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Peak-Flow Frequency Analyses and Results Based on Data through Water Year 2011 for Selected Streamflow-Gaging Stations in or near Montana

Chapter C of
Montana StreamStats

Scientific Investigations Report 2015–5019–C

U.S. Department of the Interior
U.S. Geological Survey

Cover photograph: Aerial view of the Musselshell River flooding at Two Dot, Montana, May, 2011. (Photograph by Kestrel Aerial Services. Used with permission.)

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U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
SALLY JEWELL, Secretary

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Conversion Factors

[U.S. customary units to International System of Units]

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	28.32	cubic decimeter (dm^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Datum

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Supplemental Information

Water year is the 12-month period from October 1 through September 30 of the following calendar year. The water year is designated by the calendar year in which it ends. For example, water year 2011 is the period from October 1, 2010, through September 30, 2011.

Abbreviations

AEP	annual exceedance probability
GIS	geographic information system
MDT	Montana Department of Transportation
MOVE.1	maintenance of variance type I
MT DNRC	Montana Department of Natural Resources and Conservation
NWIS	National Water Information System
USGS	U.S. Geological Survey

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Peak-Flow Frequency Analyses and Results Based on Data through Water Year 2011 for Selected Streamflow-Gaging Stations in or near Montana

By Steven K. Sando, Peter M. McCarthy, and DeAnn M. Dutton

Abstract

Chapter C of this Scientific Investigations Report documents results from a study by the U.S. Geological Survey, in cooperation with the Montana Department of Transportation and the Montana Department of Natural Resources, to provide an update of statewide peak-flow frequency analyses and results for Montana. The purpose of this report chapter is to present peak-flow frequency analyses and results for 725 streamflow-gaging stations in or near Montana based on data through water year 2011. The 725 streamflow-gaging stations included in this study represent nearly all streamflow-gaging stations in Montana (plus some from adjacent states or Canadian Provinces) that have at least 10 years of peak-flow records through water year 2011. For 29 of the 725 streamflow-gaging stations, peak-flow frequency analyses and results are reported for both unregulated and regulated conditions. Thus, peak-flow frequency analyses and results are reported for a total of 754 analyses. Estimates of peak-flow magnitudes for 66.7-, 50-, 42.9-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent annual exceedance probabilities are reported. These annual exceedance probabilities correspond to 1.5-, 2-, 2.33-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year recurrence intervals.

Introduction

Many individuals and agencies, including the Montana Department of Transportation (MDT) and the Montana Department of Natural Resources (MT DNRC), have continuing needs for peak-flow information for the design of highway infrastructure, flood-plain mapping, and many other purposes. The MDT has been a long-term cooperator with the U.S. Geological Survey (USGS) in operating partial-record crest-stage gaging stations throughout Montana that provide peak-flow data for numerous locations where continuous-record stations are not operated. A study was completed by the USGS, in cooperation with MDT and MT DNRC, to provide an update of statewide peak-flow frequency analyses and results through water year 2011.

In this report chapter, all streamflow data are referenced to water years. A water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. In this report chapter, the term “peak flow” is frequently used. Peak flow refers to the annual maximum instantaneous discharge, which is recorded for each water year that a streamflow-gaging station (hereinafter referred to as gaging station) is operated. Peak-flow frequencies refer to peak-flow magnitudes, in cubic feet per second, associated with given annual exceedance probabilities (AEPs), in percent.

Stationarity is an important issue in the statistical analysis of hydrologic characteristics. For a given gaging station, stationarity of peak-flow data requires that all of the data represent a consistent hydrologic regime within the same (albeit highly variable) fundamental climatic system. Sando, McCarthy, and others (2016) investigated stationarity in peak flows for selected unregulated long-term gaging stations in Montana. The study results provided evidence that peak flows for most of the long-term gaging stations could be reasonably considered as stationary for application of peak-flow frequency analyses within a statewide gaging station network. However, for two low-elevation gaging stations in eastern Montana, there were substantial downward trends in peak flows after the mid-1970s. Sando, McCarthy, and others (2016) concluded that a conservative approach for handling the potential nonstationarity issues for low-elevation sites in eastern Montana would be to compute peak-flow frequency analyses based on the entire periods of record. Thus, the results of Sando, McCarthy, and others (2016) provide a basis for using all available data for computing peak-flow frequency analyses for Montana gaging stations.

Purpose and Scope

The study described in Chapter C of this Scientific Investigations Report is part of a larger study to develop a StreamStats application for Montana, compute streamflow characteristics at streamflow-gaging stations, and develop regional regression equations to estimate streamflow characteristics at ungaged sites (as described fully in Chapters A through G of this Scientific Investigations Report). The purpose of Chapter C is to present peak-flow frequency analyses and results for 725 streamflow-gaging stations (fig. 1; table 1–1 in appendix 1 at the back of this report chapter [available at http://dx.doi.org/10.3133/sir20155019C]; map numbers assigned according to McCarthy and others [2016]) in or near Montana based on data through water year 2011. Estimates of peak-flow magnitudes for 66.7-, 50-, 42.9-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent AEPs are reported. These AEPs correspond to 1.5-, 2-, 2.33-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year recurrence intervals. The procedures used for the peak-flow frequency analyses are documented.

Data Compilation and Pre-Analysis Augmentation and Manipulation

The 725 gaging stations included in this study (table 1–1) represent nearly all gaging stations in Montana (plus some from adjacent States or Canadian Provinces) that have at least 10 years of peak-flow records through water year 2011. Site information for all gaging stations is presented in table 1–1 and locations of gaging stations are shown in figure 1. Gaging stations in table 1–1 are arranged according to the USGS downstream order system and are grouped according to major river basins. Gaging stations beginning with 05 (for example, 05010000) are referred to as part 5 gaging stations and are in the Saskatchewan River Basin, which flows into the Hudson Bay. Gaging stations beginning with 06 are referred to as part 6 gaging stations and are in the Missouri River Basin, which flows into the Gulf of Mexico. Gaging stations beginning with 12 are referred to as part 12 gaging stations and are in the Columbia River Basin, which flows into the Pacific Ocean.

In this report chapter, the term “systematic record” is sometimes used and warrants discussion. In a given year, peak-flow data are collected at gaging stations that were part of the statewide gaging-station network operated during that year, and the peak-flow data are considered to be systematic. In a given year, if an individual gaging station was not part of the statewide gaging-station network but a peak-flow record was collected based on a special (nonsystematic) effort, the peak-flow record generally is considered to be nonsystematic. In many cases, a nonsystematic peak flow was (1) determined to be the largest peak flow in a period longer than the period of systematic record and defined as a historic peak flow, and (2) included in the peak-flow frequency (hereinafter referred to as frequency) analysis by using a historical adjustment procedure (Appendix 6 in U.S. Interagency Advisory Council on Water Data, 1982). In older records (that is, those generally before about 1980), when a small number of peak flows (generally one or two) are detached from the main series of peak flows and not specifically defined as historic peak flows, it can be difficult to confidently determine whether the gaging station was part of the statewide gaging-station network in the detached years. Thus, it can be difficult to determine whether the peak flows in the detached years should be considered systematic or nonsystematic. In cases of uncertainty in determining whether a detached peak flow was systematic or nonsystematic, the detached peak flow was considered to be systematic and included in the frequency analysis. This method for handling uncertainty in whether detached peak flows are considered systematic or nonsystematic is consistent with the method used in the previous reporting of frequency analyses for Montana gaging stations (Parrett and Johnson, 2004).

Peak-flow records were retrieved from the peak-flow database in the USGS National Water Information System (NWIS; U.S. Geological Survey, 2014a) database. The specific Web site for the peak-flow data used in this study is presented in U.S. Geological Survey (2014b). The peak-flow records were collected according to procedures described by Rantz and others (1982). In some cases, the raw data retrieved from NWIS were manipulated before analysis. The manipulations were related to (1) data augmentation and (2) manual manipulation of individual peak-flow records.

Data Augmentation

Data augmentation refers to combining peak-flow records of two or more closely located gaging stations on the same channel, generally with drainage areas that differ by less than about 5 percent. When two or more closely located gaging stations are on the same channel, frequency analyses on the combined peak-flow records represent a larger range in hydrologic conditions than analyses on the records of the individual gaging stations. Information on combining records of multiple gaging stations is presented in table 1–2 in appendix 1 at the back of this report chapter (also available at http://dx.doi.org/10.3133/sir20155019C).

Manual Manipulation of Individual Peak-Flow Records

Manual manipulations of individual peak-flow records are related to (1) changes to the gage base within the period of systematic record; (2) handling of peak flows coded in the NWIS database as historic peak flows; (3) and manual exclusion, substitution, or insertion of peak-flow values to maintain consistency with the previous reporting of frequency analyses for Montana gaging stations (Parrett and Johnson, 2004).

For an individual gaging station, the gage base represents the lowest streamflow that can be measured by instrumentation of the gaging station. For many gaging stations, the gage base is zero streamflow. For 20 gaging stations (table 1–3 in appendix 1 at the back of this report chapter [also available at http://dx.doi.org/10.3133/sir20155019C]), during the routine operations, the gage base was temporarily altered from zero streamflow to a value in the typical range of the systematic peak flows. In some cases, the temporary alteration in the gage base resulted in peak flows that were coded as “less than gage base” in the database. For all of the 20 gaging stations with peak flows coded as “less than gage base,” peak-flow records before and after the gage-base alterations were less than the temporary gage bases. In the frequency analysis using the PEAKFQ program (Flynn and others, 2006), for an individual gaging station, the highest gage base in the period of record is applied to all peak-flow records. Any peak-flow that is less than the highest gage base is handled as a low outlier, which can substantially and sometimes inappropriately affect the frequency results. To avoid the potential problems associated with temporary alteration of the gage base, the values of all peak flows coded as “less than gage base” (34 individual peak flows) were manually set to one-half of the temporary gage base. The frequency analyses for the affected gaging stations were reviewed and the data manipulations were considered to provide accurate frequency results.

Nonsystematic peak flows that were determined to be the largest peak flow during a period longer than the period of systematic record are defined as historic peak flows and coded as such in the database. In some cases, additional data collection has resulted in the original historic coding to be considered inappropriate. In these cases, the historic coding was removed, and the affected peak flows were considered part of the systematic record. This method for handling inappropriately coded historic peak flows is consistent with the method used in the previous reporting of frequency analyses for Montana gaging stations (Parrett and Johnson, 2004).

In three cases, peak-flow values were manually excluded, substituted, or inserted to maintain consistency with the previous reporting of frequency analyses for Montana gaging stations (Parrett and Johnson, 2004). The August 1959 peak flow for Madison River below Hebgen Lake, near Grayling, Montana (gaging station 06038500; map number 70) was excluded from the frequency analysis because the peak flow resulted from an earthquake seiche wave in Hebgen Lake. The June 1964 peak flow for Marias River near Shelby, Montana (gaging station 06099500; map number 161) was affected by a dam break; a value of 150,000 cubic feet per second (ft^3/s) was substituted for the measured 241,000 ft^3/s based on investigation of the effect of the dam break (Charles Parrett, U.S. Geological Survey, written commun., June 2000). No peak-flow data were collected for Marias River near Brinkman, Montana (gaging station 06102000; map number 173) in 1964; however, it was determined that the estimated peak flow at Marias River near Shelby, Montana (gaging station 06099500; map number 161) could reasonably be extrapolated downstream to gaging station 06102000 (Charles Parrett, U.S. Geological Survey, written commun., June 2000). Thus, a value of 150,000 ft^3/s for 1964 was inserted into the peak-flow records for gaging station 06102000.

Determination of Regulation Status of Streamflow-Gaging Stations

Reservoir storage and operations have the potential to substantially affect streamflow characteristics. Documentation of methods of classification of the regulation status of gaging stations is important. The USGS maintains a geospatial database of dams in Montana (McCarthy and others, 2016) that was used to define the regulation status for Montana gaging stations. The specific methods used to determine the regulation classification of gaging stations in Montana are described by McCarthy and others (2016).

Based on the USGS regulation-classification criteria, a gaging station is considered to be regulated if the cumulative drainage area of all upstream dams exceeds 20 percent of the drainage area of the gaging station. If the drainage area of a single upstream dam exceeds 20 percent of the drainage area of a given gaging station, the regulation is classified as major. If no single upstream dam has a drainage area that exceeds 20 percent of the drainage area of a given gaging station, the regulation is classified as minor. In this study, for cases where a large diversion canal was known to be located on the channel upstream from a gaging station, the gaging station also was classified as major regulation. A gaging station is considered to be unregulated where the cumulative drainage area upstream from all dams is less than 20 percent of the drainage area of the streamflow-gaging station and no large diversion canals are upstream from the streamflow-gaging station. Information on the regulation structures affecting most of the gaging stations classified as major regulation is presented in table 1–4 in appendix 1 at the back of this report chapter (also available at http://dx.doi.org/10.3133/sir20155019C).

In table 1–1, the regulation status and the total period of record of each gaging station is presented. The total period of record is broken down into periods of unregulated and regulated conditions, when applicable. For most of the 128 gaging stations classified as having major regulation (either dam or canal regulation), frequency analyses were done only for the regulated period; however, 29 gaging stations had 10 years or more of peak-flow records before the start of regulation. For these gaging stations, frequency analyses also were done for the unregulated period before the start of regulation to provide regional information on unregulated peak-flow characteristics.

For gaging stations classified as having minor dam regulation, frequency analysis was done on the total period of record. If the total period of record was within unregulated conditions, the period of record for the frequency analysis is classified as unregulated. If the total period of record was within regulated conditions, the period of record for the frequency analysis is classified as regulated. If the total period of record encompasses unregulated and regulated conditions, the period of record for the frequency analysis is classified as “total.” Many dams contribute to the minor dam regulation classification and the effects of these dams on streamflow characteristics are poorly understood. The dams that contribute

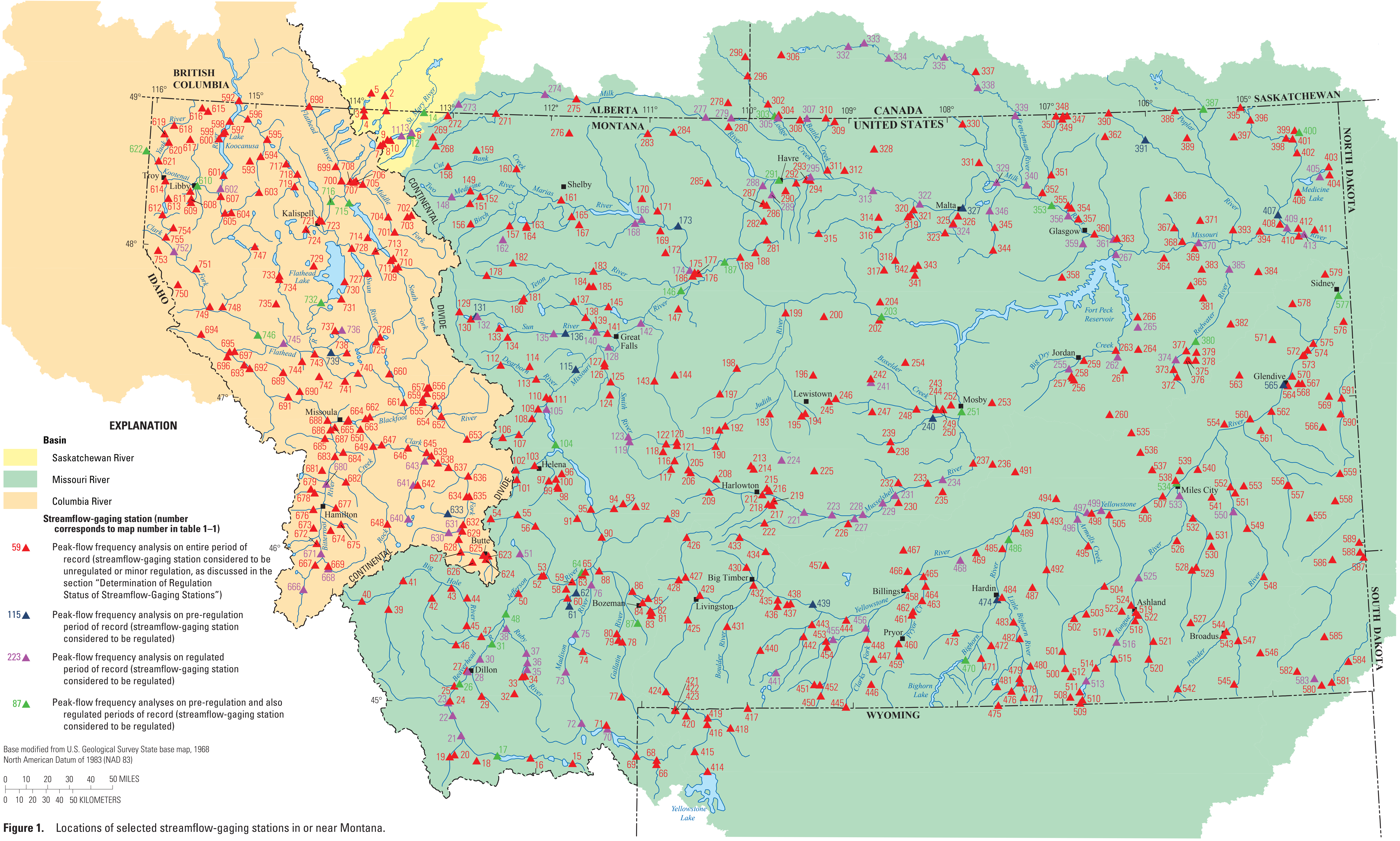

Figure 1. Locations of selected streamflow-gaging stations in or near Montana.

to the minor dam regulation classification generally have substantially less storage capacity than the dams that contribute to the major dam regulation classification, and currently (2015) little documentation is available on the operations and primary purposes of the minor regulation dams. All of the gaging stations with minor regulation that were included in the previous reporting of frequency analyses for Montana (Parrett and Johnson, 2004) were considered to be unregulated in that report.

Classification of the regulation status of a gaging station is based on a 2014 analysis of dams present in the gaging-station drainage basins and the storage start dates of the dams (McCarthy and others, 2016). In a few cases, a gaging station was classified as regulated in 2014, but the construction of dams in the gaging-station drainage basin was such that the 20-percent regulation criteria was not met until after the gaging station was discontinued. Thus, a gaging station might have been classified as regulated in 2014, but have no peak-flow data (or associated frequency analysis) for a regulated period. In such a case, the approach for classifying the regulation status of the gaging station is intended to provide accurate classification if the gaging station is reactivated.

The current (2015) criteria of the USGS for defining regulation status of gaging stations in Montana is based solely on affected drainage area and does not account for storage capacity characteristics of the dams or other regulating factors such as stream diversions. Storage capacity data are included in the geospatial database of dams (McCarthy and others, 2016), and future activities to more clearly define regulation effects on streamflow characteristics should incorporate storage capacity information considered in relation to streamflow characteristics. Furthermore, datasets for irrigation diversions currently (2015) are not readily available at sufficient scale and coverage for assessing effects on the application of frequency analyses within a statewide gaging-station network. Compilation of a statewide dataset of locations and capacities of irrigation canals would be important for better definition of regulation effects on streamflow characteristics.

Peak-Flow Frequency Analyses and Results

Frequency analyses procedures and results are reported for 725 gaging stations in tables 1–5 and 1–6, respectively, in appendix 1 at the back of this report chapter (available at http://dx.doi.org/10.3133/sir20155019C). For 29 of the 725 gaging stations, frequency analyses are reported for both unregulated and regulated conditions; thus, a total of 754 analyses are reported. Documentation on various details of analytical procedures for each gaging station is included in table 1–5 . The frequency results for each gaging station are presented in table 1–6 .

In addition to the frequency results in table 1–6, additional graphical and tabular information for each gaging station can be accessed by links included in tables 1–5 and 1–6. This additional information for each gaging station includes (1) a graph showing the frequency curve in association with the probability plots of the peak flows (with plotting positions determined by using the Cunnane formulation, as described by Helsel and Hirsch [2002]), (2) a time-series graph of the peak flows, (3) a table with summary information on the frequency analysis, and (4) a table of the peak flows (in time series and also ranked). In the probability plots of the peak flows, all peak flows less than or equal to 0.1 ft^3/s have been adjusted to 0.1 ft^3/s, and the plotting positions of individual peak flows reflect effects of historical adjustments in the frequency analyses.

Procedures for Frequency Analyses

Frequency analyses for 725 gaging stations (table 1–1) were developed by using various specific procedures that are described in this section of the report chapter. Selected information regarding application of these specific procedures for all stations is summarized in table 1–5.

Most Federal agencies and many State, local, and private entities follow procedures described in Bulletin 17B "Guidelines for Determining Flood Flow Frequency" (U.S. Interagency Advisory Council on Water Data, 1982; hereinafter referred to as Bulletin 17B) for developing frequency estimates. Bulletin 17B uses the log-Pearson III probability distribution, which is fit by using the mean, standard deviation, and skew of the logs of the peak flows for a given gaging station. Procedures described in Bulletin 17B were used as primary guidelines for developing the frequency estimates presented in this report chapter. The computer program PEAKFQ, which was developed by the U.S. Geological Survey (Flynn and others, 2006), was used to run the frequency analyses.

Frequencies initially were analyzed for the 725 gaging stations by using standard Bulletin 17B procedures for fitting the log-Pearson III distribution (as described in the following section "Standard Procedures for Fitting the Log-Pearson Type III Probability Distribution"). The resulting preliminary frequency curves were next plotted on a log-probability scale in conjunction with the peak flows, for which plotting positions were determined by using the Cunnane formulation, as described by Helsel and Hirsch (2002). In cases where historical adjustments were used, the plotting positions were adjusted using procedures described in Bulletin 17B. Fits of the preliminary frequency curves with the probability plots of the peak flows were then evaluated. In most cases (about 80 percent of the frequency analyses), fits of the standard Bulletin 17B analyses were determined to be satisfactory.

In other cases, however, the frequency results could be improved by using alternative procedures for handling specific characteristics of the peak-flow records for some gaging stations. The specific characteristics of peak-flow records addressed by alternative procedures include (1) regulated peak-flow records, (2) mixed-population peak-flow records, and (3) atypical low-end peak-flow records. The alternative procedures are described in the section “Alternative Procedures Used for Fitting the Log-Pearson Type III Probability Distribution.”

Standard Procedures for Fitting the Log-Pearson Type III Probability Distribution

In this report chapter, standard Bulletin 17B procedures are considered to include the use of weighted skew coefficients, the use of the Grubbs-Beck outlier test (Grubbs and Beck, 1972) for identifying low outliers, and, where applicable, the use of historical adjustment procedures. The standard procedures were applied to about 80 percent of the reported frequency analyses. Specific information regarding application of the standard procedures is presented in the following sections: “Standard Procedures for Determining Weighted Skew Coefficients,” “Standard Procedures for Handling Low-Outliers,” and “Standard Procedures for Historical Adjustments.”

Standard Procedures for Determining Weighted Skew Coefficients

Bulletin 17B recommends the use of a skew coefficient that is based on the skew of the logs of the peak flows (commonly termed the “station skew”) weighted with a generalized, or regional, skew coefficient. The weighting is based on the length of the peak-flow record and the estimated standard error for the method used to determine the generalized skew coefficient. The generalized skew coefficient can be determined by using a national skew map presented in Bulletin 17B (plate 1 in U.S. Interagency Advisory Council on Water Data, 1982) or by using methods based on data from long-term gaging stations in the area of interest as described in Bulletin 17B. Parrett and Johnson (2004) analyzed skew coefficients in Montana and determined that the skew coefficients of the Bulletin 17B national map could be slightly improved by skew coefficients determined from their analysis; however, Parrett and Johnson (2004) concluded that the differences between the skew coefficients from the Bulletin 17B national map and the skew coefficients from their analysis were “small and probably not significant” and, thus, Parrett and Johnson (2004, p. 8) used the Bulletin 17B national skew map to determine the generalized skew coefficients used to determine weighted skew coefficients. Parrett and Johnson (2004) determined that the standard error of the Bulletin 17B national map was 0.64 for Montana gaging stations. Consistent with Parrett and Johnson (2004), the frequency analyses presented in this report chapter also used the Bulletin 17B national skew map (with a standard error of 0.64) to determine the generalized skew coefficients used to determine weighted skew coefficients.

Standard Procedures for Handling Low-Outliers

Bulletin 17B recommends the use of the Grubbs-Beck outlier test to determine the low-outlier threshold on the basis of the mean and standard deviation of the log series of peak flows. The low-outlier threshold serves to censor low-lying data points so that they do not exert a large distorting effect on the fitted frequency curve (Advisory Committee on Water Information, 2007). However, the Bulletin 17B procedures for handling low outliers do not ignore the censored low-lying data points, but rather incorporate their frequency of occurrence through the use of a conditional probability adjustment (Appendix 5 in U.S. Interagency Advisory Council on Water Data, 1982).

Standard Procedures for Historical Adjustments

Bulletin 17B recommends the use of historical adjustment procedures in frequency analyses when information indicates that any peak flows that were before, during, or after the period of systematic record are the largest in a period longer than the period of systematic record (referred to as the “historic period;” U.S. Interagency Advisory Council on Water Data, 1982, p. 6–1). In this study, the Bulletin 17B historical adjustment procedure (Appendix 6 in U.S. Interagency Advisory Council on Water Data, 1982) was applied to frequency analyses for 230 gaging stations.

For gaging stations with historical adjustments, information regarding large peak flows used to define the high-outlier threshold in the historical adjustment procedures is presented in table 1–5. The large peak flows used to define the high-outlier thresholds might have been outside of the systematic record (and coded as historic peak flows in the database) or part of the systematic record and determined by the frequency analyst (or user) to have not been exceeded during the historic period.

For some Montana gaging stations with historical adjustments, documentation of especially large peak flows has been maintained as part of the gaging-station history file and variously consists of newspaper accounts, published information, or reliable recorded information from local residents. Documentation of a large peak flow used in a historical adjustment relates to the year and magnitude of the peak flow and also to the ungaged period during which the peak flow was not exceeded.

Because of the large number of Montana gaging stations with historical adjustments and because many of the gaging stations are in remote, sparsely inhabited locations, specific information on streamflow conditions during ungaged periods often is difficult to acquire. To assist in determining appropriate historic periods for historical adjustments, the magnitudes of peak flows (normalized by drainage area) for all active gaging stations for each year of Montana peak-flow data collection were plotted in a geographic information system (GIS) using standard tools available in ArcMap (Environmental Systems Research Institute, Inc., 2014). Normalizing was done by dividing each peak flow by the drainage area of the gaging station raised to the 0.57 power. The 0.57 coefficient was based on the mean (for all hydrologic regions in Montana) of the regression coefficients from ordinary least squares regressions relating 2- and 1-percent peak flows to drainage area (Parrett and Johnson, 2004, table 13). The plots of normalized peak flows were investigated to identify the spatial characteristics of important regional flood events that were used to appropriately define the historic period used in the historical adjustment for an individual gaging station. For this investigation, the drainage area of the gaging station was an important consideration because there is larger uncertainty that relatively small drainage areas (less than about 20 square miles [mi^2]) would be affected by regional flood events in comparison to uncertainty associated with drainage areas greater than 20 mi^2. Historic periods for gaging stations with relatively small drainage areas (less than about 20 mi^2) generally were defined more conservatively than for gaging stations with relatively large drainage areas (greater than about 20 mi^2). The approach used to determine the appropriate historic period for an individual gaging station with historical adjustment is based on consideration of peak-flow data from nearby gaging stations, which is consistent with the methods used in the previous reporting of frequency analyses for Montana (Parrett and Johnson, 2004).

Alternative Procedures Used for Fitting the Log-Pearson Type III Probability Distribution

In cases where the standard Bulletin 17B analyses were considered to provide inappropriate results, the analyses were improved by using alternative procedures for handling specific characteristics of the peak-flow records for some gaging stations. The specific characteristics of peak-flow records addressed by alternative procedures include (1) regulated peak-flow records, (2) mixed-population peak-flow records, and (3) atypical low-end peak-flow records, which include a special case for gaging stations that have a large proportion (generally greater than about 35 percent) of peak flows that are less than the gage base (that is, zero streamflows) and strongly negative skews.

In all cases, the alternative procedures used a fit of the log-Pearson Type III probability distribution. The deviations from the standard Bulletin 17B analysis in all cases involved selection of the station skew instead of the weighted skew, definition of a user-defined low-outlier threshold instead of the standard Grubbs-Beck low-outlier threshold, or both. Frequency analyses based on alternative procedures are specifically noted in table 1–5 in the column “Primary reason for deviation from standard Bulletin 17B procedures.”

Alternative Procedures Used for Handling Regulated Peak-Flow Records

Frequency analyses on regulated peak-flow records are presented for 128 gaging stations. Most (greater than 90 percent) of the regulated peak-flow records are affected by major dam regulation (as discussed in the section “Determination of Regulation Status of Gaging Stations”). The following discussion focuses on alternative procedures for handling peak-flow records affected by major dam regulation; however, similar concepts also apply to major canal regulation. Examples of gaging stations with regulated peak-flow records include Ruby River below reservoir, near Alder, Montana (gaging station 06020600; map number 35), Tongue River at Tongue River Dam, near Decker, Montana (gaging station 06307500; map number 513), and Flint Creek near Southern Cross, Montana (gaging station 12325500; map number 640) shown in table 1–1. Examples of gaging stations with both unregulated and regulated peak-flow records include Bighorn River near St. Xavier, Montana (gaging station 06287000; map number 470) and Flathead River near Polson, Montana (gaging station 12372000; map number 732) shown in table 1–1. For the example gaging stations, examination of the frequency curves plotted in conjunction with the peak flows (which are accessed by links in tables 1–5 and 1–6) provides insights concerning regulation effects on peak-flow records.

Dam regulation effects on peak-flow records can be complex and are dependent on many factors, some of which include (1) the drainage area upstream from the dam in relation to the drainage area of the gaging station, (2) available storage capacity in relation to streamflow conditions, and (3) the operating criteria of the reservoir. Depending on the interaction of the various factors, regulation can affect frequency curves in many variable ways. Recommendations on the application of Bulletin 17B procedures to regulated peak-flow records (Advisory Committee on Water Information, 2007) allow substantial freedom on the part of the analyst.

For regulated peak-flow records, peak-flow frequencies initially were analyzed by using standard Bulletin 17B procedures, and the preliminary frequency curves were then evaluated. Additional frequency analyses were then done using the station skew, a user-defined low-outlier threshold, or both. For a given gaging station, final selection of the appropriate frequency analysis was based on several considerations, including (1) the fit of the frequency curve in relation to the peak flows (especially in the range of AEPs from 50 to 2 percent), (2) the percent of the drainage area affected by regulation, (3) the maximum storage capacity of the dam in relation to the median peak flow of the gaging station, and (4) where possible, maintaining consistency in analytical approach among regulated gaging stations with similar hydrologic characteristics. For gaging stations with greater than 85 percent of drainage area affected by regulation, the station skew was used in most (about 75 percent) of the cases.

In some cases, the regulation effects resulted in abnormal slope changes in the probability plots of peak flows in the low end of the frequency curve at high AEPs (greater than about 50 percent). To address the low-end abnormal slope changes, a user-defined low-outlier threshold was applied on a case-by-case basis.

Alternative Procedures for Handling Mixed-Population Peak-Flow Records

Peak flows for gaging stations in Montana can result from different types of events, primarily snowmelt, rainfall, or the combination of rainfall and snowmelt. In such cases, the peak flows “may not be homogeneous and may require special treatment” (from Bulletin 17B; U.S. Interagency Council on Water Data, 1982, p. 7). For most Montana gaging stations, the peak flows are reasonably homogeneous, even though they contain different types of events; however, in some cases, the mixed-population characteristics result in nonhomogeneity and are not well represented by the standard Bulletin 17B procedures.

Examples of gaging stations with strong mixed-population characteristics include Swiftcurrent Creek at Many Glacier, Montana (gaging station 05014500; map number 9), Tenmile Creek near Rimini, Montana (gaging station 06062500; map number 101), Marias River near Shelby, Montana (gaging station 06099500; map number 161), and Middle Fork Flathead River near West Glacier, Montana (gaging station 12358500; map number 708) shown in table 1–1. Examples of gaging stations with weaker mixed-population characteristics include Flower Creek near Libby, Montana (gaging station 12303100; map number 611), Lake Creek at Troy, Montana (gaging station 12303500; map number 614), Clark Fork near Drummond, Montana (gaging station 12331800; map number 646), and Prospect Creek at Thompson Falls, Montana (gaging station 12390700; map number 749). For the example gaging stations, examination of the frequency curves plotted in conjunction with the peak flows (accessed by links in tables 1–5 and 1–6) provides insights concerning issues relating to frequency analyses for mixed-population gaging stations.

The selected approach for handling nonhomogeneous mixed-population peak-flow records that was used in this study (and was applied to all of the example gaging stations) differs from Bulletin 17B guidelines and from the previous reporting of frequency analyses for Montana (Parrett and Johnson, 2004). Discussion of the differences is considered important.

In the discussion on the handling of nonhomogeneous mixed-population peak-flow records in the following sections (“Bulletin 17B Guidelines for Analysis of Mixed-Population Peak-Flow Records,” “Mixed-Population Procedures of Previous Frequency Analyses,” and “Selected Approach for Handling Mixed-Population Peak-Flow Records”), general observations are made on types of peak-flow events (snowmelt, rainfall, and the combination of snowmelt and rainfall) in relation to peak-flow timing (that is, the calendar day of occurrence). The observations are relevant to considerations in segregating peak-flow events into discrete types of events. A detailed analysis of the type of event for individual peak flows was not done for this study. General observations on types of events in relation to peak-flow timing are based on consideration of mean monthly temperature and precipitation characteristics in Montana (PRISM Climate Group, 2015), as well as principles described by Mock (1996), Knowles and others (2006), Pederson and others (2010), and Shinker (2010).

Bulletin 17B Guidelines for Analysis of Mixed-Population Peak-Flow Records

In the case where the nonhomogeneous peak flows for a gaging station can be confidently segregated into discrete types of events, Bulletin 17B guidelines include a mixed-population procedure (U.S. Interagency Council on Water Data, 1982, p. 14). In the case where the nonhomogeneous peak flows for a gaging station cannot be confidently segregated into discrete types of events, Bulletin 17B states “the record shall be treated as coming from one population” (U.S. Interagency Council on Water Data, 1982, p. 16).

The Bulletin 17B guidelines for mixed-population analyses present particular difficulties for flood-frequency analysis for Montana gaging stations. The Bulletin 17B mixed-population procedure is not well defined and the presented examples for application bear little resemblance to Montana gaging stations. The primary problems with application of Bulletin 17B guidelines for mixed-population analyses relate to (1) confident segregation of peak flows into discrete types of events, and (2) in some cases, inappropriate frequency results when the entire peak-flow record for a given gaging station is treated as coming from a single population. In Bulletin 17B, the identification and treatment of mixed-population distributions was specifically cited as a topic requiring additional study (U.S. Interagency Council on Water Data, 1982, p. 28).

For many gaging stations in Montana, accurately segregating peak flows into discrete types of events (snowmelt, rainfall, and the combination of snowmelt and rainfall) is not feasible. In many areas of Montana (especially mountainous areas), the timing of high rainfall periods (typically May and June) is somewhat synchronized with or substantially overlaps the typical period of snowmelt runoff (May through mid-July; Pederson and others, 2010). Distinguishing the relative contributions of snowmelt and rainfall for all peak flows would be a large, if not impossible, task. Furthermore, throughout the range of peak flows for many individual gaging stations, the relative contributions of snowmelt and rainfall likely are within a continuum ranging from near zero to near 100 percent; however, with respect to magnitudes of peak-flow events, the relative contributions of snowmelt and rainfall might not be uniformly distributed across the snowmelt- and rainfall-dominance continuum. For many Montana gaging stations, in the probability plots of the peak flows, the large peak flows that plot at the high end of the frequency curve at low AEPs (generally in the range of AEPs from 4 to 0.2 percent) likely are dominated by events caused by the combination of rainfall and snowmelt or, in a few cases, rainfall only. A snowmelt-only event generally is not the cause of unusually large peak flows.

As specifically recognized in Bulletin 17B, frequency analysis of peak-flow records that include snowmelt, rainfall, and the combination of snowmelt and rainfall events can result in “flood frequency curves with abnormally large skew coefficients reflected by abnormal slope changes when plotted on logarithmic normal probability paper” (U.S. Interagency

Council on Water Data, 1982, p. 16). In some cases, treating the data as coming from a single population (as recommended in Bulletin 17B when the peak-flow events cannot be confidently segregated) can result in frequency curves that are substantially above the plotting positions of the peak flows in the lower end of the frequency curve (typically in the range of AEPs from 10 to 4 percent) and are substantially below the plotting positions of the peak flows in the high end of the frequency curve (typically in the range of AEPs from 1 to 0.2 percent). In some cases, the standard Bulletin 17B procedures result in frequency curves that are so far below the plotting positions of individual large gaged peak flows that the individual peak flows have estimated AEPs less than 0.01 percent (corresponding to a recurrence interval greater than 10,000 years) based on the frequency curves. Thus, in some cases, the standard Bulletin 17B procedures were considered to substantially underestimate peak-flow magnitudes for low AEPs; this underestimation was considered to have the potential to increase risk of failure in structure design applications.

Mixed-Population Procedures of Previous Frequency Analyses

The handling of mixed-population analyses in the previous reporting of frequency analyses for Montana (Parrett and Johnson, 2004) is relevant to the discussion of mixed-population issues. The discussion of their methods is intended to present the approach they used to handle the difficulties presented by mixed-population characteristics, the differences between their approach and the selected approach used for this report chapter, and the effect of the differences on the reported frequency results.

In general, the Parrett and Johnson (2004) mixed-population approach was applied at a given gaging station by (1) estimating the nonexceedance period for a large predominantly rainfall peak flow, (2) estimating the frequency of predominantly rainfall peak flows, (3) developing a straight-line frequency curve between the estimated exceedance probability of the large predominantly rainfall peak flow and another selected predominantly rainfall peak flow (that typically was similar in magnitude to presumed large predominantly snowmelt events), (4) calculating a frequency curve for a dataset of presumed predominantly snowmelt events, with the predominantly rainfall events excluded, and (5) combining the frequency curves for predominantly rainfall and presumed predominantly snowmelt events using a joint probability method for mixed-population analysis (U.S. Army Corps of Engineers, 1958). In the Parrett and Johnson (2004) approach, the high end of the frequency curve (generally in the range of AEPs from about 2 to about 0.2 percent) is strongly affected by three subjectively based decisions, including estimation of the nonexceedance period of the large predominantly rainfall peak flow; estimation of the frequency of predominantly rainfall peak flows; and selection of a predominantly rainfall peak flow similar in magnitude to presumed large snowmelt events.

The Parrett and Johnson (2004) approach addressed the mixed-population characteristics of the gaging stations to which it was applied and provided reasonable frequency estimates throughout the frequency curves of individual gaging stations. The approach was based on a large amount of hydrologic expertise; however, some characteristics of the Parrett and Johnson (2004) approach are problematic for routine application. Subjectively based simplifying presumptions are used to classify peak flows into two discrete populations (predominantly rainfall and predominantly snowmelt), when in reality snowmelt runoff and rainfall runoff likely contribute across a continuum, which makes accurate classification difficult. For a given gaging station, the simplifying presumptions affect the estimate of the frequency of predominantly rainfall events and the magnitude of the lowest predominantly rainfall peak used to fit the predominantly rainfall frequency curve. Also, the nonexceedance period of the large predominantly rainfall peak flow at a given gaging station was "somewhat arbitrarily estimated" (Parrett and Johnson, 2004, p. 8) with consideration of recorded precipitation at a nearby rain gage (Parrett, 1997) and general information from a regional flood report (Boner and Stermitz, 1967). In some cases, documentation of the parameters used in the Parrett and Johnson (2004) mixed-population analyses was not possible. As new peak-flow records become available, consistent application of the Parrett and Johnson (2004) mixed-population approach to the changing datasets is problematic.

The Parrett and Johnson (2004) approach also is problematic in maintaining consistency in flood-frequency analyses between gaging stations in areas where the strength of the mixed-population characteristics of the peak-flow records are variable. The decision to apply the Parrett and Johnson (2004) mixed-population approach at an individual gaging station results in using computational procedures that are distinctly different from and more complex than analyzing the data using the PEAKFQ computer program (Flynn and others, 2006) that was used for other gaging stations. In some cases, gaging stations that were geographically closely located and had generally similar peak-flow characteristics were not consistently handled (with respect to applying or not applying the mixed-population approach) by Parrett and Johnson (2004).

The Parrett and Johnson (2004) mixed population approach does not allow determination of distributional parameters for the combined predominantly snowmelt and predominantly rainfall frequency curves. Thus, the approach does not allow calculation of confidence intervals about the frequency results and also limits the use of the results in various applications.

Selected Approach for Handling Mixed-Population Peak-Flow Records

The selected approach for handling mixed-population peak-flow records (as described herein) was applied to 79 gaging stations (table 1–5) for which the nonhomogeneous peak flows were considered not well represented as coming from a single population according to standard Bulletin 17B procedures. The decision to apply the selected approach to an individual gaging station was based on the following considerations: (1) in the probability plots of the peak flows, at least two large peak flows are somewhat substantially elevated above the main body of peak flows and the elevated peak flows were known to be caused by large rainfall events, alone or in combination with snowmelt, (2) in the probability plots, a somewhat distinct upward break in slope is apparent in the plotting position pattern of peak flows, typically in the range of AEPs from about 20 to 2 percent, (3) in the probability plots, a somewhat distinct downward break in slope is apparent in the plotting position pattern in the low end of the frequency curve, typically in the range of AEPs from about 66.7 to 50 percent, (4) other gaging stations in the geographic vicinity also are considered to have mixed-population characteristics, and (5) the gaging station was considered by Parrett and Johnson (2004) to have mixed population characteristics. Nearly all of the gaging stations that were considered to have mixed-population characteristics met at least three of the considerations.

The primary characteristics of the selected approach for handling mixed-population peak-flow records are the use of the station skew, definition of a user-defined low-outlier threshold (selected by the peak-flow analyst), or both. The primary objectives of the selected approach are to de-emphasize subjectively based presumptions, emphasize the information directly contained in the gaged records, and allow effective handling of the data when considered as coming from a single population.

The most important characteristic of the selected approach is the use of the station skew instead of the weighted skew. Bulletin 17B states that mixed-population peak-flow records can result in “flood frequency curves with abnormally large skew coefficients reflected by abnormal slope changes when plotted on logarithmic normal probability paper” (U.S. Interagency Council on Water Data, 1982, p. 16). Presumably, the Bulletin 17B statements on abnormality relate to comparison of mixed populations to homogeneous populations. For many Montana gaging stations with mixed-population characteristics, large skew coefficients and unusual slope changes are typical. Thus, use of the station skew, instead of the weighted skew, can more appropriately represent the peak-flow distributional characteristics of a gaging station with mixed-population characteristics. In most cases where the selected approach was applied, use of the station skew is consistent with Bulletin 17B guidelines that permit altering the skew-weighting procedure when the station and generalized skews differ by more than 0.5 (U.S. Interagency Council on Water Data, 1982, p. 15). For an individual Montana gaging station considered to have mixed-population characteristics, frequency analysis was initially done using the station skew. If the resulting frequency curve appropriately represented the probability plot of the peak flows, the analysis was accepted. If the frequency curve was still considered to not well represent the probability plot of the peak flows, a user-defined low-outlier threshold (selected by the peak-flow analyst) was defined.

Definition of a user-defined low-outlier threshold manipulates the frequency analysis so that the mixed-population records are more effectively treated as coming from a single population. For many of the Montana gaging stations considered to have mixed-population characteristics, a somewhat distinct downward break in slope is apparent in the plotting position pattern in the low end of the frequency curve, typically in the range of AEPs from about 66.7 to 50 percent. Presumably, the unusual changes in slope reflect transitions between snowmelt dominance and rainfall dominance within the snowmelt- and rainfall-dominance continuum. The downward breaks in slope in the low end of the frequency curve can distort the fit of the frequency curve in the high end where the data are more representative of substantial flood or near-flood events (Advisory Committee on Water Information, 2007). For some of the Montana gaging stations considered to have mixed-population characteristics, downward breaks in slope in the low end of the frequency curve are not apparent; however, definition of a user-defined low-outlier threshold sometimes was used to improve the frequency results. Most users of peak-flow data have little interest in frequency estimates for AEPs greater than about 50 percent, but this high range of AEPs accounts for a large proportion of the gaged data. When treating the entire nonhomogeneous gaged record as coming from a single population, directly incorporating all of the specific values in the high range of AEPs substantially affects the distributional parameters used in the frequency analysis. As a result, the high end of the frequency curve in the low range of AEPs (from about 2 to 0.2 percent) can be misrepresented. Setting a user-defined low-outlier threshold allows more effective treatment of the dataset as coming from a single population, but does not exclude the data in the high range of AEPs. Instead, the frequency of occurrence of values below the user-defined low-outlier threshold is incorporated into the analysis through a conditional probability adjustment (Appendix 5 in U.S. Interagency Council on Water Data, 1982) but the specific values below the threshold are not directly incorporated into the determination of the overall distributional parameters. In essence, this places greater emphasis on low AEP peak flows and allows more appropriate treatment as a single population.

In applying the selected approach for handling mixed-population peak-flow records, if the use of the station skew alone did not result in a frequency curve that appropriately represented the probability plot of the peak flows, a user-defined low-outlier threshold was defined. Initially, the user-defined low-outlier threshold was set to a value about equal to the 20th nonexceedance percentile of the peak flows. If the frequency curve appropriately represented the probability plot of the peak flows, the analysis was accepted. If the frequency curve was still considered to not well represent the probability plot of the peak flows, the user-defined low-outlier threshold was set to some other value generally less than the 45th nonexceedance percentile of the peak flows. In most cases that the selected approach was applied and a user-defined low-outlier threshold was used, the user-defined low-outlier threshold was set to a value about equal to the 20th nonexceedance percentile of the peak flows.

The selected approach for handling mixed-population peak-flow records generally provides frequency results that are similar to results produced by using the Parrett and Johnson (2004) approach, but the selected approach is more easily and consistently applied. The selected approach is somewhat robust. In cases where mixed-population characteristics are weak, the selected approach generally provides frequency results that are similar to results produced by using standard Bulletin 17B procedures.

Alternative Procedures Used for Handling Atypical Low-End Peak-Flow Records

Many partial-record crest-stage gaging stations in Montana have been located along ephemeral channels that seldom flow, and many gaged streams can be subject to low- or zero-streamflow conditions for extended periods. Probability plots of peak flows for gaging stations that are strongly affected by low- or zero-streamflow values frequently deviate from typical patterns, primarily in the low end of the frequency curve at high AEPs (greater than about 50 percent). The atypical patterns in the low end of the frequency curve include abnormal slope changes in the probability plots of peak flows or, for some gaging stations, a few low peak flows that are somewhat distinctly separated from the main body of peak flows. Examples of gaging stations with atypical low-end peak-flow records include Little Prickly Pear Creek near Marysville, Montana (gaging station 06068500; map number 106), Powell Coulee near Browning, Montana (gaging station 06098700; map number 159), Unger Coulee near Vandalia, Montana (gaging station 06172300; map number 355), and Snell Creek near Hathaway, Montana (gaging station 06296100; map number 506) shown in table 1–1. For the example gaging stations, examination of the frequency curves plotted in conjunction with the peak flows (accessed by links in tables 1–5 and 1–6) provides insights concerning issues relating to frequency analyses for gaging stations with atypical low-end peak-flow records.

For some gaging stations (for example, Powell Coulee near Browning, Montana [gaging station 06098700; map number 159] and Snell Creek near Hathaway, Montana [gaging station 06296100; map number 506] [table 1–1]), atypical low-end peak-flow records can result in probability plots with abnormal slope changes, and varying degrees of sigmoid or S-shape curves. The log-Pearson III distribution typically is most effective in fitting data that plot on log-probability scales as either straight lines or arcs that are uniformly either convex or concave. Standard Bulletin 17B procedures are not well suited to S-shape curves.

For some gaging stations (for example, Little Prickly Pear Creek near Marysville, Montana [gaging station 06068500; map number 106] and Unger Coulee near Vandalia, Montana [gaging station 06172300; map number 355], a few peak flows are somewhat distinctly separated from the main body of peak flows. Because of the distributional properties of the peak-flow data (typically having a large standard deviation), the unusually low peak flows are not identified as low outliers by the Grubbs-Beck outlier test used in standard Bulletin 17B procedures; however, the unusually low peak flows can distort the fit of the frequency curve in the high end where the data are more representative of substantial flood or near-flood events (Advisory Committee on Water Information, 2007).

The alternative procedures used for handling atypical low-end peak-flow records involved the application of a user-defined low-outlier threshold (selected by the frequency analyst) to improve the fit of the frequency curve. The user-defined low-outlier threshold serves to censor low-lying data points so that they do not exert a distorting effect on the fitted frequency curve (Advisory Committee on Water Information, 2007); however, the Bulletin 17B procedures for handling low outliers do not ignore the censored low-lying data points, but rather incorporate their frequency of occurrence through the use of a conditional probability adjustment (Appendix 5 in U.S. Interagency Advisory Council on Water Data, 1982).

Some gaging stations are considered to have atypical low-end curves because of a special case. The gaging stations have a large proportion (generally greater than about 35 percent) of peak flows that are less than the gage base (that is, zero streamflows) and strongly negative skews that are substantially less than the generalized skew coefficients from the Bulletin 17B national skew map. Frequency curves determined from standard Bulletin 17B procedures plotted substantially above the plotting positions of the peak flows in the high end of the frequency curve (typically in the range of AEPs from 2 to 0.2 percent). The alternative procedures used for handling the atypical low-end peak-flow records involved the use of the station skew instead of the weighted skew. Several of the gaging stations have 10 or less peak flows greater than the gage base; uncertainty in the frequency results is large for these gaging stations.

Peak-Flow Frequency Results

Frequency results (estimates of peak-flow magnitudes for 66.7-, 50-, 42.9-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2 percent AEPs) are reported for 725 gaging stations (table 1–6 in appendix 1 at the back of this report chapter). For 29 of the 725 gaging stations, frequency results are reported for both unregulated and regulated conditions. Thus, frequency results are reported for a total of 754 analyses.

Considerations for Interpreting Peak-flow Frequency Analyses and Results for Montana

For gaging stations classified as having major dam regulation, the frequency estimates for low AEPs at the high end of the frequency curve (AEPs less than or equal to about 1 percent) for the regulated periods of record should be used with caution; frequency estimates for high AEPs in the low end of the frequency curve (AEPs greater than or equal to about 2 percent) generally are considered to be reliable. Concerning frequency analyses for regulated gaging stations, Bulletin 17B states that “procedures do not cover watersheds where flood flows are appreciably altered by reservoir regulation or where the possibility of unusual events, such as dam failures, must be considered” (U.S. Interagency Advisory Council on Water Data, 1982, p. 2–3). For gaging stations classified as having major dam regulation, frequency results for the low AEPs are presented for informational and consistency purposes, but caution should be used when using the results for important applications, such as structure design. For many regulated streams, the potential effects of regulation diminish progressively in a downstream direction. The proximity of the gaging station to the regulating dam might be a consideration when evaluating usage of the low AEPs.

Frequency analyses are reported for nearly all gaging stations in Montana that have at least 10 years of peak-flow records; however, the climatic conditions of the specific time period during which the data were collected can substantially affect how well the frequency results represent long-term hydrologic conditions. Differences in the timing of the periods of record can result in substantial inconsistencies in frequency results for hydrologically similar gaging stations. Potential for inconsistency is increased for short-term gaging stations that have less than about 25 years of peak-flow records. The representativeness of the frequency estimates for a short-term gaging station can be improved by weighting the reported results in association with frequency estimates from regional regression equations (as described by Sando, Roy, and others, 2016). Frequency estimates for short-term gaging stations might also be improved by investigation of record extension procedures, including the two-station procedure (Matalas and Jacobs, 1964) recommended in Bulletin 17B, or the maintenance of variance type I procedure (MOVE.1; Alley and Burns, 1983). Application of the MOVE.1 procedure to peak-flow records is described by Sando and others (2008) and Sando, S.K., Sando, Roy, and others, 2016).

Several gaging stations have peak-flow records with greater than 25 percent zero values. Frequency results for these gaging stations generally should be used with caution.

The frequency analyses reported in this study differ in some respects from the analyses done by Parrett and Johnson (2004). The mixed-population procedures of this study differ from the procedures of Parrett and Johnson (2004) and are considered to be simpler and more consistently applied, while still providing reasonable frequency results. Another difference between this study and Parrett and Johnson (2004) includes the use of a documented method for consistent classification of regulation status of gaging stations. Furthermore, Parrett and Johnson (2004) reported only a single frequency analysis for an individual regulated gaging station. For 29 of the 725 gaging stations included in this study, frequency analyses and results are reported for both unregulated and regulated conditions.

The number of gaging stations included in this study (725) increased from 660 gaging stations included in the previous reporting of frequency analyses for Montana (Parrett and Johnson, 2004), which was based on data through water year 1998. For 35 of the additional 65 gaging stations, the incremental data collected after 1998 provided enough data (at least 10 years) for frequency analysis. The other 30 additional gaging stations were not reported by Parrett and Johnson (2004) for discretionary reasons.

In some cases, the additional data collected during water years 1999–2011 has resulted in substantial changes in frequency estimates. During water years 1999–2011, 78 gaging stations recorded the largest peak flow of record, 68 gaging stations recorded the second largest peak flow of record, and 82 gaging stations recorded the third largest peak flow of record. A large amount of flooding occurred in water year 2007 in northwestern Montana and in water year 2011 in central and southeastern Montana. For some gaging stations, the large floods resulted in substantial increases in peak-flow magnitudes associated with low AEPs (less than about 4 percent). The St. Mary River Basin (not shown in fig. 1) was the primary drainage basin affected by the water year 2007 flooding. The Judith, Musselshell, Pryor Creek, Little Bighorn River, and Rosebud Creek Basins (not shown in fig. 1) were the primary drainage basins affected by the water year 2011 flooding. The water year 2011 flooding accounted for the largest recorded peak flow for 40 gaging stations, the second largest recorded peak flow for 30 gaging stations, and the third largest recorded peak flow for 31 gaging stations. Furthermore, the water year 2011 peak flow served to define the high-outlier threshold in historically adjusted flood-frequency analyses for 17 individual gaging stations.

Summary

Chapter C of this Scientific Investigations Report documents results from a study by the U.S. Geological Survey, in cooperation with the Montana Department of Transportation and Montana Department of Natural Resources, to provide an update of statewide peak-flow frequency analyses and results for Montana. The purpose of this report chapter is to present peak-flow frequency analyses and results for 725 streamflow-gaging stations (hereinafter referred to as gaging stations) in or near Montana based on data through water year 2011. The 725 gaging stations included in this study represent nearly all gaging stations in Montana (plus some from adjacent States or Canadian Provinces) that have at least 10 years of peak-flow records through water year 2011. For 29 of the 725 gaging stations, frequency analyses and results are reported for both unregulated and regulated conditions. Thus, peak-flow frequency analyses and results are reported for a total of 754 analyses. Estimates of peak-flow magnitudes for 66.7-, 50-, 42.9-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent annual exceedance probabilities (AEPs) are reported. These AEPs

correspond to 1.5-, 2-, 2.33-, 5-, 10-, 25-, 50-, 100-, 200-, and 500-year recurrence intervals.

Methods of data compilation and analysis are described in this report chapter. These methods relate to determination of the regulation status of gaging stations, data compilation and pre-analysis manipulation, and frequency analysis.

Most Federal agencies and many State, local, and private entities follow procedures described in Bulletin 17B "Guidelines for Determining Flood Flow Frequency" (hereinafter referred to as Bulletin 17B) for frequency analysis. Bulletin 17B recommends the use of the log-Pearson III probability distribution, which is fit by using the mean, standard deviation, and skew of the logs of the peak flows (maximum instantaneous discharge for each year) for a given gaging station. Procedures described in Bulletin 17B were used as primary guidelines for developing the frequency estimates presented in this report chapter, and the computer program PEAKFQ, developed by the U.S. Geological Survey, was used to run the frequency analyses.

Peak-flow frequencies initially were analyzed for the 725 gaging stations by using standard Bulletin 17B procedures for fitting the log-Pearson III distribution. Fits of the preliminary frequency curves with the probability plots of the peak flows were then evaluated. In most cases (about 80 percent of the frequency analyses), fits of the standard Bulletin 17B analyses were determined to be satisfactory. In other cases, however, the frequency results could be improved by using alternative procedures for handling specific characteristics of the peak-flow records for some gaging stations. The specific characteristics of peak-flow records addressed by alternative procedures include (1) regulated peak-flow records, (2) mixed-population peak-flow records, and (3) atypical low-end peak-flow records. The alternative procedures are described in this report chapter.

A large amount of flooding occurred in water year 2007 in northwestern Montana and in water year 2011 in central and southeastern Montana, which resulted in substantial increases in peak-flow magnitudes associated with low AEPs (less than about 4 percent) for some gaging stations. The water year 2011 flooding accounted for the largest recorded peak flow for 40 gaging stations, the second largest recorded peak flow for 30 gaging stations, and the third largest recorded peak flow for 31 gaging stations. Furthermore, the water year 2011 peak flow served to define the high-outlier threshold in historically adjusted flood-frequency analyses for 17 individual gaging stations.

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Appendix 1

Appendix 1. Information on Streamflow-Gaging Stations, Data Augmentation, Regulation Structures, and Peak-Flow Frequency Analyses and Results

This appendix presents information on streamflow-gaging stations (table 1–1), data augmentation (table 1–2) and manipulation (table 1–3), regulation structures (table 1–4), peak-flow analyses (table 1–5), and peak-flow frequency results (table 1–6). In addition to the frequency results in table 1–6, additional graphical and tabular information for each streamflow-gaging station can be accessed by links included in tables 1–5 and 1–6 in the “Station identification number” column. This additional information for each gaging station includes (1) a graph showing the frequency curve in association with the probability plots of the peak flows (with plotting positions determined by using the Cunnane formulation, as described by Helsel and Hirsch [2002]), (2) a time-series graph of the peak flows, (3) a table with summary information on the frequency analysis, and (4) a table of the peak flows (in time series and also ranked). In the probability plots of the peak flows, all peak flows less than or equal to 0.1 ft^3/s have been adjusted to 0.1 ft^3/s, and the plotting positions of individual peak flows reflect effects of historical adjustments in the frequency analyses.

An Excel file containing the tables is available at http://dx.doi.org/10.3133/sir20155019C.

Table 1–1. Information on streamflow-gaging stations for which peak-flow frequency analyses are reported.

Table 1–2. Information on data augmentation by combining records of multiple streamflow-gaging stations.

Table 1–3. Information on data manipulation by substituting values for peak flows in years of gage base alterations.

Table 1–4. Information on major regulation structures affecting peak-flow records.

Table 1–5. Documentation regarding analytical procedures for peak-flow frequency analyses.

Table 1–6. Peak-flow frequency results.

Table 1–2. Information on data augmentation by combining records of multiple streamflow-gaging stations.

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

Primary streamflow-gaging station					
Map number (fig. 1)	**Station identification number**	**Station name**	**Contributing drainage area, in square miles**	**Number of years of peak-flow records**	**Period of record, in water years**
48	06026500	Jefferson River near Twin Bridges, Montana	7,616	35	1942–43, 1958–72, 1994–2011
64	06036650	Jefferson River near Three Forks, Montana	9,558	33	1979–2011
68	06037100	Gibbon River at Madison Junction, Yellowstone National Park, Wyoming	125	9	2003–2011
80	06043500	Gallatin River near Gallatin Gateway, Montana	819	83	1890–94, 1931–81, 1985–2011
131	06080000	Sun River near Augusta, Montana	609	27	1890, 1905–29, 1964
136	06086000	Sun River at Fort Shaw, Montana	1,395	16	1913–28
148	06091700	Two Medicine River below South Fork, near Browning, Montana	250	35	1977–2011
151	06093200	Badger Creek below Four Horns Canal, near Browning, Montana	153	38	1974–2011
178	06102500	Teton River below South Fork, near Choteau, Montana	110	22	1948–54, 1964, 1998–2011
209	06118500	South Fork Musselshell River above Martinsdale, Montana	268	38	1942–79
221	06123030	Musselshell River above Mud Creek, near Shawmut, Montana	1,518	14	1998–2011
321	06154550	Peoples Creek below Kuhr Coulee, near Dodson, Montana	688	21	1989–2009
393	06181000	Poplar River near Poplar, Montana	3,157	61	1909, 1915, 1921, 1923, 1946, 1948–63, 1965–69, 1975–79, 1982–2011
402	06183450	Big Muddy Creek near Antelope, Montana	955	33	1979–2011
423	06191000	Gardner River near Mammoth, Yellowstone National Park, Wyoming	198	62	1939–72, 1984–2011
448	06208500	Clarks Fork Yellowstone River at Edgar, Montana	2,034	72	1922–32, 1934–69, 1987–2011
486	06294500	Bighorn River above Tullock Creek, near Bighorn, Montana	22,419	30	1982–2011
505	06296003	Rosebud Creek at mouth, near Rosebud, Montana	1,307	32	1975–2006
525	06307830	Tongue River below Brandenberg bridge, near Ashland, Montana	3,879	18	1974–84, 2001–7
607	12302055	Fisher River near Libby, Montana	842	44	1948, 1969–2011
646	12331800	Clark Fork near Drummond, Montana	2,516	19	1993–2011
652	12335100	Blackfoot River above Nevada Creek, near Helmville, Montana	498	12	2000–11
665	12340500	Clark Fork above Missoula, Montana	6,021	83	1908, 1930–2011
669	12343400	East Fork Bitterroot River near Conner, Montana	380	21	1956–72, 2001–4
677	12348500	Willow Creek near Corvallis, Montana	22.6	19	1920–22, 1958–73
721	12365700	Stillwater River at Lawrence Park, at Kalispell, Montana	596	5	2007–11
723	12366080	Whitefish River near mouth at Kalispell, Montana	180	5	2007–11

Table 1–2. Information on data augmentation by combining records of multiple streamflow-gaging stations.—Continued

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

Primary streamflow-gaging station		Secondary streamflow-gaging station(s) used to augment records of primary streamflow-gaging station			
Map number (fig. 1)	Station identification number	Station name	Drainage area, in square miles	Number of years of peak-flow records	Period of record, in water years
48	06027000	Jefferson River near Silver Star, Montana	7,616	35	1942–43, 1958–72, 1994–2011
64	06034500	Jefferson River at Sappington, Montana	9,558	33	1979–2011
68	06037000	Gibbon River near West Yellowstone, Montana	125	9	2003–2011
80	06044000	Gallatin River near Salesville, Montana	819	83	1890–94, 1931–81, 1985–2011
131	06080900	Sun River below diversion dam, near Augusta, Montana	609	27	1890, 1905–29, 1964
136	06087500	Sun River at Sun River, Montana	1,395	16	1913–28
148	06092000	Two Medicine River near Browning, Montana	250	35	1977–2011
151	06092500	Badger Creek near Browning, Montana	153	38	1974–2011
178	06103000	Teton River at Strabane, Montana	110	22	1948–54, 1964, 1998–2011
209	06119500	South Fork Musselshell River near Martinsdale, Montana	268	38	1942–79
221	06122800	Musselshell River near Shawmut, Montana	1,518	14	1998–2011
321	06154500	Peoples Creek near Dodson, Montana	688	21	1989–2009
393	06180500	Poplar River near Bredette, Montana	3,157	61	1909, 1915, 1921, 1923, 1946, 1948–63, 1965–69, 1975–79, 1982–2011
402	06183500	Big Muddy Creek at Reserve, Montana	955	33	1979–2011
423	06190500	Gardner River at Mammoth, Yellowstone National Park, Wyoming	198	62	1939–72, 1984–2011
448	06208000	Clarks Fork Yellowstone River at Fromberg, Montana	2,034	72	1922–32, 1934–69, 1987–2011
	06208800	Clarks Fork Yellowstone River near Silesia, Montana	2,109	17	1970–86
486	06294700	Bighorn River at Bighorn, Montana	22,889	37	1945–81
505	06296000	Rosebud Creek near Forsyth, Montana	1,285	19	1948–53, 1955–57, 1959, 1961–67, 1969, 1978
525	06307800	Tongue River near Ashland, Montana	3,763	6	1967–72
607	12302000	Fisher River near Jennings, Montana	784	21	1948, 1951–69, 1974
646	12331600	Clark Fork at Drummond, Montana	2,386	12	1967, 1973–83
652	12335000	Blackfoot River near Helmville, Montana	482	16	1941–53, 1964, 1974–75
665	12341500	Clark Fork at Missoula, Montana	6,108	9	1899–1907
669	12343500	East Fork Bitterroot River at Conner, Montana	404	21	1937–57
677	12349000	Willow Creek at Anfinson Ranch, near Corvallis, Montana	24.8	6	1938–43
721	12365000	Stillwater River near Whitefish, Montana	558	55	1931–50, 1964, 1973–2006
723	12366000	Whitefish River near Kalispell, Montana	170	57	1929–50, 1964, 1973–2006

Table 1–2. Information on data augmentation by combining records of multiple streamflow-gaging stations.—Continued

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

Primary streamflow-gaging station		Combined characteristics for primary streamflow-gaging station	
Map number (fig. 1)	Station identification number	Combined number of years of peak-flow records	Combined period of record, in water years
48	06026500	60	1911–16, 1921–39, 1942–43, 1958–72, 1994–2011
64	06036650	75	1895, 1897–1905, 1939–69, 1975, 1979–2011
68	06037100	22	1984–96, 2003–11
80	06043500	98	1890–94, 1896–1905, 1912–13, 1921–23, 1931–81, 1985–2011
131	06080000	28	1890, 1905–29, 1964, 1975
136	06086000	23	1906–28
148	06091700	37	1964, 1975, 1977–2011
151	06093200	61	1951–2011
178	06102500	40	1908–25, 1948–54, 1964, 1998–2011
209	06118500	47	1908–14, 1930, 1932, 1942–79
221	06123030	26	1986–2011
321	06154550	49	1952–66, 1968–73, 1982–2009
393	06181000	74	1909, 1915, 1921, 1923, 1934–63, 1965–69, 1975–79, 1982–2011
402	06183450	41	1920–21, 1923–24, 1950–53, 1979–2011
423	06191000	78	1923–72, 1984–2011
448	06208500	98	1905–13, 1922–32, 1934–2011
486	06294500	67	1945–2011
505	06296003	50	1948–53, 1955–57, 1959, 1961–67, 1969, 1975–2006
525	06307830	24	1967–72, 1974–84, 2001–7
607	12302055	62	1948, 1951–2011
646	12331800	31	1967, 1973–83, 1993–2011
652	12335100	28	1941–53, 1964, 1974–75, 2000–2011
665	12340500	92	1899–1908, 1930–2011
669	12343400	40	1937–72, 2001–4
677	12348500	25	1920–22, 1938–43, 1958–73
721	12365700	60	1931–50, 1964, 1973–2011
723	12366080	62	1929–50, 1964, 1973–2011

Table 1–3. Information on data manipulation by substituting values for peak flows in years of gage base alterations.

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

Map number (fig. 1)	Station identification number	Station name	Contributing drainage area, in square miles	Number of years of peak-flow records	Period of record, in water years	Water year of gage base alteration	Substituted peak flow, in cubic feet per second
24	06015430	Clark Canyon near Dillon, Montana	17.3	39	1969, 1974–2011	2001	12
						2002	9.5
93	06056300	Cabin Creek near Townsend, Montana	11.9	52	1960–2011	1999	3.0
						2000	3.0
1440	06090550	Little Otter Creek near Raynesford, Montana	40.4	38	1974–2011	1999	4.0
						2001	4.0
159	06098700	Powell Coulee near Browning, Montana	12.6	38	1974–2011	2000	0.5
238	06127585	Little Wall Creek tributary near Flatwillow, Montana	1.6	38	1974–2011	2004	0.4
						2006	0.4
284	06137600	Sage Creek tributary No. 2 near Joplin, Montana	2.7	38	1974–2011	2003	1.4
						2008	0.5
311	06151500	Battle Creek near Chinook, Montana	1,485	44	1905–14, 1917–21, 1952, 1984–2011	1984	0.1
312	06153400	Fifteenmile Creek tributary near Zurich, Montana	1.7	38	1974–2011	2006	2.5
331	06156100	Lush Coulee near Whitewater, Montana	8.9	39	1972, 1974–2011	2000	1.0
						2006	1.0
337	06163400	Denniel Creek near Val Marie, Saskatchewan	192	14	1963–76	1968	0.5
461	06216200	West Wets Creek near Billings, Montana	8.8	57	1955–2011	2004	2.2
						2005	8.5
						2006	8.5
487	06294600	East Cabin Creek tributary near Hardin, Montana	8.0	39	1973–2011	2006	4.5
						2008	4.5
500	06295100	Rosebud Creek near Kirby, Montana	35.5	36	1960–74, 1982–2002	2002	2.5
545	06324995	Badger Creek at Biddle, Montana	6.1	40	1972–2011	2005	5.0
555	06326580	Lame Jones Creek tributary near Willard, Montana	0.5	38	1974–2011	2002	0.5
						2006	0.4
562	06326950	Yellowstone River tributary No. 5 near Marsh, Montana	1.0	50	1962–2011	1982	0.5
						1994	0.5
						2005	0.5
						2006	0.7

Table 1–3. Information on data manipulation by substituting values for peak flows in years of gage base alterations.—Continued

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

Map number (fig. 1)	Station identification number	Station name	Contributing drainage area, in square miles	Number of years of peak-flow records	Period of record, in water years	Water year of gage base alteration	Substituted peak flow, in cubic feet per second
563	06326960	Timber Fork Upper Sevenmile Creek tributary near Lindsay, Montana	1.1	38	1974–2011	2005	0.3
570	06328100	Yellowstone River tributary No. 6 near Glendive, Montana	2.9	38	1974–2011	2008	1.0
584	06334330	Little Missouri River tributary near Albion, Montana	1.4	40	1972–2011	2001	0.4
586	06334625	Coal Creek tributary near Mill Iron, Montana	0.9	38	1974–2011	2005	1.1
						2008	1.2

Table 1–4. Information on major regulation structures affecting streamflow records.

[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]

Dam indentification number[1]	Name of structure	Major river basin	Primary affected stream(s)	First water year that streamflow records are considered to be affected by regulation	Contributing drainage area upstream from regulation structure, in square miles[2]	Owner of structure
MT00572	Lake Sherburne dam	Saskatchewan	Swift Current Creek	1920	64	Bureau of Reclamation
--	St. Mary River diversion dam and canal	Saskatchewan	St. Mary River, North Fork Milk River	1915	Unknown	Bureau of Reclamation
MT00905	Lima dam	Missouri	Red Rock River	1934	566	Beaverhead County
MT00569	Clark Canyon dam	Missouri	Beaverhead River	1964	2,314	Bureau of Reclamation
--	Barretts diversion dam	Missouri	Beaverhead River	1964	Unknown	Bureau of Reclamation
MT00004	Ruby dam	Missouri	Ruby River	1938	595	State of Montana
MT00022	Willow Creek dam	Missouri	Willow Creek	1938	154	State of Montana
MT00134	Hebgen dam	Missouri	Madison River	1915	931	Northwestern Energy
MT00561	Madison dam	Missouri	Madison River	1906	2,139	Northwestern Energy
MT00018	Middle Creek dam	Missouri	Hyalite Creek	1951	28	State of Montana
MT00568	Canyon Ferry dam	Missouri	Missouri River	1951	15,853	Bureau of Reclamation
MT00560	Hauser dam	Missouri	Missouri River	1907	16,669	Northwestern Energy
MT00559	Holter dam	Missouri	Missouri River	1918	16,923	Northwestern Energy
MT00009	North Fork Smith River dam	Missouri	North Fork Smith River	1936	72	State of Montana
MT00571	Gibson Dam	Missouri	Sun River	1928	555	Bureau of Reclamation
--	Sun River diversion dam	Missouri	Sun River	1915	609	Bureau of Reclamation
MT00563	Morony dam	Missouri	Missouri River	1930	22,881	Northwestern Energy
MT00573	Lower Two Medicine dam	Missouri	Two Medicine River	[3]1912	52	Bureau of Indian Affairs
MT00581	Swift (Pondera) dam	Missouri	Birch Creek	[4]1913	75	Pondera County Canal and Reservoir Company
MT00579	Tiber dam	Missouri	Marias River	1956	4,395	Bureau of Reclamation
--	Deadman's Basin diversion canal	Missouri	Musselshell River	1941	Unknown	State of Montana
MT00008	Petrolia dam	Missouri	Flatwillow Creek	1951	593	Petrolia Water Users
MT00570	Fresno dam	Missouri	Milk River	1939	3,019	Bureau of Reclamation
MT00586	Paradise diversion dam	Missouri	Milk River	1966	5,829	Bureau of Reclamation
MT00583	Dodson diversion dam	Missouri	Milk River	1910	10,438	Bureau of Reclamation
MT00584	Vandalia diversion dam	Missouri	Milk River	1917	18,853	Bureau of Reclamation
MT00025	Fort Peck dam	Missouri	Missouri River	1937	56,408	Army Corps of Engineers

Table 1–4. Information on major regulation structures affecting streamflow records.—Continued

[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]

Dam indentification number[1]	Name of structure	Major river basin	Primary affected stream(s)	First water year that streamflow records are considered to be affected by regulation	Contributing drainage area upstream from regulation structure, in square miles[2]	Owner of structure
MT00646	Big Muddy Creek dam	Missouri	Big Muddy Creek	1953	2,046	Unknown
MT00562	Mystic Lake dam	Missouri	West Rosebud Creek	1927	48	Northwestern Energy
MT00001	Cooney dam	Missouri	Red Lodge Creek	1937	200	State of Montana
MT00576	Yellowtail dam	Missouri	Bighorn River	1965	19,625	Bureau of Reclamation
MT00002	Tongue River dam	Missouri	Tongue River	1939	1,781	State of Montana
MT00652	Libby dam	Columbia	Kootenai River	1973	8,998	Army Corps of Engineers
MT00221	Lake Creek dam	Columbia	Lake Creek	1917	202	Montana Light and Power Company
MT01400	Warm Springs Ponds	Columbia	Silver Bow Creek	1911	466	Atlantic Richfield Company
MT03761	Meyer’s dam	Columbia	Warm Springs Creek	1902	110	Unknown
MT00019	West Fork dam	Columbia	West Fork Bitterroot River	1940	317	State of Montana
MT00565	Hungry Horse dam	Columbia	Sourth Fork Flathead River	1951	1,659	Bureau of Reclamation
MT00226	Salish-Kootenai Dam	Columbia	Flathead River	1939	7,077	Confederated Salish and Kootenai Tribes
MT00589	Mission dam	Columbia	Mission Creek	1935	15	Unknown
MT00224	Thompson Falls dam	Columbia	Clark Fork	1916	20,904	Northwestern Energy

Table 1–4. Information on major regulation structures affecting streamflow records.—Continued

[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]

Dam indentification number[1]	Name of structure	Major river basin	Primary purpose(s)	Storage, in acre-feet	Diversion capacity, in cubic feet per second	Reference(s)
MT00572	Lake Sherburne dam	Saskatchewan	Irrigation	68,060	--	Bureau of Reclamation, 2015
--	St. Mary River diversion dam and canal	Saskatchewan	Irrigation diversion	Minor (diversion dam)	850	Bureau of Reclamation, 2015
MT00905	Lima dam	Missouri	Irrigation	84,000	--	Bureau of Land Management, 2005
MT00569	Clark Canyon dam	Missouri	Multipurpose	325,324	--	Bureau of Reclamation, 2015
--	Barretts diversion dam	Missouri	Irrigation diversion	Minor (diversion dam)	640	Bureau of Reclamation, 2015
MT00004	Ruby dam	Missouri	Irrigation	36,633	--	Montana Department of Natural Resources and Conservation, 2015
MT00022	Willow Creek dam	Missouri	Irrigation	18,000	--	Montana Department of Natural Resources and Conservation, 2015
MT00134	Hebgen dam	Missouri	Multipurpose	379,000	--	Northwestern Energy, 2015
MT00561	Madison dam	Missouri	Hydropower	Minor (run-of-river dam)	--	Northwestern Energy, 2015
MT00018	Middle Creek dam	Missouri	Irrigation, domestic	10,184	--	Montana Department of Natural Resources and Conservation, 2015
MT00568	Canyon Ferry dam	Missouri	Multipurpose	2,051,000	--	Bureau of Reclamation, 2015
MT00560	Hauser dam	Missouri	Hydropower	Minor (run-of-river dam)	--	Northwestern Energy, 2015
MT00559	Holter dam	Missouri	Hydropower	Minor (run-of-river dam)	--	Northwestern Energy, 2015
MT00009	North Fork Smith River dam	Missouri	Irrigation	11,406	--	Montana Department of Natural Resources and Conservation, 2015
MT00571	Gibson Dam	Missouri	Irrigation	96,477	--	Bureau of Reclamation, 2015
--	Sun River diversion dam	Missouri	Irrigation diversion	Minor (diversion dam)	1,400	Bureau of Reclamation, 2015
MT00563	Morony dam	Missouri	Hydropower	Minor (run-of-river dam)	--	Northwestern Energy, 2015
MT00573	Lower Two Medicine dam	Missouri	Irrigation, flood control	25,120	--	--
MT00581	Swift (Pondera) dam	Missouri	Irrigation	34,000	--	Pondera County Canal and Reservoir Company, 2010
MT00579	Tiber dam	Missouri	Multipurpose	1,555,898	--	Bureau of Reclamation, 2015
--	Deadman's Basin diversion canal	Missouri	Irrigation diversion	Minor (diversion dam)	600	Montana Department of Natural Resources and Conservation, 2015
MT00008	Petrolia dam	Missouri	Irrigation	9,000	--	Montana Department of Natural Resources and Conservation, 2015

Table 1–4. Information on major regulation structures affecting streamflow records.—Continued

[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]

Dam indentification number[1]	Name of structure	Major river basin	Primary purpose(s)	Storage, in acre-feet	Diversion capacity, in cubic feet per second	Reference(s)
MT00570	Fresno dam	Missouri	Irrigation, flood control	127,200	--	Bureau of Reclamation, 2015
MT00586	Paradise diversion dam	Missouri	Irrigation diversion	Minor (diversion dam)	Unknown	Bureau of Reclamation, 2015
MT00583	Dodson diversion dam	Missouri	Irrigation diversion	Minor (diversion dam)	500	Bureau of Reclamation, 2015
MT00584	Vandalia diversion dam	Missouri	Irrigation diversion	Minor (diversion dam)	300	Bureau of Reclamation, 2015
MT00025	Fort Peck dam	Missouri	Multipurpose	18,463,000	--	U.S. Army Corps of Engineers, 2015a
MT00646	Big Muddy Creek dam	Missouri	Unknown	Unknown	--	--
MT00562	Mystic Lake dam	Missouri	Multipurpose	21,000	--	Northwestern Energy, 2015
MT00001	Cooney dam	Missouri	Irrigation	28,400	--	Montana Department of Natural Resources and Conservation, 2015
MT00576	Yellowtail dam	Missouri	Multipurpose	1,381,189	--	Bureau of Reclamation, 2015
MT00002	Tongue River dam	Missouri	Irrigation	79,071	--	Montana Department of Natural Resources and Conservation, 2015
MT00652	Libby dam	Columbia	Multipurpose	4,979,500	--	U.S. Army Corps of Engineers, 2015b
MT00221	Lake Creek dam	Columbia	Hydropower	Minor (run-of-river dam)	--	--
MT01400	Warm Springs Ponds	Columbia	Remediation	Minor (run-of-river dam)	--	--
MT03761	Meyer's dam	Columbia	Unknown	Unknown	--	--
MT00019	West Fork dam	Columbia	Multipurpose	32,362	--	Montana Department of Natural Resources and Conservation, 2015
MT00565	Hungry Horse dam	Columbia	Multipurpose	3,161,000	--	Bureau of Reclamation, 2015
MT00226	Salish-Kootenai Dam	Columbia	Multipurpose	Unknown	--	Energy Keepers, Inc., 2015
MT00589	Mission dam	Columbia	Unknown	Unknown	--	--
MT00224	Thompson Falls dam	Columbia	Hydropower	8,300	--	Northwestern Energy, 2015

[1] Dam identification number used by Montana Department of Natural Resources (Chadrick Hill, written commun., 2011) and NHDPlusV2 (Horizon Systems Corporation, 2013).

[2] The Wyoming-Montana Water Science Center computed the contributing drainage area using methods described by Dupree and Crowfoot (2012) and Lins (2012).

[3] Lower Two Medicine Dam was originally constructed in 1912, failed in 1964, and was reconstructed in 1967.

[4] Swift (Pondera) Dam was originally constructed in 1912, failed in 1964, and was reconstructed in 1967.

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