Prepared in cooperation with the Montana Department of Environmental Quality and Montana Department of Natural Resources and Conservation

Streamflow Characteristics Based on Data through Water Year 2009 for Selected Streamflow-Gaging Stations in or near Montana

Chapter E of
Montana StreamStats

Scientific Investigations Report 2015–5019–E

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

Cover photograph: Dry streambed at the Teton River at Loma, Montana. Photograph by U.S. Geological Survey personnel, September 7, 2015.

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

U.S. Geological Survey
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Conversion Factors

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

Multiply	By	To obtain
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	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 the North American Datum of 1983 (NAD 83)

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 2009 is the period from October 1, 2008, through September 30, 2009.

Climatic year is the 12-month period from March 1 through February 28 (February 29 in leap years) and is designated by the calendar year in which it begins.

Abbreviations

ADAPS	Automated Data Processing System
NHD	National Hydrography Dataset
SWSTAT	Surface-Water Statistics (computer program)
USGS	U.S. Geological Survey

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Streamflow Characteristics Based on Data through Water Year 2009 for Selected Streamflow-Gaging Stations in or near Montana

By Peter M. McCarthy

Abstract

Chapter E of this Scientific Investigations Report documents results from a study by the U.S. Geological Survey, in cooperation with the Montana Department of Environmental Quality and the Montana Department of Natural Resources and Conservation, to provide an update of statewide streamflow characteristics based on data through water year 2009 for streamflow-gaging stations in or near Montana. Streamflow characteristics are presented for 408 streamflow-gaging stations in Montana and adjacent areas having 10 or more years of record. Data include the magnitude and probability of annual low and high streamflow, the magnitude and probability of low streamflow for three seasons (March–June, July–October, and November–February), streamflow duration statistics for monthly and annual periods, and mean streamflows for monthly and annual periods. Streamflow is considered to be regulated at streamflow-gaging stations where dams or other large-scale human modifications affect 20 percent or more of the contributing drainage basin. Separate streamflow characteristics are presented for the unregulated and regulated periods of record for streamflow-gaging stations with sufficient data.

Introduction

Information about streamflow characteristics is essential for development and management of surface-water resources. Water and land-use managers, planners, administrators, builders, engineers, recreationists, and the general public use information on all aspects of streamflow to assess water conditions and evaluate land-use alternatives.

The magnitude and duration of annual and seasonal streamflows are particularly useful for characterizing streamflow variability. Low-flow frequency data for annual and seasonal periods indicate the duration and frequency of low flows and are used for assessing the capability of streams to receive and assimilate treated wastewater, developing wastewater permits, determining total maximum daily loads of streams, and assessing health of aquatic habitat. Annual high-flow frequency data, in conjunction with peak flows (which refer to the annual maximum instantaneous discharge recorded for each water year that a streamflow-gaging station is operated and are used for deriving peak-flow frequency estimates), provide information about the frequency, duration, and magnitude of high streamflows, and are useful for effective flood planning and safe and economical design of highway bridges, culverts, dams, levees, and other structures on or near streams.

The U.S. Geological Survey (USGS) has previously published reports that describe and document streamflow characteristics at streamflow-gaging stations (hereinafter referred to as gaging stations) in Montana (Shields and White, 1981; Waltemeyer and Shields, 1982; Omang, 1984; and McCarthy, 2005). Since the completion of these reports, several additional gaging stations have been installed that had 10 or more years of record as of water year 2009; a water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. Additionally, streamflows in the beginning of the 21st century have been lower, on average, than mean streamflows in the 20th century for many gaging stations in Montana (U.S. Geological Survey, 2014). Inclusion of more recent data in the 21st century gives a more accurate picture of the variability and magnitude of streamflow characteristics than the use of 20th century data alone. In response to the need to have more current information about streamflow characteristics in Montana, the USGS, in cooperation with the Montana Department of Environmental Quality and the Montana Department of Natural Resources and Conservation, analyzed daily mean streamflows and reported streamflow characteristics for 408 gaging stations having at least 10 years of record as of water year 2009.

Purpose and Scope

The study described in Chapter E 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 E is to present streamflow characteristics at 408 gaging stations in and near Montana using data through water year 2009 (fig.1, table 1–1 in appendix 1 at the back of this report chapter [available at http://dx.doi.org/10.3133/sir20155019E]; map numbers assigned according to McCarthy, Dutton, and others [2016]). Streamflow characteristics include the magnitude and probability of annual-low and annual-high streamflows, the magnitude and probability of low streamflows for three seasons (March–June, July–October, and November–February), streamflow duration statistics of daily mean flows for monthly and annual periods, and the mean monthly and annual streamflows.

Estimates of the magnitude and probability of annual low streamflows (hereinafter referred to as annual low-flow frequencies) are reported for nonexceedance probabilities of 50, 20, 10, 5, 2, and 1 percent for consecutive *n*-day periods of 1, 3, 7, 14, 20, 30, 60, 90, 120, and 183 days. Estimates of magnitude and probability of low flows for three seasons (hereinafter referred to as seasonal low-flow frequencies) are reported for nonexceedance probabilities of 50, 20, 10, 5, 2, and 1 percent for consecutive *n*-day periods of 1, 3, 7, 14, 20, and 30 days. The seasons for the seasonal low-flow frequencies are spring (March–June), summer (July–October), and winter (November–February). Estimates of magnitude and probability of annual high streamflows (hereinafter referred to as high-flow frequencies) are reported for exceedance probabilities of 50, 20, 10, 4, 2, and 1 percent for consecutive *n*-day periods of 1, 3, 7, 15, 20, 30, 60, and 90 days. Streamflow duration statistics are reported for the 99-, 98-, 95-, 90-, 80-, 70-, 60-, 50-, 40-, 30-, 20-, 10-, 5-, 2-, and 1-percent exceedance probabilities for each month and for the annual period. The mean streamflow, standard deviation of the mean, and the years of record also are reported for each month and for the annual period.

Streamflow Characteristics Analyses and Results

Streamflow data are available from more than 900 gaging stations operated by the USGS in or near Montana. Low-flow frequencies, high-flow frequencies, and seasonal low-flow frequencies can be estimated for any gaging station having 10 or more years or seasons of streamflow data, respectively. The period of record for gaging stations in and near Montana were reviewed and evaluated for streamflow regulation and data inconsistencies, and streamflow characteristics were estimated for 408 gaging stations in or near Montana.

Regulation Status of Streamflow-Gaging Stations

Reservoir storage and operations may affect flow characteristics, especially low-flow conditions. The National Hydrography Dataset (NHD; Horizon Systems Corporation, 2013) includes a point layer for dams derived from a national inventory of dams (U.S. Army Corps of Engineers, 2014) that the Wyoming and Montana Water Science Center of USGS (WY-MT WSC) used to evaluate regulation and classify gaging stations as regulated or unregulated as described by McCarthy, Dutton, and others (2016). Gaging stations were classified as unregulated if the cumulative drainage area upstream from all dams is less than 20 percent of the drainage area of the gaging station and no large diversion canals are upstream from the gaging station. Gaging stations were classified as regulated if the cumulative drainage area of all upstream dams exceeds 20 percent of the drainage area of a given 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. 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. Streamflow characteristics were computed for the entire period of record for gaging stations that were classified as unregulated. The period of record for regulated gaging stations was split from the unregulated period of record on the year of regulation, as applicable. If 10 or more years of record were available prior to the year of regulation, streamflow characteristics were computed for the unregulated period of record. Similarly, if more than 10 years of record were available after the year of regulation, streamflow characteristics were computed for the regulated period of record. For some gaging stations, streamflow characteristics were computed for unregulated and regulated periods.

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, Dutton, 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 streamflow data 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.

Of the 408 gaging stations included in this report, 281 were analyzed using the entire period of record. These gaging stations are considered unregulated using the 20-percent criterion; however, the NHD database of dams does not include all of the dams in Montana and therefore some of these gaging

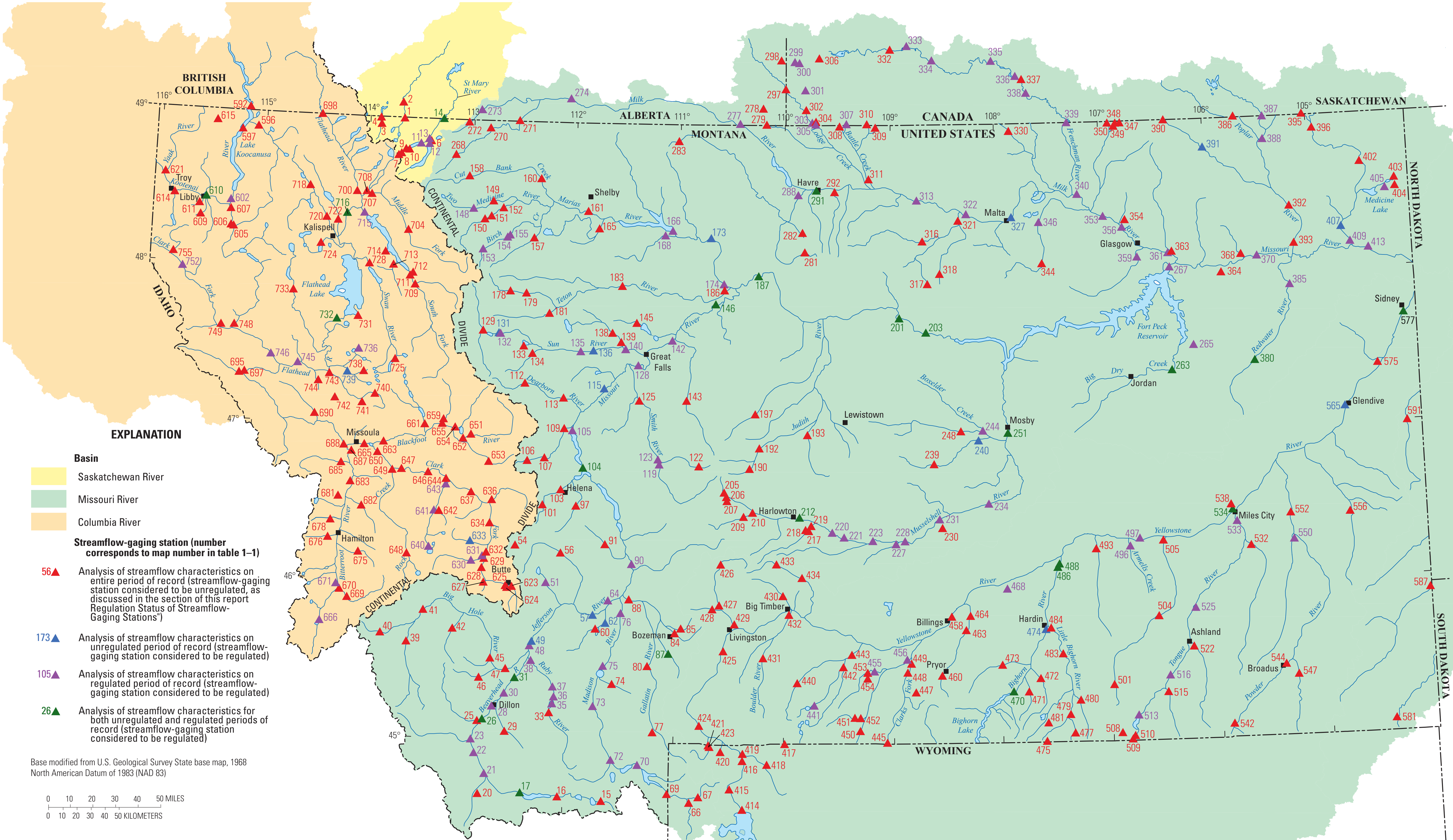

Figure 1. Locations of selected streamflow-gaging stations in or near Montana for which streamflow characteristics are reported through water year 2009.

stations may have regulated streamflow. For gaging stations that were classified as regulated, 15 were analyzed using unregulated streamflow data prior to the date of regulation, 89 were analyzed using regulated streamflow data after the date of regulation, and 23 were analyzed for both unregulated and regulated periods. The 23 gaging stations that were analyzed for both unregulated and regulated periods have streamflow characteristics reported for the unregulated period and streamflow characteristics reported for the regulated period. Streamflow characteristics were analyzed for unregulated periods at gaging stations classified as regulated primarily for use in development of regional regression equations on unregulated streamflow characteristics (McCarthy, Dutton, and others, 2016). Table 1–1 in appendix 1 at the back of this report chapter includes regulation information, and hyperlinks are provided to the streamflow characteristics for each gaging station.

Streamflow Data Compilation and Review

Streamflow characteristics were computed using daily mean streamflows. Daily mean streamflows are computed streamflow values that represent the mean of the instantaneous streamflows recorded at a gaging station for each day and are determined using approved methods for streamflow gaging operations and streamflow measurements (Rantz and others, 1982), and are available for gaging stations operated by the USGS in or near Montana from the National Water Information System (U.S. Geological Survey, 2014). Daily mean streamflows for all of the gaging stations were retrieved using the computer program Automated Data Processing System (ADAPS) (U.S. Geological Survey, 2003). Upon review, some streamflows prior to 1950 were found to have errors associated with deriving daily mean streamflows from monthly mean streamflows rather than using the previously computed daily mean streamflows. The streamflows in question were originally recorded on a daily basis and used to compute monthly mean streamflows, which were reported in various reports (for example, Wells, 1959). In the late 1970s and early 1980s, the USGS developed a database for storing daily streamflows, and historical daily streamflows were manually entered from prior gaging operations. In some cases, the monthly mean streamflows were used to populate daily mean streamflows resulting in the same streamflow for the entire month. The daily streamflows for the gaging stations were reviewed, and daily streamflows that were repeated through the entire month and suspected to be erroneous were removed from the analyses. Gaging stations for which daily streamflow values were removed from the analyses are flagged in table 1–1.

Methods for Analyses of Streamflow Characteristics

Streamflows approved for analyses were used to compute streamflow characteristics, which are summarized for each gaging station in appendix 1. Annual high-flow frequencies and annual and seasonal low-flow frequencies were computed using the computer program Surface-Water Statistics (SWSTAT) (U.S. Geological Survey, 2002a). Monthly duration analyses and monthly mean values were computed in spreadsheets. Information related to each gaging station is presented in table 1–1 and includes the map number (fig. 1), station identification number, station name, location, contributing drainage area, percentage of contributing drainage basin regulated by dams, regulation status as of 2014, first year of regulation if applicable, period of record used in the analyses, regulation classification for the period of record analyzed, whether daily streamflow values were removed from the analyses, and whether manual adjustments were made to the estimated streamflow characteristics. The station identification number in table 1–1 is hyperlinked to the summary of streamflow characteristics for each gaging station. Descriptions of the methods used to estimate streamflow characteristics are provided in the following sections.

Annual and Seasonal Low-Flow Frequencies

Annual low-flow frequencies were computed from an annual series of the lowest mean streamflows for specified consecutive *n*-day periods within a climatic year. The climatic year is the 12-month period from March 1 through February 28 (February 29 for leap years) and is designated by the calendar year in which it begins. Seasonal low-flow frequencies are developed from an annual series of the lowest mean streamflows for each of the spring (March–June), summer (July–October; also referred to as season 2 [McCarthy, Sando, and others, 2016]), and winter (November–February) seasons for specified consecutive *n*-day periods within a climatic year. The periods selected for spring, summer, and winter were based on those used by McCarthy (2005) and reflect typical runoff and irrigation patterns in Montana.

The Pearson Type III probability distribution was used to estimate annual and seasonal low-flow frequencies (U.S. Geological Survey, 2002a). The Pearson Type III distribution is a three-parameter distribution, commonly applied to the base-10 logarithms of streamflow, which requires estimates of the population mean, standard deviation, and the skew coefficient to determine streamflow magnitude for various nonexceedance or exceedance probabilities. For low-flow frequencies, the population values are assumed to be equal to the values computed from the station record; therefore, a regional skew value is not necessary for computing low-flow frequencies. The computer program SWSTAT was used to compute the annual and seasonal low-flow frequencies. This computer program determines nonexceedance probability using only nonzero values of streamflow and then uses a conditional adjustment probability to adjust the nonexceedance probability for streamflow values of zero in the record. The computer program SWSTAT was unable to compute the annual and seasonal low-flow frequencies when the absolute value of the skew coefficient is greater than 3.3; thus, the low-flow frequencies that have an absolute skew coefficient greater than 3.3 are noted in the low-flow tables for applicable gaging stations in appendix 1.The annual low-flow frequencies indicate the lowest mean streamflows for consecutive periods of 1, 3, 7, 14, 20, 30, 60, 90, 120, and 183 days for nonexceedance probabilities of 50, 20, 10, 5, 2, and 1 percent. The nonexceedance probability (in decimal form before conversion to percent) is the reciprocal of the recurrence interval, in years. The seasonal low-flow frequencies indicate the lowest mean streamflows for consecutive periods of 1, 3, 7, 14, 20, and 30 days for nonexceedance probabilities of 50, 20, 10, 5, 2, and 1 percent.

Each streamflow value in the annual and seasonal low-flow tables presented for each gaging station in appendix 1 is the mean streamflow for a consecutive *n*-day period that has a specified *x*-percent nonexceedance probability that, in any given year, a smaller mean *n*-day streamflow will occur; for example, the low-flow value for a consecutive 7-day period and a 50-percent nonexceedance probability has a 50 percent chance of being lower in any given year. The reciprocal of the nonexceedance probability, commonly referred to as the recurrence interval, indicates that a smaller mean *n*-day streamflow can be expected on average, once in any specified interval.

For any *n*-day period, streamflows decrease with increasing recurrence interval and decreasing nonexceedance probability. Conversely, for any given recurrence interval or nonexceedance probability, streamflows increase with increasing *n*-day periods. Seasonal and annual low-flow frequencies are only reported in the tables for recurrence intervals of twice the period of record or less (Parrett, 1997); for example, if the period of record for a given gaging station is 10 years, only low-flow frequencies for recurrence intervals of 20 years or less are presented. Seasonal low-flow data commonly include more years of record than the annual low-flow data; thus, the seasonal low-flow frequencies might be shown for longer recurrence intervals than the annual low-flow frequencies because of partial-record years.

Annual and seasonal low-flow frequencies were computed independently for given *n*-day periods. The presence of days with zero streamflow and multiple days of the same streamflow in the independent analyses resulted in some streamflows that did not consistently decrease with increasing recurrence interval or some streamflows that did not consistently increase with increasing *n*-day period. These computed streamflows were manually adjusted using graphical methods to produce consistent tabular results such that streamflows consistently decrease with increasing recurrence interval and increase with increasing *n*-day periods (McCarthy, 2005). Manually adjusted streamflows were adjusted the minimal amount possible to produce consistent tabular results. Table 1–1 indicates whether streamflow characteristics for a given gaging station were manually adjusted.

Kendall's tau test (Kendall and Gibbons, 1990), a nonparametric test that can be used to indicate the likelihood of an upward or downward trend over time, was computed for each of the *n*-day analyses for the annual low-flow and seasonal low-flow periods by using the computer program SWSTAT. The Kendall's tau test was only used for informational purposes, and *n*-day periods where a trend was indicated using a 95-percent confidence level are noted in the low-flow tables for applicable gaging stations in appendix 1.

Annual High-Flow Frequencies

Annual high-flow frequencies are developed from annual series of the highest mean streamflows for specified consecutive *n*-day periods within a water year. A water year is the 12-month period from October 1 through September 30 and is designated by the calendar year in which it ends. The Pearson Type III probability distribution was used to estimate high-flow frequency data (U.S. Geological Survey, 2002a). The Pearson Type III distribution is a three-parameter distribution, commonly applied to the base-10 logarithms of streamflow data, which requires estimates of the logarithms of the population mean, the standard deviation, and the skew coefficient. For high-flow frequencies, the population values are assumed to be equal to the values computed from the station record; therefore, a regional skew value is not necessary for computing high-flow frequencies.

The annual high-flow frequencies indicate the highest mean streamflows for consecutive periods of 1, 3, 7, 15, 20, 30, 60, and 90 days for exceedance probabilities of 50, 20, 10, 4, 2, and 1 percent. The exceedance probability (in decimal form before conversion to percent) associated with a high-flow frequency is the reciprocal of the recurrence interval, in years.

Each streamflow value in the annual high-flow table presented for each gaging station in appendix 1 is the mean streamflow within the year for a consecutive *n*-day period that has a *x*-percent exceedance probability that, in any given year, a larger mean *n*-day streamflow will occur; for example, the high-flow value for a consecutive 3-day period and a 1-percent exceedance probability has a 1-percent chance of being higher in any given year. The reciprocal of the exceedance probability, commonly referred to as the recurrence interval, indicates that a larger mean *n*-day streamflow can be expected on average, once in any specified interval.

For any *n*-day period, streamflows increase with increasing recurrence interval and decreasing exceedance probability. Conversely, for any given recurrence interval or exceedance probability streamflows decrease with increasing *n*-day periods. High-flow frequencies were reported for recurrence intervals of twice the period of record or less (Parrett, 1997); for example, if the period of record for a given gaging station is 25 years, the high-flow data are reported for recurrence intervals of 50 years or less.

Kendall's tau test (Kendall and Gibbons, 1990), a nonparametric test that can be used to indicate the likelihood of an upward or downward trend over time, was computed for each of the *n*-day analyses for the annual high-flow frequencies in SWSTAT. The Kendall's tau test was only used for informational purposes, and *n*-day periods where a trend was indicated using a 95-percent confidence level are noted in the high-flow table for applicable gaging stations in appendix 1.

Annual and Monthly Streamflow Characteristics

Flow-duration curves (presented as flow-duration statistics in tabular format) and mean streamflow values were computed for annual and monthly streamflow periods. Flow-duration curves are used to represent the distribution of daily streamflows within a monthly or annual period (Searcy, 1959). The streamflows in the flow-duration tables presented for each gaging station in appendix 1 have an indicated percent chance of being equaled or exceeded in the month or year. Flow-duration statistics were developed from daily mean streamflows for the entire period of record of the gaging station; however, partial months or partial years of streamflow data were excluded from the monthly or annual flow-duration statistics, respectively. Flow-duration statistics were reported for any annual period or monthly period having 1 or more years of record. Flow-duration statistics were computed in spreadsheets using the manually adjusted daily streamflows following the methods used in ADAPS for processing monthly duration data (U.S. Geological Survey, 2002b).

Mean annual and mean monthly streamflows, and the standard deviation of the mean streamflows, were computed for the entire period of record. Annual and monthly streamflow characteristics were reported for any annual period or monthly period having 1 or more years of record. The annual and monthly streamflow characteristics were computed in spreadsheets using streamflows approved for analyses.

Summary

Chapter E of this Scientific Investigations Report documents results from a study by the U.S. Geological Survey, in cooperation with the Montana Department of Environmental Quality and the Montana Department of Natural Resources and Conservation, to provide an update of statewide streamflow characteristics based on data through water year 2009 for streamflow-gaging stations in or near Montana. Streamflow characteristics were computed for 408 streamflow-gaging stations in or near Montana having 10 or more years or seasons of record through water year 2009. Streamflow-gaging stations were classified as either regulated or unregulated based on the percentage of the contributing drainage basin area that is upstream from dams or other major regulating structures. If more than 20 percent of the contributing drainage basin is upstream from one or more dams, the streamflow-gaging station was classified as regulated. A total of 127 streamflow-gaging stations were classified as regulated; 15 streamflow-gaging stations were analyzed using unregulated streamflow data prior to the date of regulation, 89 were analyzed using regulated streamflow data from the period after the date of regulation, and 23 were analyzed for both unregulated and regulated periods. The remaining 281 streamflow-gaging stations were classified as unregulated, and the entire period of record from the streamflow-gaging station was used in the analyses.

Daily streamflow data were reviewed, and some streamflows prior to 1950 were found to have errors associated with deriving daily mean streamflows from monthly mean streamflows rather than using the previously computed daily mean streamflows. Daily streamflows that were repeated through the entire month and suspected to be erroneous were removed from the analyses.

Streamflow data approved for analyses were used to compute streamflow characteristics for each streamflow-gaging station. Annual and seasonal low-flow frequencies and annual high-flow frequencies were computed using the U.S. Geological Survey computer program Surface-Water Statistics. Annual and seasonal low-flow frequencies were reported for nonexceedance probabilities of 50, 20, 10, 5, 2, and 1 percent. Annual low-flow frequencies were reported for *n*-day periods of 1, 3, 7, 14, 20, 30, 60, 90, 120, and 183 days. Seasonal low-flow frequencies were reported for *n*-day periods of 1, 3, 7, 14, 20, and 30 days. Annual high-flow frequencies were reported for exceedance probabilities of 50, 20, 10, 4, 2, and 1 percent and *n*-day periods of 1, 3, 7, 15, 20, 30, 60, and 90 days. Flow-duration curves (presented as flow-duration statistics in tabular format) and mean streamflow values were computed for annual and monthly streamflow periods.

Information related to each streamflow-gaging station is presented in this report chapter and includes the map number, station identification number, station name, location, contributing drainage area, percentage of contributing drainage basin regulated by dams, regulation status, first year of regulation if applicable, period of record used in the analyses, regulation classification for the period of record analyzed, whether daily streamflow values were removed from the analyses, and whether manual adjustments were made to the estimated streamflow characteristics. A summary of streamflow characteristics is presented for each streamflow-gaging station.

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Appendix 1

Appendix 1. Information and Streamflow Characteristics for Streamflow-Gaging Stations

Information on streamflow-gaging stations for which streamflow characteristics are reported is presented in table 1–1. Tabular information on streamflow characteristics for each gaging station can be accessed by links in the "Station identification number" column in table 1–1.

An Excel file containing the tables is available at http://dx.doi.org/10.3133/sir20155019E.

Table 1–1. Information on streamflow-gaging stations for which streamflow characteristics are reported through water year 2009.

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