1969	05/28/1969	6,460	6.70	
1972	06/08/1972	5,360	6.11		1984	06/21/1984	6,250	6.85	
1973	05/21/1973	3,910	5.03		1982	06/30/1982	6,010	6.63	
1974	06/17/1974	7,080	7.04		1967	06/23/1967	6,000	6.45	
1975	06/26/1975	5,250	6.14		1964	06/28/1964	5,660	6.19	
1976	05/20/1976	4,610	5.60		2014	05/29/2014	5,560	6.14	
1977	11/24/1976	2,940	4.31		2010	06/11/2010	5,540	6.19	
1978	06/07/1978	3,700	4.93		1999	05/31/1999	5,500	6.17	
1979	05/28/1979	3,960	5.13		2006	05/27/2006	5,390	5.90	
1980	06/12/1980	4,070	5.21		2008	06/23/2008	5,390	5.99	
1981	06/02/1981	4,920	5.95		1983	06/12/1983	5,370	6.31	
1982	06/30/1982	6,010	6.63		1972	06/08/1972	5,360	6.11	
1983	06/12/1983	5,370	6.31		1968	06/21/1968	5,260	5.75	
1984	06/21/1984	6,250	6.85		1975	06/26/1975	5,250	6.14	
1985	11/15/1984	3,160	4.68		2002	06/02/2002	5,180	5.96	
1986	06/06/1986	7,050	7.11		1981	06/02/1981	4,920	5.95	
1987	10/13/1986	2,380	3.81		2012	06/05/2012	4,810	5.66	
1988	05/18/1988	2,740	4.29		1990	06/12/1990	4,730	5.68	
1989	05/12/1989	2,840	4.38		1963	06/16/1963	4,710	5.41	
1990	06/12/1990	4,730	5.68		2003	05/31/2003	4,670	5.62	
1991	06/06/1991	6,770	6.93		1976	05/20/1976	4,610	5.60	
1992	07/06/1992	2,640	4.06		1965	06/13/1965	4,540	5.27	
1993	05/29/1993	7,300	7.23		2015	06/07/2015	4,490	5.45	
1994	11/21/1993	3,140	4.51		2005	06/23/2005	4,470	5.48	
1995	06/16/1995	7,360	7.11		1960	10/25/1959	4,450	5.25	
1996	06/10/1996	7,980	7.60		2000	05/30/2000	4,450	5.46	
1997	06/06/1997	7,910	7.42		1962	06/21/1962	4,200	4.95	
1998	06/27/1998	6,820	6.83		1980	06/12/1980	4,070	5.21	
1999	05/31/1999	5,500	6.17		2009	05/29/2009	4,050	5.17	
2000	05/30/2000	4,450	5.46		1979	05/28/1979	3,960	5.13	
2001	05/16/2001	2,460	3.81		1973	05/21/1973	3,910	5.03	
2002	06/02/2002	5,180	5.96		1978	06/07/1978	3,700	4.93	
2003	05/31/2003	4,670	5.62		1966	10/19/1965	3,450	4.32	
2004	06/10/2004	3,440	4.70		2004	06/10/2004	3,440	4.70	
2005	06/23/2005	4,470	5.48		2007	07/23/2007	3,400	4.67	
2006	05/27/2006	5,390	5.90		2016	05/22/2016	3,190	4.40	
2007	07/23/2007	3,400	4.67		1985	11/15/1984	3,160	4.68	
2008	06/23/2008	5,390	5.99		1994	11/21/1993	3,140	4.51	
2009	05/29/2009	4,050	5.17		1977	11/24/1976	2,940	4.31	
2010	06/11/2010	5,540	6.19		2013	07/07/2013	2,850	4.06	
2011	06/24/2011	7,100	7.00		1989	05/12/1989	2,840	4.38	
2012	06/05/2012	4,810	5.66		1988	05/18/1988	2,740	4.29	
2013	07/07/2013	2,850	4.06		1992	07/06/1992	2,640	4.06	
2014	05/29/2014	5,560	6.14		2001	05/16/2001	2,460	3.81	
2015	06/07/2015	4,490	5.45		1987	10/13/1986	2,380	3.81	
2016	05/22/2016	3,190	4.40		1961	09/19/1961	2,000	2.87	

06040000.11 Madison River near Cameron, Montana
Analysis for regulated period of record
Analysis period of record, water years: 1960–2016
Peak-flow frequency analysis conducted on recorded and synthesized data

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[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. PILF; potentially influential low flow; MGBT, multiple Grubbs-Beck test]

Contributing drainage area, in square miles									Type of peak-flow frequency analysis
1,665									MOVE.3
Peak flow, in cubic feet per second, for indicated annual exceedance probability (bold values), in percent									
	50	**42.9**	**20**	**10**	**4**	**2**	**1.0**	**0.5**	**0.2**
	4,350	4,670	6,010	7,050	8,290	9,160	10,000	10,800	11,900
Upper and lower 90-percent confidence intervals, in cubic feet per second, for indicated annual exceedance probability, in percent									
	50	**42.9**	**20**	**10**	**4**	**2**	**1.0**	**0.5**	**0.2**
	5,000	5,370	7,010	8,510	10,700	12,500	14,500	16,600	19,600
	3,750	4,040	5,220	6,060	6,980	7,520	7,940	8,280	8,590

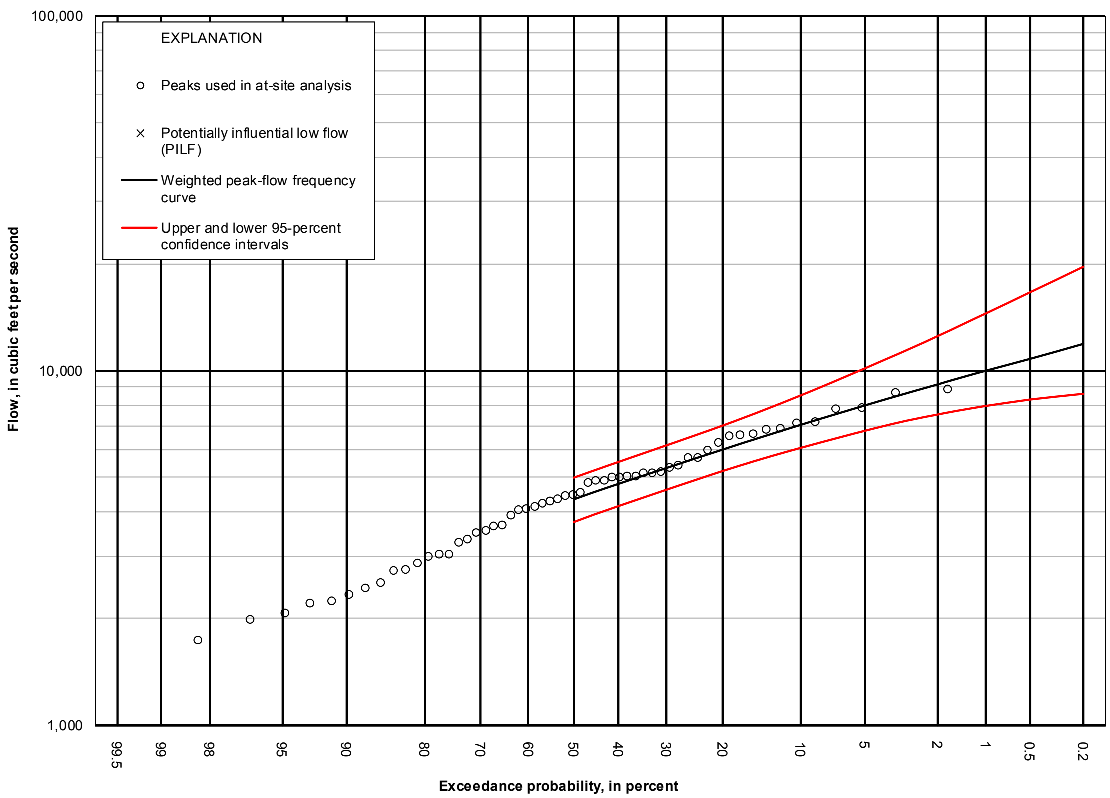

Figure 1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and HIrsch, 2002) and peak-flow frequency curve

[1]Peak flows with a value of zero are not plotted in figure 1 .
[2]In cases where the month, day, or both are not present in the date of a peak flow (as indicated by adjacent slash marks with no intervening values), the month, day, or both are unknown.
[3]Flood-frequency results not reported because of too many values less than the PILF threshold used in the at-site analysis.
[4]Definitions of peak-flow designations used in analysis include:
PT definition: The peak flow is used to define perception thresholds in ungaged historical periods;
Opportunistic: The peak flow was excluded from the analysis because it is outside of the systematic record and was of insufficient magnitude to determine nonexceedance during an ungaged period;
PILF: The peak flow was identified as a potentially influential low flow;

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06040000.11 Madison River near Cameron, Montana
Analysis for regulated period of record
Analysis period of record, water years: 1960–2016
Peak-flow frequency analysis conducted on recorded and synthesized data

Table 1-1 Table 1-2 Table 1-3 Table 1-4 Table 1-5 Table 1-6 Table 1-7 Table 1-8

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends.]

Peak-flow data[2]					Ranked (largest to smallest) peak-flow data[2]				
Water year	Date[3]	Peak flow, in cubic feet per second	Gage height, in feet	Peak-flow designation in analysis[4]	Water year	Date[3]	Peak flow, in cubic feet per second	Gage height, in feet	Peak-flow designation in analysis[4]
1960	10/24/1959	4,890	4.09		1970	06/11/1970	8,830	5.31	
1961	05/30/1961	1,730	2.75		1971	//1971	8,650	--	Synthesized
1962	06/21/1962	3,330	2.00		1996	//1996	7,820	--	Synthesized
1963	06/15/1963	4,430	3.87		1997	//1997	7,740	--	Synthesized
1964	//1964	5,300	--	Synthesized	1995	//1995	7,130	--	Synthesized
1965	//1965	4,120	--	Synthesized	1993	//1993	7,070	--	Synthesized
1966	//1966	3,020	--	Synthesized	1974	//1974	6,820	--	Synthesized
1967	//1967	5,660	--	Synthesized	1986	//1986	6,790	--	Synthesized
1968	06/13/1968	5,130	4.13		2011	06/24/2011	6,600	4.83	
1969	05/28/1969	6,220	4.38		1998	//1998	6,540	--	Synthesized
1970	06/11/1970	8,830	5.31		1991	//1991	6,490	--	Synthesized
1971	//1971	8,650	--	Synthesized	1969	05/28/1969	6,220	4.38	
1972	//1972	4,980	--	Synthesized	1984	//1984	5,930	--	Synthesized
1973	//1973	3,480	--	Synthesized	1982	//1982	5,670	--	Synthesized
1974	//1974	6,820	--	Synthesized	1967	//1967	5,660	--	Synthesized
1975	//1975	4,860	--	Synthesized	2014	05/29/2014	5,370	4.39	
1976	//1976	4,200	--	Synthesized	1964	//1964	5,300	--	Synthesized
1977	//1977	2,520	--	Synthesized	2010	//2010	5,170	--	Synthesized
1978	//1978	3,270	--	Synthesized	1968	06/13/1968	5,130	4.13	
1979	//1979	3,530	--	Synthesized	1999	//1999	5,130	--	Synthesized
1980	//1980	3,640	--	Synthesized	2006	//2006	5,010	--	Synthesized
1981	//1981	4,520	--	Synthesized	2008	//2008	5,010	--	Synthesized
1982	//1982	5,670	--	Synthesized	1983	//1983	4,990	--	Synthesized
1983	//1983	4,990	--	Synthesized	1972	//1972	4,980	--	Synthesized
1984	//1984	5,930	--	Synthesized	1960	10/24/1959	4,890	4.09	
1985	//1985	2,740	--	Synthesized	1975	//1975	4,860	--	Synthesized
1986	//1986	6,790	--	Synthesized	2002	//2002	4,790	--	Synthesized
1987	//1987	1,980	--	Synthesized	1981	//1981	4,520	--	Synthesized
1988	//1988	2,330	--	Synthesized	2012	06/05/2012	4,460	4.05	
1989	//1989	2,420	--	Synthesized	1963	06/15/1963	4,430	3.87	
1990	//1990	4,320	--	Synthesized	1990	//1990	4,320	--	Synthesized
1991	//1991	6,490	--	Synthesized	2003	//2003	4,260	--	Synthesized
1992	//1992	2,230	--	Synthesized	1976	//1976	4,200	--	Synthesized
1993	//1993	7,070	--	Synthesized	1965	//1965	4,120	--	Synthesized
1994	//1994	2,720	--	Synthesized	2005	//2005	4,050	--	Synthesized
1995	//1995	7,130	--	Synthesized	2000	//2000	4,030	--	Synthesized
1996	//1996	7,820	--	Synthesized	2015	06/03/2015	3,880	3.82	
1997	//1997	7,740	--	Synthesized	1980	//1980	3,640	--	Synthesized
1998	//1998	6,540	--	Synthesized	2009	//2009	3,620	--	Synthesized
1999	//1999	5,130	--	Synthesized	1979	//1979	3,530	--	Synthesized
2000	//2000	4,030	--	Synthesized	1973	//1973	3,480	--	Synthesized
2001	//2001	2,060	--	Synthesized	1962	06/21/1962	3,330	2.00	
2002	//2002	4,790	--	Synthesized	1978	//1978	3,270	--	Synthesized
2003	//2003	4,260	--	Synthesized	1966	//1966	3,020	--	Synthesized
2004	//2004	3,010	--	Synthesized	2004	//2004	3,010	--	Synthesized
2005	//2005	4,050	--	Synthesized	2007	//2007	2,970	--	Synthesized
2006	//2006	5,010	--	Synthesized	2016	06/08/2016	2,860	3.42	
2007	//2007	2,970	--	Synthesized	1985	//1985	2,740	--	Synthesized
2008	//2008	5,010	--	Synthesized	1994	//1994	2,720	--	Synthesized
2009	//2009	3,620	--	Synthesized	1977	//1977	2,520	--	Synthesized
2010	//2010	5,170	--	Synthesized	1989	//1989	2,420	--	Synthesized
2011	06/24/2011	6,600	4.83		1988	//1988	2,330	--	Synthesized
2012	06/05/2012	4,460	4.05		1992	//1992	2,230	--	Synthesized
2013	05/15/2013	2,190	3.08		2013	05/15/2013	2,190	3.08	
2014	05/29/2014	5,370	4.39		2001	//2001	2,060	--	Synthesized
2015	06/03/2015	3,880	3.82		1987	//1987	1,980	--	Synthesized
2016	06/08/2016	2,860	3.42		1961	05/30/1961	1,730	2.75	

06038800.11 Madison River at Kirby Ranch, near Cameron, Montana
Analysis for regulated period of record
Analysis period of record, water years: 1960–2016
Peak-flow frequency analysis conducted on recorded and synthesized data

Table 1-1 Table 1-2 Table 1-3 Table 1-4 Table 1-5 Table 1-6 Table 1-7 Table 1-8

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. PILF; potentially influential low flow; MGBT, multiple Grubbs-Beck test]

Contributing drainage area, in square miles									Type of peak-flow frequency analysis
1,092									MOVE.3
Peak flow, in cubic feet per second, for indicated annual exceedance probability (bold values), in percent									
	50	**42.9**	**20**	**10**	**4**	**2**	**1.0**	**0.5**	**0.2**
	2,820	3,020	3,870	4,550	5,410	6,040	6,660	7,290	8,120
Upper and lower 90-percent confidence intervals, in cubic feet per second, for indicated annual exceedance probability, in percent									
	50	**42.9**	**20**	**10**	**4**	**2**	**1.0**	**0.5**	**0.2**
	3,210	3,450	4,510	5,550	7,190	8,650	10,300	12,200	15,000
	2,480	2,650	3,380	3,940	4,560	4,960	5,300	5,590	5,920

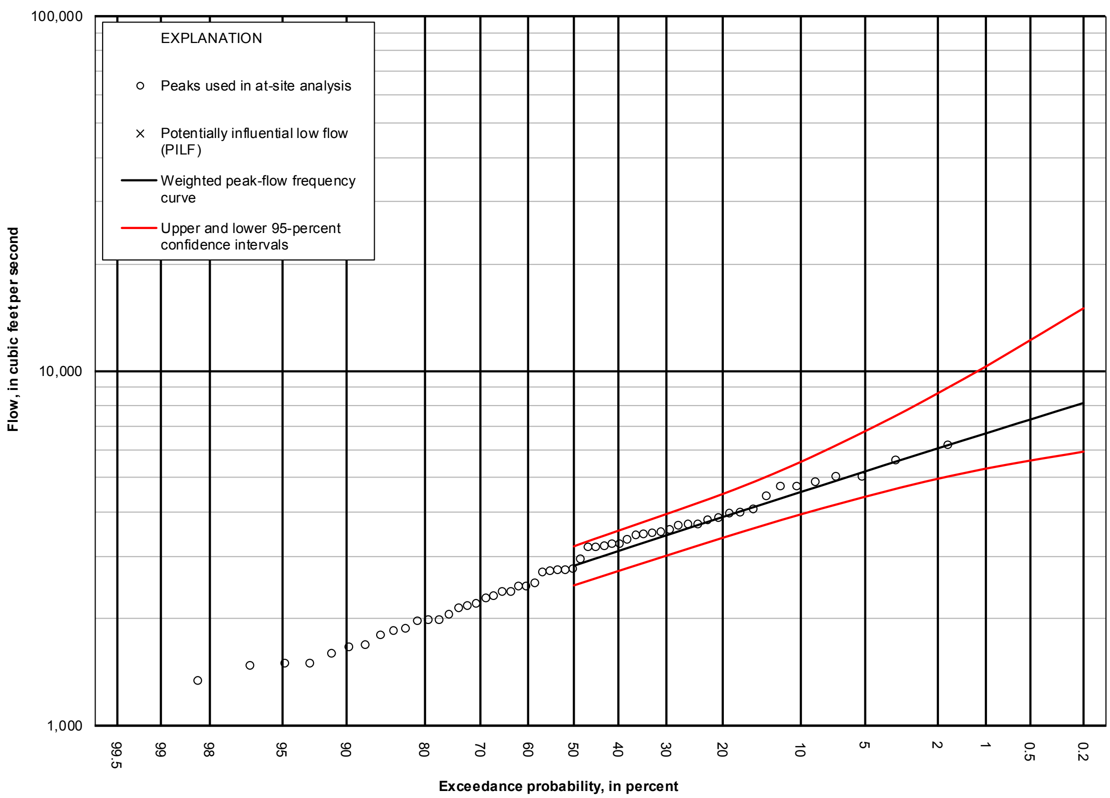

Figure 1. Annual peak flows (plotting positions determined using the Cunnane formulation; Helsel and HIrsch, 2002) and peak-flow frequency curve

[1]Peak flows with a value of zero are not plotted in figure 1 .
[2]In cases where the month, day, or both are not present in the date of a peak flow (as indicated by adjacent slash marks with no intervening values), the month, day, or both are unknown.
[3]Flood-frequency results not reported because of too many values less than the PILF threshold used in the at-site analysis.
[4]Definitions of peak-flow designations used in analysis include:
PT definition: The peak flow is used to define perception thresholds in ungaged historical periods;
Opportunistic: The peak flow was excluded from the analysis because it is outside of the systematic record and was of insufficient magnitude to determine nonexceedance during an ungaged period;
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06038800.11 Madison River at Kirby Ranch, near Cameron, Montana
Analysis for regulated period of record
Analysis period of record, water years: 1960–2016
Peak-flow frequency analysis conducted on recorded and synthesized data

Table 1-1 Table 1-2 Table 1-3 Table 1-4 Table 1-5 Table 1-6 Table 1-7 Table 1-8

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends.]

Peak-flow data[2]					Ranked (largest to smallest) peak-flow data[2]				
Water year	Date[3]	Peak flow, in cubic feet per second	Gage height, in feet	Peak-flow designation in analysis[4]	Water year	Date[3]	Peak flow, in cubic feet per second	Gage height, in feet	Peak-flow designation in analysis[4]
1960	10/23/1959	4,710	3.54		1970	//1970	6,150	--	Synthesized
1961	09/11/1961	1,470	2.12		1971	//1971	5,560	--	Synthesized
1962	//1962	2,460	--	Synthesized	1993	05/31/1993	5,030	3.15	
1963	06/05/1963	3,480	3.07		1986	06/06/1986	5,000	3.14	
1964	//1964	3,430	--	Synthesized	1996	06/07/1996	4,840	3.97	
1965	//1965	2,690	--	Synthesized	1960	10/23/1959	4,710	3.54	
1966	//1966	1,980	--	Synthesized	1997	06/06/1997	4,700	--	
1967	//1967	3,660	--	Synthesized	1974	//1974	4,410	--	Synthesized
1968	//1968	3,170	--	Synthesized	2011	06/24/2011	4,050	3.68	
1969	//1969	3,980	--	Synthesized	1969	//1969	3,980	--	Synthesized
1970	//1970	6,150	--	Synthesized	1995	06/14/1995	3,950	3.50	
1971	//1971	5,560	--	Synthesized	1984	//1984	3,840	--	Synthesized
1972	//1972	3,230	--	Synthesized	1991	06/08/1991	3,780	2.67	
1973	//1973	2,270	--	Synthesized	2008	09/02/2008	3,680	3.49	
1974	//1974	4,410	--	Synthesized	1982	//1982	3,670	--	Synthesized
1975	//1975	3,160	--	Synthesized	1967	//1967	3,660	--	Synthesized
1976	//1976	2,730	--	Synthesized	1998	06/26/1998	3,560	3.40	
1977	//1977	1,660	--	Synthesized	2010	06/10/2010	3,510	3.41	
1978	//1978	2,140	--	Synthesized	1963	06/05/1963	3,480	3.07	
1979	//1979	2,310	--	Synthesized	2006	05/26/2006	3,450	3.38	
1980	//1980	2,380	--	Synthesized	1964	//1964	3,430	--	Synthesized
1981	//1981	2,940	--	Synthesized	1999	06/16/1999	3,340	3.32	
1982	//1982	3,670	--	Synthesized	1983	//1983	3,240	--	Synthesized
1983	//1983	3,240	--	Synthesized	1972	//1972	3,230	--	Synthesized
1984	//1984	3,840	--	Synthesized	2014	05/29/2014	3,200	3.26	
1985	06/02/1985	2,190	1.91		1968	//1968	3,170	--	Synthesized
1986	06/06/1986	5,000	3.14		1975	//1975	3,160	--	Synthesized
1987	07/23/1987	1,790	1.69		1981	//1981	2,940	--	Synthesized
1988	05/17/1988	1,680	1.62		2012	06/06/2012	2,760	3.03	
1989	05/11/1989	1,870	1.74		2015	06/03/2015	2,740	3.02	
1990	06/11/1990	2,380	2.02		1976	//1976	2,730	--	Synthesized
1991	06/08/1991	3,780	2.67		2005	06/22/2005	2,720	3.01	
1992	07/05/1992	1,490	1.50		1965	//1965	2,690	--	Synthesized
1993	05/31/1993	5,030	3.15		2000	05/29/2000	2,520	2.86	
1994	05/29/1994	1,980	1.81		1962	//1962	2,460	--	Synthesized
1995	06/14/1995	3,950	3.50		2009	05/28/2009	2,460	2.88	
1996	06/07/1996	4,840	3.97		1980	//1980	2,380	--	Synthesized
1997	06/06/1997	4,700	--		1990	06/11/1990	2,380	2.02	
1998	06/26/1998	3,560	3.40		1979	//1979	2,310	--	Synthesized
1999	06/16/1999	3,340	3.32		1973	//1973	2,270	--	Synthesized
2000	05/29/2000	2,520	2.86		1985	06/02/1985	2,190	1.91	
2001	07/12/2001	1,330	2.13		2003	05/30/2003	2,170	2.71	
2002	06/02/2002	2,050	2.60		1978	//1978	2,140	--	Synthesized
2003	05/30/2003	2,170	2.71		2002	06/02/2002	2,050	2.60	
2004	07/08/2004	1,490	2.30		1966	//1966	1,980	--	Synthesized
2005	06/22/2005	2,720	3.01		1994	05/29/1994	1,980	1.81	
2006	05/26/2006	3,450	3.38		2007	07/13/2007	1,960	2.60	
2007	07/13/2007	1,960	2.60		1989	05/11/1989	1,870	1.74	
2008	09/02/2008	3,680	3.49		2013	07/15/2013	1,840	2.53	
2009	05/28/2009	2,460	2.88		1987	07/23/1987	1,790	1.69	
2010	06/10/2010	3,510	3.41		1988	05/17/1988	1,680	1.62	
2011	06/24/2011	4,050	3.68		1977	//1977	1,660	--	Synthesized
2012	06/06/2012	2,760	3.03		2016	08/04/2016	1,590	2.34	
2013	07/15/2013	1,840	2.53		1992	07/05/1992	1,490	1.50	
2014	05/29/2014	3,200	3.26		2004	07/08/2004	1,490	2.30	
2015	06/03/2015	2,740	3.02		1961	09/11/1961	1,470	2.12	
2016	08/04/2016	1,590	2.34		2001	07/12/2001	1,330	2.13	

06038500.10 Madison River below Hebgen Lake, near Grayling, Montana
Analysis for regulated period of record
Analysis period of record, water years: 1960–67; 1969–2016
At-site peak-flow frequency analysis conducted on recorded data

Table 1-1 Table 1-2 Table 1-3 Table 1-4 Table 1-5 Table 1-6 Table 1-7 Table 1-8

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. PILF; potentially influential low flow; MGBT, multiple Grubbs-Beck test]

Contributing drainage area, in square miles	Number of recorded peak flows used in the analysis	Skew type used in analysis	Type of PILF threshold[1]	PILF threshold, in cubic feet per second				Type of peak-flow frequency analysis
931	56	Station	MGBT	--				At-site
Peak flow, in cubic feet per second, for indicated annual exceedance probability (bold values), in percent								
50	**42.9**	**20**	**10**	**4**	**2**	**1.0**	**0.5**	**0.2**
2,300	2,430	2,980	3,420	3,980	4,400	4,830	5,260	5,840
Upper and lower 90-percent confidence intervals, in cubic feet per second, for indicated annual exceedance probability, in percent								
50	**42.9**	**20**	**10**	**4**	**2**	**1.0**	**0.5**	**0.2**
2,510	2,650	3,320	3,970	5,010	5,960	7,080	8,390	10,500
2,110	2,230	2,720	3,090	3,530	3,830	4,110	4,380	4,710

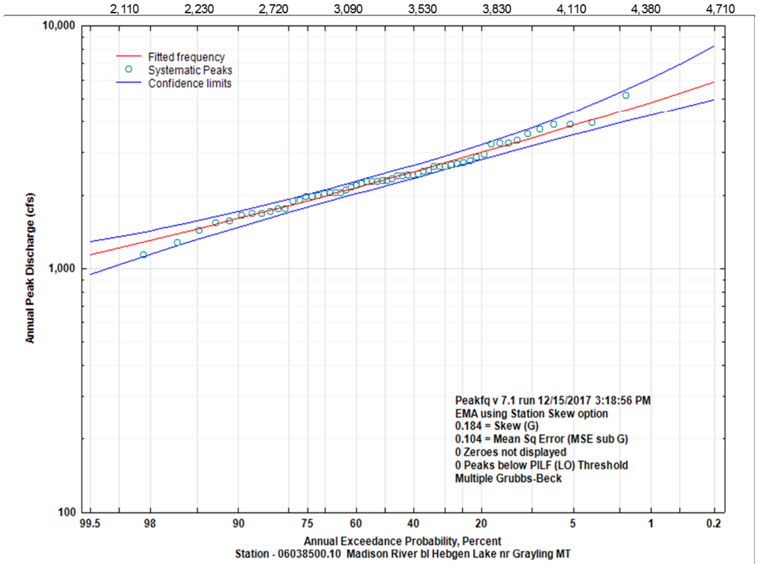

Figure 1. Annual peak flows (probability plotting positions) and peak-flow frequency curve.

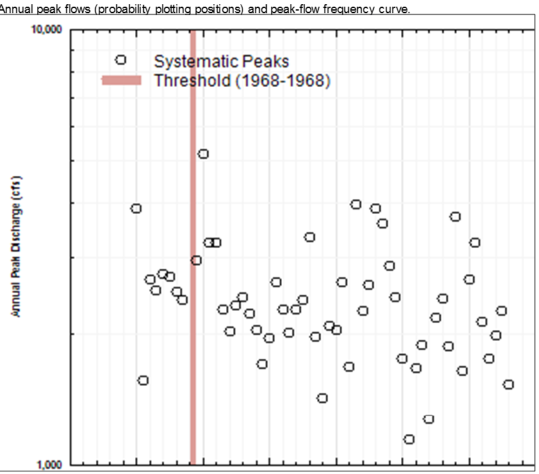

Figure 2. Annual peak flows and perception thresholds.

[1]Definitions of types of PILF thresholds include:
MGBT: PILF threshold calculated by using the multiple Grubbs-Beck Test as specifed in Bulletin 17C (England and others, 2016);
Manual: PILF threshold based on a systematic peak flow selected by the peak-flow frequency analyst.

[2]Peak-flow data with a value of zero are not plotted in figures 1 or 2.
[3]In cases where the month, day, or both are not present in the date of a peak flow (as indicated by adjacent slash marks with no intervening values), the month, day, or both are unknown.
[4]Definitions of peak-flow designations used in analysis include:
PT definition: The peak flow is used to define perception thresholds in ungaged historical periods;
Opportunistic: The peak flow was excluded from the analysis because it is outside of the systematic record and was of insufficient magnitude to determine nonexceedance during an ungaged period;
PILF: The peak flow was identified as a potentially influential low flow;
Synthesized: The peak flow was synthesized using Maintenance of Variance Extension Type III record extension.

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[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends.]

Peak-flow data[2]					Ranked (largest to smallest) peak-flow data[2]				
Water year	Date[3]	Peak flow, in cubic feet per second	Gage height, in feet	Peak-flow designation in analysis[4]	Water year	Date[3]	Peak flow, in cubic feet per second	Gage height, in feet	Peak-flow designation in analysis[4]
1960	11/05/1959	3,880	3.20		1970	06/10/1970	5,170	3.76	
1961	07/05/1961	1,560	1.93		1993	05/27/1993	3,970	3.29	
1962	11/22/1961	2,660	2.59		1960	11/05/1959	3,880	3.20	
1963	06/06/1963	2,510	2.84		1996	06/07/1996	3,880	3.26	
1964	06/19/1964	2,750	2.99		2008	08/31/2008	3,710	3.20	
1965	06/29/1965	2,700	2.86		1997	06/12/1997	3,570	3.15	
1966	11/15/1965	2,500	2.76		1986	06/05/1986	3,340	3.08	
1967	11/04/1966	2,400	2.71		1971	06/28/1971	3,250	3.13	
1969	05/28/1969	2,940	3.01		1972	09/21/1972	3,250	3.13	
1970	06/10/1970	5,170	3.76		2011	06/19/2011	3,230	2.97	
1971	06/28/1971	3,250	3.13		1969	05/28/1969	2,940	3.01	
1972	09/21/1972	3,250	3.13		1998	06/27/1998	2,860	2.87	
1973	11/18/1972	2,270	2.64		1964	06/19/1964	2,750	2.99	
1974	06/25/1974	2,030	2.51		1965	06/29/1965	2,700	2.86	
1975	10/13/1974	2,320	2.61		2010	06/09/2010	2,670	2.79	
1976	10/21/1975	2,420	2.70		1962	11/22/1961	2,660	2.59	
1977	10/12/1976	2,220	2.59		1981	06/10/1981	2,620	2.81	
1978	03/15/1978	2,040	2.48		1991	06/08/1991	2,620	2.81	
1979	10/09/1978	1,710	2.27		1995	06/11/1995	2,600	2.80	
1980	07/03/1980	1,960	2.43		1963	06/06/1963	2,510	2.84	
1981	06/10/1981	2,620	2.81		1966	11/15/1965	2,500	2.76	
1982	06/28/1982	2,280	2.62		1999	06/13/1999	2,430	2.73	
1983	11/19/1982	2,020	2.47		1976	10/21/1975	2,420	2.70	
1984	11/14/1983	2,280	2.62		2006	05/25/2006	2,410	3.69	
1985	11/21/1984	2,400	2.73		1967	11/04/1966	2,400	2.71	
1986	06/05/1986	3,340	3.08		1985	11/21/1984	2,400	2.73	
1987	11/08/1986	1,970	2.46		1975	10/13/1974	2,320	2.61	
1988	08/05/1988	1,430	2.07		1982	06/28/1982	2,280	2.62	
1989	12/13/1988	2,090	2.51		1984	11/14/1983	2,280	2.62	
1990	11/14/1989	2,040	2.51		1973	11/18/1972	2,270	2.64	
1991	06/08/1991	2,620	2.81		1994	11/03/1993	2,260	2.64	
1992	11/18/1991	1,680	2.29		2015	06/02/2015	2,260	2.58	
1993	05/27/1993	3,970	3.29		1977	10/12/1976	2,220	2.59	
1994	11/03/1993	2,260	2.64		2005	06/15/2005	2,180	2.56	
1995	06/11/1995	2,600	2.80		2012	06/07/2012	2,140	2.51	
1996	06/07/1996	3,880	3.26		1989	12/13/1988	2,090	2.51	
1997	06/12/1997	3,570	3.15		1978	03/15/1978	2,040	2.48	
1998	06/27/1998	2,860	2.87		1990	11/14/1989	2,040	2.51	
1999	06/13/1999	2,430	2.73		1974	06/25/1974	2,030	2.51	
2000	05/26/2000	1,750	2.36		1983	11/19/1982	2,020	2.47	
2001	07/09/2001	1,140	1.89		2014	05/29/2014	1,990	2.43	
2002	07/16/2002	1,670	2.28		1987	11/08/1986	1,970	2.46	
2003	07/21/2003	1,890	2.41		1980	07/03/1980	1,960	2.43	
2004	07/07/2004	1,270	2.00		2003	07/21/2003	1,890	2.41	
2005	06/15/2005	2,180	2.56		2007	08/01/2007	1,880	2.40	
2006	05/25/2006	2,410	3.69		2000	05/26/2000	1,750	2.36	
2007	08/01/2007	1,880	2.40		2013	07/14/2013	1,750	2.31	
2008	08/31/2008	3,710	3.20		1979	10/09/1978	1,710	2.27	
2009	05/26/2009	1,640	2.26		1992	11/18/1991	1,680	2.29	
2010	06/09/2010	2,670	2.79		2002	07/16/2002	1,670	2.28	
2011	06/19/2011	3,230	2.97		2009	05/26/2009	1,640	2.26	
2012	06/07/2012	2,140	2.51		1961	07/05/1961	1,560	1.93	
2013	07/14/2013	1,750	2.31		2016	08/02/2016	1,530	2.19	
2014	05/29/2014	1,990	2.43		1988	08/05/1988	1,430	2.07	
2015	06/02/2015	2,260	2.58		2004	07/07/2004	1,270	2.00	
2016	08/02/2016	1,530	2.19		2001	07/09/2001	1,140	1.89	

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Analysis for unregulated period of record
Analysis period of record, water years: 1914–17; 1919–73; 1984–86; 1989–2016
At-site peak-flow frequency analysis conducted on recorded data

Table 1-1 Table 1-2 Table 1-3 Table 1-4 Table 1-5 Table 1-6 Table 1-7 Table 1-8

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. PILF; potentially influential low flow; MGBT, multiple Grubbs-Beck test]

Contributing drainage area, in square miles	Number of recorded peak flows used in the analysis	Skew type used in analysis	Type of PILF threshold[1]	PILF threshold, in cubic feet per second					Type of peak-flow frequency analysis
435	90	Station	MGBT	--					At-site
Peak flow, in cubic feet per second, for indicated annual exceedance probability (bold values), in percent									
	50	**42.9**	**20**	**10**	**4**	**2**	**1.0**	**0.5**	**0.2**
	1,360	1,430	1,730	1,970	2,270	2,480	2,700	2,920	3,210
Upper and lower 90-percent confidence intervals, in cubic feet per second, for indicated annual exceedance probability, in percent									
	50	**42.9**	**20**	**10**	**4**	**2**	**1.0**	**0.5**	**0.2**
	1,440	1,520	1,860	2,160	2,590	2,950	3,330	3,750	4,350
	1,270	1,340	1,620	1,830	2,080	2,240	2,400	2,550	2,730

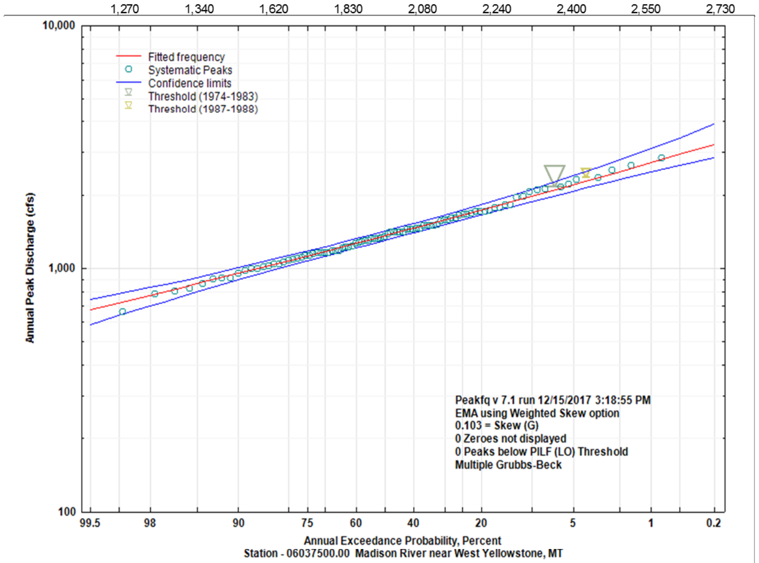

Figure 1. Annual peak flows (probability plotting positions) and peak-flow frequency curve.

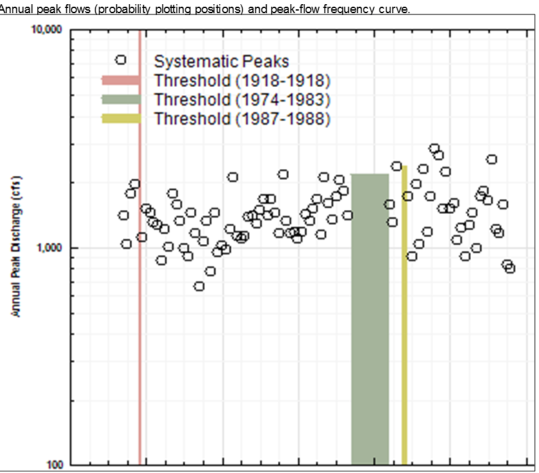

Figure 2. Annual peak flows and perception thresholds.

[1]Definitions of types of PILF thresholds include:
MGBT: PILF threshold calculated by using the multiple Grubbs-Beck Test as specifed in Bulletin 17C (England and others, 2016);
Manual: PILF threshold based on a systematic peak flow selected by the peak-flow frequency analyst.

[2]Peak-flow data with a value of zero are not plotted in figures 1 or 2.
[3]In cases where the month, day, or both are not present in the date of a peak flow (as indicated by adjacent slash marks with no intervening values), the month, day, or both are unknown.
[4]Definitions of peak-flow designations used in analysis include:
PT definition: The peak flow is used to define perception thresholds in ungaged historical periods;
Opportunistic: The peak flow was excluded from the analysis because it is outside of the systematic record and was of insufficient magnitude to determine nonexceedance during an ungaged period;
PILF: The peak flow was identified as a potentially influential low flow;
Synthesized: The peak flow was synthesized using Maintenance of Variance Extension Type III record extension.

England, J.F. Jr., Cohn, T.A., Faber, B.A., Stedinger, J.R., Thomas Jr., W.O., Veilleux, A.G., Kiang, J.E., and Mason, R.R., 2017, Guidelines for Determining Flood Flow Frequency – Bulletin 17C: U.S. Geological Survey Techniques and Methods book 4, chap. B5, 167 p., https://dx.doi.org/10.3133/tm4–B5/, accessed October 2, 2017 at https://acwi.gov/hydrology/Frequency/b17c/bulletin17c-draft-for-soh-31Aug2017.pdf.

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Table 1-1 Table 1-2 Table 1-3 Table 1-4 Table 1-5 Table 1-6 Table 1-7 Table 1-8

[Water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends.]

Peak-flow data[2]					Ranked (largest to smallest) peak-flow data[2]				
Water year	Date[3]	Peak flow, in cubic feet per second	Gage height, in feet	Peak-flow designation in analysis[4]	Water year	Date[3]	Peak flow, in cubic feet per second	Gage height, in feet	Peak-flow designation in analysis[4]
1914	05/21/1914	1,400	--		1996	05/18/1996	2,820	3.78	
1915	06/01/1915	1,040	--		1997	05/18/1997	2,630	3.58	
1916	06/13/1916	1,770	--		2011	06/08/2011	2,520	3.51	
1917	06/10/1917	1,950	--		1986	05/31/1986	2,340	3.56	PT definition
1919	05/11/1919	1,110	--		1993	05/22/1993	2,300	3.43	
1920	06/09/1920	1,510	--		1999	05/29/1999	2,210	3.35	
1921	06/11/1921	1,440	--		1956	05/24/1956	2,150	3.44	PT definition
1922	06/02/1922	1,300	--		1967	05/30/1967	2,110	3.46	
1923	05/23/1923	1,270	--		1943	06/01/1943	2,090	3.43	
1924	05/16/1924	864	--		1971	06/15/1971	2,050	--	
1925	01/03/1925	1,220	--		1991	05/22/1991	1,960	3.27	
1926	05/21/1926	1,010	--		1917	06/10/1917	1,950	--	
1927	06/09/1927	1,770	--		2009	05/20/2009	1,820	3.08	
1928	05/12/1928	1,580	--		1972	06/03/1972	1,810	3.33	
1929	05/25/1929	1,330	2.02		1916	06/13/1916	1,770	--	
1930	05/21/1930	992	--		1927	06/09/1927	1,770	--	
1931	05/16/1931	902	2.39		1995	06/06/1995	1,720	3.05	
1932	05/22/1932	1,450	2.82		2008	05/20/2008	1,710	3.00	
1933	06/02/1933	1,160	2.63		1970	06/08/1970	1,700	--	
1934	06/08/1934	661	2.14		1989	05/10/1989	1,700	--	
1935	05/26/1935	1,060	2.54		1965	06/07/1965	1,670	3.24	
1936	05/15/1936	1,320	2.75		1951	05/28/1951	1,660	3.10	
1937	05/16/1937	780	2.23		1953	05/29/1953	1,660	3.07	
1938	05/29/1938	1,440	2.82		2010	06/05/2010	1,650	2.96	
1939	05/05/1939	951	2.41		1968	06/10/1968	1,600	3.10	
1940	05/13/1940	1,020	2.46		2001	05/16/2001	1,600	2.96	
1941	05/14/1941	973	2.42		1928	05/12/1928	1,580	--	
1942	05/11/1942	1,220	2.63		2014	05/25/2014	1,580	2.90	
1943	06/01/1943	2,090	3.43		1984	05/21/1984	1,560	3.07	
1944	06/09/1944	1,130	2.62		1920	06/09/1920	1,510	--	
1945	06/07/1945	1,090	2.59		1964	06/18/1964	1,500	--	
1946	05/09/1946	1,130	2.65		1998	05/08/1998	1,500	2.80	
1947	05/10/1947	1,380	2.84		2000	05/26/2000	1,500	2.84	
1948	05/22/1948	1,400	2.86		1950	06/07/1950	1,490	2.92	
1949	05/17/1949	1,280	2.74		1932	05/22/1932	1,450	2.82	
1950	06/07/1950	1,490	2.92		2006	05/20/2006	1,450	2.81	
1951	05/28/1951	1,660	3.10		1921	06/11/1921	1,440	--	
1952	05/04/1952	1,400	2.86		1938	05/29/1938	1,440	2.82	
1953	05/29/1953	1,660	3.07		1954	05/17/1954	1,440	2.89	
1954	05/17/1954	1,440	2.89		1962	05/13/1962	1,410	2.95	
1955	05/31/1955	1,160	2.70		1914	05/21/1914	1,400	--	
1956	05/24/1956	2,150	3.44	PT definition	1948	05/22/1948	1,400	2.86	
1957	05/14/1957	1,320	2.84		1952	05/04/1952	1,400	2.86	
1958	05/24/1958	1,160	2.68		1973	05/21/1973	1,400	3.05	
1959	06/07/1959	1,180	2.67		1947	05/10/1947	1,380	2.84	
1960	05/13/1960	1,100	2.60		1969	05/21/1969	1,340	2.93	
1961	05/26/1961	1,180	2.67		1929	05/25/1929	1,330	2.02	
1962	05/13/1962	1,410	2.95		1936	05/15/1936	1,320	2.75	
1963	05/20/1963	1,320	2.84		1957	05/14/1957	1,320	2.84	
1964	06/18/1964	1,500	--		1963	05/20/1963	1,320	2.84	
1965	06/07/1965	1,670	3.24		1922	06/02/1922	1,300	--	
1966	05/10/1966	1,150	2.77		1985	05/11/1985	1,300	2.86	
1967	05/30/1967	2,110	3.46		1949	05/17/1949	1,280	2.74	
1968	06/10/1968	1,600	3.10		1923	05/23/1923	1,270	--	
1969	05/21/1969	1,340	2.93		2005	05/20/2005	1,260	2.68	
1970	06/08/1970	1,700	--		2003	05/25/2003	1,230	2.65	
1971	06/15/1971	2,050	--		1925	01/03/1925	1,220	--	
1972	06/03/1972	1,810	3.33		1942	05/11/1942	1,220	2.63	
1973	05/21/1973	1,400	3.05		2012	04/27/2012	1,210	2.62	
1984	05/21/1984	1,560	3.07		1959	06/07/1959	1,180	2.67	
1985	05/11/1985	1,300	2.86		1961	05/26/1961	1,180	2.67	
1986	05/31/1986	2,340	3.56	PT definition	1994	05/13/1994	1,180	2.65	
1989	05/10/1989	1,700	--		1933	06/02/1933	1,160	2.63	
1990	04/23/1990	909	2.47		1955	05/31/1955	1,160	2.70	
1991	05/22/1991	1,960	3.27		1958	05/24/1958	1,160	2.68	
1992	04/30/1992	1,040	2.54		2013	05/14/2013	1,160	2.53	
1993	05/22/1993	2,300	3.43		1966	05/10/1966	1,150	2.77	
1994	05/13/1994	1,180	2.65		1944	06/09/1944	1,130	2.62	
1995	06/06/1995	1,720	3.05		1946	05/09/1946	1,130	2.65	
1996	05/18/1996	2,820	3.78		1919	05/11/1919	1,110	--	
1997	05/18/1997	2,630	3.58		1960	05/13/1960	1,100	2.60	
1998	05/08/1998	1,500	2.80		1945	06/07/1945	1,090	2.59	
1999	05/29/1999	2,210	3.35		2002	05/20/2002	1,080	2.55	
2000	05/26/2000	1,500	2.84		1935	05/26/1935	1,060	2.54	
2001	05/16/2001	1,600	2.96		1915	06/01/1915	1,040	--	
2002	05/20/2002	1,080	2.55		1992	04/30/1992	1,040	2.54	
2003	05/25/2003	1,230	2.65		1940	05/13/1940	1,020	2.46	
2004	05/23/2004	909	2.36		1926	05/21/1926	1,010	--	

1% ‘plus’ documentation

84% Confidence Interval data from PeakFQ

Analysis		0.5	0.4292	0.4	0.3	0.2	0.1	0.05	0.04	0.025	0.02	0.01	0.005	0.002
6019500.00	estimate	937.5	1000	1029	1143	1303	1585	1887	1990	2216	2329	2702	3115	3730
	84% CI-lower	877.2	933.8	959.7	1064	1208	1448	1688	1766	1932	2013	2269	2537	2911
	84% CI-upper	1001	1071	1103	1234	1423	1788	2241	2411	2813	3026	3800	4768	6430
6020600.10	estimate	915.6	986.9	1019	1143	1309	1584	1858	1946	2136	2227	2516	2815	3230
	84% CI-lower	839.1	904.6	933.6	1047	1195	1430	1651	1720	1862	1929	2131	2328	2583
	84% CI-upper	999	1078	1114	1254	1446	1784	2155	2284	2573	2719	3211	3768	4617
6020600.11	estimate	849.4	913.6	942.4	1056	1209	1468	1731	1818	2004	2095	2387	2696	3132
	84% CI-lower	791.6	851.1	877.6	981.6	1120	1344	1560	1628	1771	1839	2049	2259	2539
	84% CI-upper	911.6	982.1	1014	1141	1318	1641	2006	2135	2425	2573	3078	3659	4564
6021500.10	estimate	366.1	407.1	425.4	497.4	594.3	753.6	909.7	959.7	1065	1115	1271	1427	1636
	84% CI-lower	282.4	316.4	331.4	389.3	465.4	589.1	702.2	734.9	797.5	824.2	897.2	957.3	1022
	84% CI-upper	469.8	521.5	544.8	640	783.1	1080	1441	1569	1858	2007	2524	3143	4165
6021500.11	estimate	376	433.7	460.7	574.2	745.8	1079	1472	1613	1935	2101	2674	3343	4396
	84% CI-lower	327.6	377.8	401.2	498.8	643.5	912.1	1209	1311	1535	1646	2010	2405	2976
	84% CI-upper	431.6	499	530.8	666	877.8	1325	1924	2157	2727	3039	4209	5751	8549
6022000.10	estimate	499.4	565.9	596.5	722.1	903.9	1236	1604	1731	2013	2154	2624	3147	3925
	84% CI-lower	406.1	460.8	485.8	586.6	728.6	975.7	1229	1312	1489	1574	1839	2109	2470
	84% CI-upper	615	700.3	740.1	908.7	1170	1714	2426	2699	3356	3711	5024	6718	9725
6022000.11	estimate	521.5	592.2	624.8	759.4	956.4	1322	1733	1877	2198	2360	2905	3520	4451
	84% CI-lower	461.9	524.5	553.3	671	839.9	1141	1460	1567	1798	1911	2275	2658	3196
	84% CI-upper	589	670.1	707.8	865.4	1104	1579	2173	2395	2918	3195	4193	5432	7528
6023000.10	estimate	648.2	709.7	737	844	986.6	1220	1447	1520	1674	1748	1977	2209	2523
	84% CI-lower	554.2	608.6	632.6	725.1	845.6	1035	1208	1260	1366	1414	1556	1686	1843
	84% CI-upper	755.2	827.9	860.7	992.2	1178	1519	1903	2037	2337	2488	2996	3571	4452
6023000.11	estimate	679.8	762.9	801	956.8	1181	1590	2042	2198	2544	2718	3298	3945	4915
	84% CI-lower	609	683.3	717.2	854.7	1049	1389	1744	1861	2114	2237	2631	3043	3618
	84% CI-upper	759.2	853.7	897.3	1078	1347	1874	2518	2755	3311	3603	4645	5920	8044
6026500.10	estimate	8623	9162	9396	10280	11390	13080	14600	15070	16020	16460	17790	19060	20690
	84% CI-lower	7024	7881	8221	9328	10430	11860	13060	13420	14130	14450	15380	16240	17270
	84% CI-upper	9363	9982	10260	11320	12700	15010	17410	18210	19910	20740	23350	26050	29750
6026500.11	estimate	8434	8992	9233	10140	11280	12990	14520	14990	15930	16360	17650	18880	20420
	84% CI-lower	7291	8042	8349	9391	10500	11990	13240	13610	14350	14680	15630	16490	17510
	84% CI-upper	9038	9644	9912	10940	12280	14460	16620	17310	18770	19460	21600	23750	26630
6026500.20	estimate	8131	8802	9095	10210	11620	13760	15690	16280	17480	18030	19670	21230	23180
	84% CI-lower	7370	8059	8349	9411	10700	12610	14260	14750	15710	16140	17370	18460	19730
	84% CI-upper	8830	9560	9881	11110	12710	15270	17740	18540	20220	21030	23600	26280	30040
6026500.21	estimate	8259	8882	9153	10180	11470	13430	15190	15720	16810	17310	18810	20230	22020
	84% CI-lower	7701	8348	8620	9615	10820	12610	14160	14620	15530	15940	17120	18180	19420
	84% CI-upper	8749	9408	9697	10800	12220	14440	16540	17210	18600	19270	21370	23520	26490
6036650.10	estimate	8223	8958	9283	10540	12200	14860	17400	18210	19890	20690	23150	25610	28860
	84% CI-lower	6331	7372	7815	9354	11000	13240	15240	15860	17110	17690	19410	21050	23090
	84% CI-upper	9053	9869	10240	11710	13730	17260	21130	22450	25350	26780	31420	36390	43480
6036650.11	estimate	9304	9954	10240	11330	12720	14880	16890	17520	18810	19410	21260	23060	25410
	84% CI-lower	7879	8786	9159	10430	11770	13620	15240	15730	16720	17170	18500	19760	21300
	84% CI-upper	9996	10710	11030	12290	13960	16760	19640	20580	22610	23580	26680	29900	34400
6036650.20	estimate	8486	9220	9543	10790	12400	14930	17300	18040	19570	20290	22470	24610	27390
	84% CI-lower	7677	8459	8789	9997	11480	13720	15740	16360	17600	18170	19850	21400	23290
	84% CI-upper	9150	9945	10300	11670	13490	16480	19470	20440	22540	23560	26870	30410	35510
6036650.21	estimate	9045	9746	10050	11220	12720	15040	17170	17830	19190	19820	21730	23580	25970
	84% CI-lower	8409	9141	9450	10580	11970	14060	15920	16480	17610	18130	19630	21010	22680
	84% CI-upper	9594	10340	10670	11940	13600	16250	18830	19660	21440	22300	25050	27950	32040
6037500.00	estimate	1356	1427	1458	1576	1729	1969	2195	2266	2415	2485	2701	2918	3207
	84% CI-lower	1296	1364	1393	1506	1648	1866	2062	2122	2244	2300	2469	2631	2836
	84% CI-upper	1418	1493	1526	1653	1821	2099	2382	2475	2677	2775	3089	3421	3890
6038500.10	estimate	2302	2428	2484	2697	2975	3420	3847	3983	4269	4405	4830	5261	5845
	84% CI-lower	2167	2285	2336	2534	2787	3175	3528	3635	3856	3958	4264	4558	4934
	84% CI-upper	2447	2584	2645	2883	3207	3771	4382	4592	5055	5287	6053	6901	8162
6038800.10	estimate	2667	2865	2953	3293	3740	4461	5159	5382	5851	6074	6772	7479	8435
	84% CI-lower	2403	2584	2663	2968	3360	3969	4522	4689	5027	5181	5636	6059	6581
	84% CI-upper	2960	3184	3284	3680	4229	5220	6336	6725	7594	8032	9505	11170	13720
6038800.11	estimate	2824	3020	3106	3438	3869	4553	5202	5407	5835	6037	6663	7289	8123
	84% CI-lower	2617	2800	2880	3187	3578	4178	4716	4878	5205	5354	5791	6199	6698
	84% CI-upper	3048	3261	3356	3723	4219	5074	5983	6290	6960	7290	8368	9536	11230
6040000.10	estimate	4290	4648	4805	5412	6203	7455	8637	9009	9781	10140	11260	12360	13810
	84% CI-lower	3517	3834	3971	4491	5147	6142	7019	7279	7793	8022	8678	9261	9938
	84% CI-upper	5173	5617	5817	6620	7761	9855	12190	13000	14790	15690	18690	22040	27130
6040000.11	estimate	4351	4669	4808	5338	6011	7047	7995	8287	8887	9165	10010	10820	11870
	84% CI-lower	4012	4312	4443	4936	5555	6479	7278	7511	7971	8174	8755	9270	9869
	84% CI-upper	4711	5054	5205	5783	6543	7801	9068	9481	10360	10790	12130	13530	15490
6041000.10	estimate	4757	5064	5197	5701	6333	7290	8151	8415	8951	9199	9944	10660	11560
	84% CI-lower	4425	4717	4843	5315	5902	6767	7497	7707	8111	8288	8782	9208	9693
	84% CI-upper	5113	5440	5582	6124	6825	7979	9131	9502	10290	10670	11860	13080	14780
6042500.11	estimate	4813	5131	5269	5790	6446	7437	8331	8604	9160	9417	10190	10930	11860
	84% CI-lower	4470	4771	4902	5391	5998	6895	7654	7871	8290	8472	8981	9419	9915
	84% CI-upper	5182	5521	5668	6229	6956	8155	9354	9741	10560	10950	12190	13470	15240

Streamgage identification number and analysis designation[1]	Streamgage name	1%plus	(A) 1% est.	(B) upper 84% CI	These data from table 1-6; to adj. MOVE3 1% plus N	at-site	ne	(C) CI adj factor	(D) Diff. (A)-(B)	(E) adjusted diff. (C)*(D)	(F) Adj. 1%plus (A)+(E)
06018500.10	Beaverhead River near Twin Bridges, Montana										
06019500.00	Ruby River above reservoir, near Alder, Montana	3,800	2702	3800							
06020600.11	Ruby River below reservoir, near Alder, Montana	3,210	2387	3078	78	54	11.48	1.19	691	823	3210
06021500.11	Ruby River at Laurin, Montana	5,940	2674	4209	78	14	22.68	2.13	1535	3265	5939
06022000.11	Ruby River below Ramshorn Creek, near Sheridan, Montana	5,310	2905	4193	78	26	15.81	1.87	1288	2403	5308
06023000.11	Ruby River near Twin Bridges, Montana	6,020	3298	4645	78	25	13.57	2.02	1347	2724	6022
06026500.21	Jefferson River near Twin Bridges, Montana	21,500	18810	21370	111	64	41.55	1.05	2560	2692	21502
06036650.21	Jefferson River near Three Forks, Montana	25,100	21730	25050	111	80	27.85	1.03	3320	3417	25147
06037500.00	Madison River near West Yellowstone, Montana	3,090	2701	3089							
06038500.10	Madison River below Hebgen Lake, near Grayling, Montana	6,050	4830	6053							
06038800.11	Madison River at Kirby Ranch, near Cameron, Montana	8,760	6663	8368	57	35	11.37	1.23	1705	2096	8759
06040000.11	Madison River near Cameron, Montana	12,800	10010	12130	57	13	30.01	1.33	2120	2809	12819
06041000.10	Madison River below Ennis Lake, near McAllister, Montana	11,900	9944	11860							
06042500.11	Madison River near Three Forks, Montana	13,100	10190	12190	57	0	39.76	1.43	2000	2867	13057

Appendix C.

Ungaged Site Analysis

Gage Transfer

		Drainage Area Transfer Coefficient:			0.755		0.69		0.647		0.609		0.533		0.609		
Pour Point	Station Number	Station Name	Drainage Area (mi^2)	log DA	Q_{10} (cfs)	log(Q_{10})	Q_4 (cfs)	log(Q_4)	Q_2 (cfs)	log(Q_2)	Q_1 (cfs)	log(Q_1)	$Q_{0.2}$ (cfs)	log($Q_{0.2}$)	$Q_{1'plus'}$ (cfs)	log($Q_{1'plus'}$)	DA ratio
Madison																	
25	100	Madison River Confluence with Jefferson River	2,556	3.4076	7,529		8,694		9,517		10,298		12,000		13,226		1.02
26	6042500	Madison River near Three Forks, MT	2,516	3.4007	7,440	3.8716	8,600	3.9345	9,420	3.9741	10,200	4.0086	11,900	4.07555	13,100	4.1172713	
28	200	Madison River above Elk Creek	2,416	3.3831	7,392	3.8688	8,543	3.9316	9,350	3.9708	10,117	4.0051	11,804	4.07204	12,708	4.104084	
30	6041000	Madison River below Ennis Lake near McAllister, MT	2,213	3.345	7,290	3.8627	8,420	3.9253	9,200	3.9638	9,940	3.9974	11,600	4.06446	11,900	4.075547	
32	6040000	Madison River near Cameron	1,729	3.2378	7,050	3.8482	8,290	3.9186	9,160	3.9619	10,000	4	11,900	4.07555	12,800	4.10721	
33	300	Madison River above Indian Creek	1,562	3.1937	6,398	3.8061	7,542	3.8775	8,353	3.9218	9,139	3.9609	10,934	4.03878	11,769	4.0707303	
35	6038800	Madison River at Kirby Ranch near Cameron	1,093	3.0386	4,550	3.658	5,410	3.7332	6,040	3.781	6,660	3.8235	8,120	3.90956	8,760	3.9425041	
36	6038500	Madison River below Hebgen Lake	932	2.9694	3,420	3.534	3,980	3.5999	4,400	3.6435	4,830	3.6839	5,840	3.76641	6,050	3.7817554	
50	6037500	Madison River near West Yellowstone	439	2.6425	1,970	3.2945	2,270	3.356	2,480	3.3945	2,700	3.4314	3,210	3.50651	3,090	3.4899585	

Appendix D.

Ice Jam Analysis

Summary of Preliminary Analyses and Issues Associated with an Ice Jam Analysis for the Madison River in Madison and Gallatin Counties in Montana

The purpose of this document is to summarize the availability of ice jam data, preliminary ice jam analyses and issues associated with an ice jam analysis on the Madison River in Madison and Gallatin Counties, Montana.

Summary of Ice Jam Data

There are five gaging stations on the Madison River either near or within two separate reaches of the Madison River for which detailed hydraulic analyses are planned. However, only two of those gaging stations have ice jam stage data in the U.S. Geological Survey (USGS) National Water Information System (NWIS). These data are briefly defined as follows:

- Madison River near Three Forks, MT (06042500), drainage area = 2,453 square miles: There are 16 years of annual peak data available from 1894-1896, 1929-1932, and 1942-1950. There are four ice jam stages available in the time period 1942 to 1950 ranging from 7.67 to 10.48 feet. No ice jam stages are available for the earliest part of the record. The Three Forks gaging station is in the downstream reach that includes the City of Three Forks.
- Madison River near Cameron, MT (06040000), drainage area = 1,665 square miles: There are 20 years of annual peak data available from 1952-1969 and 2011-2016. There are four ice jam stages available in the time period 1955 to 1962 ranging from 8.11 to 8.83 feet (note minimal range in stages). The Cameron gaging station is in the upstream reach that includes the Town of Ennis.

The U.S. Army Corps of Engineers (USACE) maintains a national data base of ice jam data that includes a significant number of ice jam events for streams in Montana (http://rsgisias.crrel.usace.army.mil/apex/f?p=524:5:0::NO). A review of this data base revealed that most (over 95 percent) of the data in the USACE data base comes from the USGS NWIS data base. When the data are not from the USGS, the data are usually qualitative with no elevation data.
There are pictures of ice jam events in the vicinity of Ennis, MT but no elevation data.
Bottom line: The available ice jam stage data on the Madison River in or near the two reaches of planned hydraulic analysis is limited to eight stage elevations at two USGS gaging stations.

Most Recent Analysis of Ice Jam Flooding on the Madison River

Van Mullem Engineering performed H&H analyses for the Madison River in 2003 and 2004 in a reach that included the City of Three Forks but not the Three Forks gaging station. The results of these analyses became effective in a Letter of Map Revision (LOMR) on June 29, 2006. Because of the limited ice jam stage data, Van Mullem developed a HEC-RAS model using an ice cover/thickness analysis approach. Van Mullem used floating type ice jams with ice thickness ranging five to 10 feet in the hydraulic analysis. The four ice jam stages noted above for the Three Forks gaging station was used to verify the hydraulic modeling analyses. Michael Baker International has Van Mullem's HEC-RAS model and was able to run it.
Nearly all the annual peak discharges on the Madison River occur in May and June during ice breakup. Nearly all the ice jam events occur from December to March when the discharges are lower. Van Mullen analyzed the highest flow in the period January to March for each year that resulted in a winter 100-year discharge of 3,280 cfs for the Madison River in the vicinity of Three Forks. Van Mullem used the 100-year winter discharge of 3,280 cfs in the HEC-RAS hydraulic analysis. The winter 100-year discharge

is much lower than the 100-year discharge of 10,200 cfs recently estimated by USGS that represents the open water period of the year.

Note: The flood discharges shown in "Table 4: Summary of Discharges" for the Madison and Jefferson Rivers of the September 2, 2011 Flood Insurance Study report for Gallatin County, MT are from the original SCS analysis in 1979. This table was not updated to include the revised Van Mullem discharges.

Preliminary Ice Jam Analyses at the Two Madison River Gaging Stations

Preliminary ice jam analyses were performed for the Three Forks (06042500) and Cameron (06040000) gaging stations on the Madison River. The annual ice jam stages were plotted on normal probability paper using Weibull plotting positions and the exceedance probabilities were adjusted by the fraction of years that ice jam floods occurred in the period of record as described in Equation 2 of FEMA's "Appendix F: Guidance for Ice-Jam Analyses and Mapping", dated April 2003. For the Three Forks station, the adjustment was 0.44 (4/9) for the four ice jam events that occurred in 9 years. For the Cameron station, the adjustment was 0.2 (4/20) for the four ice jam events that occurred in 20 years. The 10- and 100-year ice jam stages were estimated from the adjusted frequency curves. The graphical frequency curves and the associated computations are given in Attachment 1.

Open water stages were estimated by establishing rating curves for the Three Forks and Cameron stations by plotting annual peak stages versus annual peak discharges for the open water periods. The 10- and 100-year open water stages were estimated using the stage discharge relations and estimates of the 10- and 100-year discharges from the recent USGS discharge analyses.

The results are summarized below for the two gaging stations.

Three Forks gaging station

- 100-year ice jam stage = ~11.6 feet, 100-year open water stage = ~7.2 feet
- 10-year ice jam stage = ~9.1 feet, 10-year open water stage = ~6.3 feet

Cameron gaging station

- 100-year ice jam stage = ~8.8 feet, 100-year open water stage = 5.6 feet
- 10-year ice jam stage = ~7.2 feet, 10-year open water stage = ~4.9 feet

Van Mullem reported that the ice jam elevations were 3-4 feet above the open water elevations and the preliminary analysis above indicates the same. Both analyses indicate that the ice jam floods result in much higher elevations than open water conditions.

Path Forward

Two approaches moving forward are:

- Modify and extend Van Mullem's HEC-RAS model for the Madison River and use ice jam analyses at the two gaging stations to verify the hydraulic modeling, or
- Use the ice jam analyses at the two gaging stations to adjust the open water elevations for a uniform amount throughout the study reach.

The pros and cons of each approach can be discussed in the upcoming conference call and determine if there are other approaches.

Will Thomas
Michael Baker International
February 8, 2018 – revised May 29, 2018 (added Attachment 1)

Attachment 1. Computation of Ice-Jam Stage-Frequency Curves for the Madison River near Three Forks, MT (06042500) and the Madison River near Cameron, MT (06040000).

There were four ice-jam floods at the Madison River near Three Forks, MT (06042500) in nine years. The four floods are plotted in Figure A.1 using a Weibull plotting position assuming nine years of data (this frequency curve is consistent with the Van Mullem analysis in 2003). The exceedance probability from the Weibull plotting position is estimated as m/(n+1) where m = rank (1 for the largest) and n = years of record (9 years). For example, the largest ice-jam flood of 10.48 feet in nine years has an unadjusted exceedance probability of 1/10 = 0.10 or return period of 10 years. However, only four ice-jam floods occurred in nine years so the unadjusted exceedance probability is multiplied by 4/9 = 0.44, the fraction of years for which an ice-jam flood occurred (based on Equation 2 in FEMA Appendix F: Guidance for Ice Jam Analyses and Mapping). This computation accounts for the years when no ice-jam flood occurred and results in the adjusted frequency curve shown in Figure A.1. The computations are given in Table A.1.

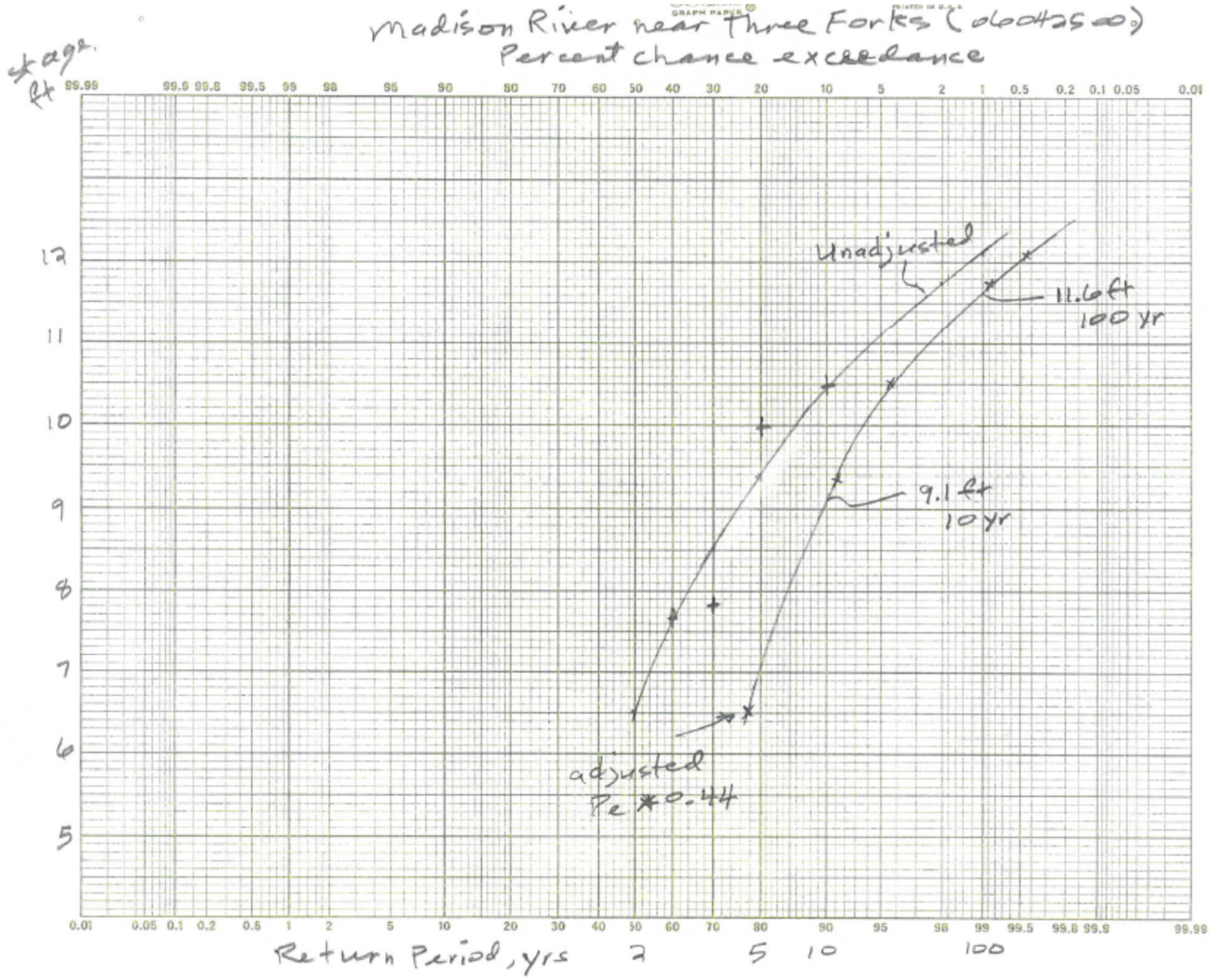

Figure A.1. Ice-jam stage-frequency curves for the Madison River near Three Forks, MT (06042500).

The elevations in column 1 of Table A.1 correspond to the exceedance probabilities in column 2 from the unadjusted frequency curve. The exceedance probabilities in column 2 are multiplied by 0.44 to give the adjusted exceedance probabilities in column 3 that define the adjusted frequency curve in Figure A.1.

Table A.1. Computation of adjusted ice-jam stage-frequency curve for Madison River near Three Forks, MT (06042500) where column 3 = column 2 * 0.44.

(1) Elevation, feet	(2) Unadjusted exceedance probability	(3) Adjusted exceedance probability	(4) Return Period, years
6.5	0.50	0.22	4.5
9.35	0.20	0.088	11.4
10.5	0.10	0.044	22.7
11.75	0.02	0.0088	113.6
12.1	0.01	0.0044	227.3

The 10-year ice-jam stage (9.1 feet) and the 100-year ice-jam stage (11.6 feet) for Madison River near Three Forks are shown in Figure A.1 and were reported earlier.

The same analysis was performed for the Madison River near Cameron, MT (06040000). The unadjusted frequency curve is based on the four ice-jam stages that occurred in 20 years using the Weibull plotting position formula described earlier. The unadjusted frequency curve assumes there are 20 years of ice-jam floods. However, only four ice-jam floods occurred in 20 years so the unadjusted exceedance probability is multiplied by 4/20 = 0.20, the fraction of years for which an ice-jam flood occurred (based on Equation 2 in FEMA Appendix F: Guidance for Ice Jam Analyses and Mapping). This computation accounts for the years when no ice-jam flood occurred and results in the adjusted frequency curve shown in Figure A.2. The computations are given in Table A.2.

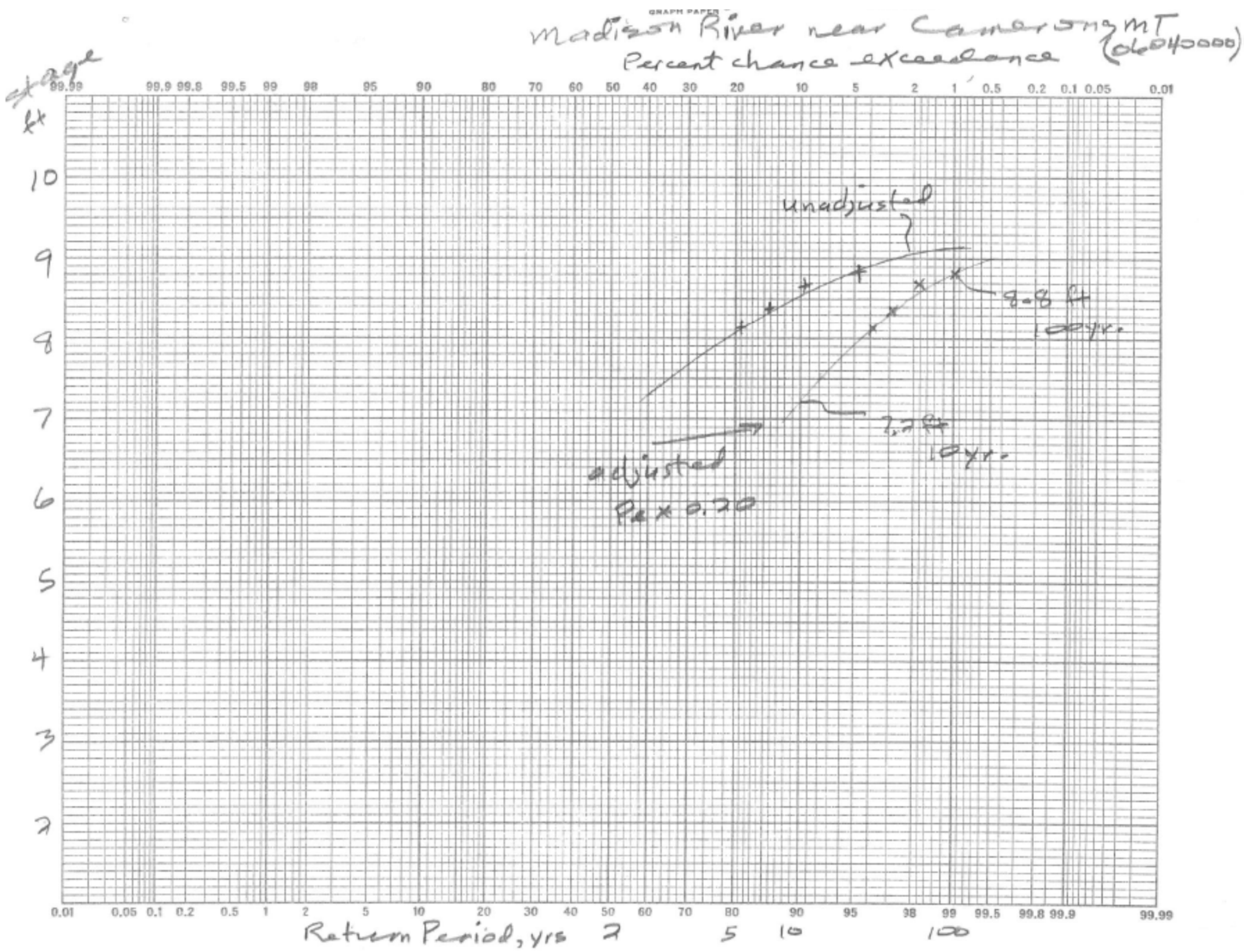

Figure A.2. Ice-jam stage-frequency curves for the Madison River near Cameron, MT (06040000).

The elevations in column 1 of Table A.2 correspond to the exceedance probabilities in column 2 from the unadjusted frequency curve. The exceedance probabilities in column 2 are multiplied by 0.20 to give the adjusted exceedance probabilities in column 3 that define the adjusted frequency curve in Figure A.2. The 10-year ice-jam stage (7.2 feet) and 100-year ice-jam stage (8.8 feet) for the Madison River near Cameron are shown in Figure A.2 and were reported earlier.

Table A.2. Computation of adjusted ice-jam stage-frequency curves for Madison River near Cameron, MT (06040000) where column 3 = column 2 * 0.20.

(1) Elevation, feet	(2) Unadjusted exceedance probability	(3) Adjusted exceedance probability	(4) Return Period, years
7.2	0.50	0.1	10
8.1	0.20	0.04	25
8.55	0.10	0.02	50
9.05	0.02	0.004	250
9.15	0.01	0.002	500