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Temporal Trends and Stationarity in Annual Peak Flow and Peak-Flow Timing for Selected Long-Term Streamflow-Gaging Stations in or near Montana through Water Year 2011

Chapter B of
Montana StreamStats

Scientific Investigations Report 2015–5019–B

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

Cover photograph: Swiftcurrent Creek at Many Glacier, Montana. Photograph by Don Bischoff, U.S. Geological Survey, November 7, 2006.

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Director

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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).

Elevation, as used in this report, refers to distance above the vertical datum.

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
LOWESS	locally weighted scatterplot smooth
NAVD 88	North American Vertical Datum of 1988
p-value	statistical significance level
USGS	U.S. Geological Survey

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Temporal Trends and Stationarity in Annual Peak Flow and Peak-Flow Timing for Selected Long-Term Streamflow-Gaging Stations in or near Montana through Water Year 2011

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

Abstract

A large-scale study by the U.S. Geological Survey, in cooperation with the Montana Department of Transportation and the Montana Department of Natural Resources and Conservation, was done to investigate general patterns in peak-flow temporal trends and stationarity through water year 2011 for 24 long-term streamflow-gaging stations (hereinafter referred to as gaging stations) in Montana. Hereinafter, all years refer 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. The primary focus of the study was to identify general patterns in peak-flow temporal trends and stationarity that are relevant to application of peak-flow frequency analyses within a statewide gaging-station network.

Temporal trends were analyzed for two hydrologic variables: annual peak flow and peak-flow timing. Annual peak flow is the maximum instantaneous discharge, in cubic feet per second, recorded each year a gaging station was operated. Peak-flow timing is the day of the annual peak flow (hereinafter referred to as day of peak), recorded each year a gaging station was operated.

Study results provide evidence that annual peak flow for most of the long-term gaging stations can be reasonably considered as stationary for application of peak-flow frequency analyses within a statewide gaging station network. Upward trends in annual peak flow during 1930–76 generally were stronger than downward trends during 1967–2011 for most long-term gaging stations. Statistical distributions of annual peak flow generally were similar among three summary time periods (1930–78, 1979–2011, and the entire period of record). However, for two low-elevation gaging stations in eastern Montana (Poplar River at international boundary [gaging station 06178000] and Powder River at Moorhead, Montana [gaging station 06324500]), substantial downward trends in annual peak flow during 1967–2011 were of similar or stronger magnitude than the upward trends during 1930–76, and the annual-peak-flow medians for 1979–2011 were substantially lower than the medians for the entire period of record.

For peak-flow timing for most long-term gaging stations, differences in trends between 1930–76 and 1967–2011 are variable and not particularly strong. Statistical distributions generally are similar among the summary time periods. However, for two high-elevation gaging stations on a Missouri River headwater tributary (Gallatin River near Gallatin Gateway, Montana [gaging station 06043500] and Gallatin River at Logan, Montana [gaging station 06052500]) and for five high-elevation gaging stations in the Yellowstone River Basin (Yellowstone River at Corwin Springs, Montana [gaging station 06191500], Yellowstone River near Livingston, Montana [gaging station 06192500], Clarks Fork Yellowstone River near Belfry, Montana [gaging station 06207500], Clarks Fork Yellowstone River at Edgar, Montana [gaging station 06208500], and Yellowstone River at Billings, Montana [gaging station 06214500]) downward trends in peak-flow timing during 1967–2011 generally were stronger than upward trends during 1930–1976, and day-of-peak medians for 1979–2011 were considerably less than medians for 1930–78. The downward trends in peak-flow timing for 1967–2011 indicate that the timing of annual peak flows changed from later in the year to earlier in the year. For the seven high-elevation gaging stations, the mean change during 1967–2011 was about 13 days (range of 8 to 22 days).

For most of the high-elevation gaging stations in the Missouri River headwaters, Yellowstone River Basin, and Columbia River Basin, there was general correspondence between trend patterns for annual peak flow and trend patterns for peak-flow timing; that is, during periods when there were upward trends in annual peak flow, there generally also were upward trends in peak-flow timing. Conversely, during periods when there were downward trends in annual peak flow, there generally also were downward trends in peak-flow timing.

The two low-elevation gaging stations in eastern Montana (Poplar River at international boundary [gaging station 06178000] and Powder River at Moorhead, Montana [gaging station 06324500]) had considerable changes in annual-peak-flow characteristics after the mid-1970s, which might provide evidence of potential nonstationarity in the peak-flow records. The two low-elevation gaging stations that have potential nonstationarity are located in drainage basins that are strongly affected by agricultural activities that potentially affect the hydrologic regimes. Primary agricultural activities that might

alter natural hydrologic conditions include construction of small impoundments (primarily for stock-watering purposes) and irrigation diversions. Temporal variability in these activities might contribute to the potential nonstationarity issues. Changes in climatic characteristics after the mid-1970s also possibly contribute to the potential nonstationarity issues. Lack of considerable indication of potential nonstationarity in annual peak flow for the other long-term gaging stations in this study might indicate that climatic changes have been more pronounced with respect to effects on peak flows in low-elevation areas in eastern Montana than in areas represented by the other long-term gaging stations. Another possibility is that climatic changes after the mid-1970s are exacerbated in low-elevation areas where small-impoundment development and potential effects of irrigation diversions might be more extensive.

Introduction

Concerns about increasing global temperatures since the mid-1970s (National Aeronautics and Space Administration Goddard Institute for Space Studies, 2013) have prompted extensive research on environmental effects of climate change. Investigators have reported hydrologic effects (for example, Wahl, 1992; McCabe and Clark, 2005; Pederson and others, 2011) associated with reported changes in climatic conditions. Of particular note, several studies have reported declining trends in snowpack (Stewart and others, 2004; Mote and others, 2005; Pederson and others, 2013), earlier snowmelt runoff (Dettinger and Cayan, 1995; Cayan and others, 2001), and declining trends in some streamflow characteristics (Westmacott and Burn, 1997; Aziz and Burn, 2006) in the western United States and Canada. The reported changes in hydrologic regimes have the potential to affect the stationarity of annual peak-flow records. Hirsch (2011) noted the importance of repeated analysis of long-term datasets to assist in water-resources management and structure-design activities that are dependent on hydrologic variables.

Stationarity is an important issue in the statistical analysis of hydrologic characteristics. For a given streamflow-gaging station (hereinafter referred to as gaging station), stationarity of annual peak-flow requires that all of the data represent a consistent hydrologic regime within the same (albeit highly variable) fundamental climatic system. If the fundamental climatic system has substantially shifted such that a new fundamental system exists, appropriate statistical analysis of hydrologic characteristics might require restricting the analysis to the data that represent the new system.

The U.S. Geological Survey (USGS), in cooperation with the Montana Department of Transportation and the Montana Department of Natural Resources and Conservation, completed an investigation of peak-flow frequency analyses for gaging stations in Montana (Sando and others, 2016). Peak-flow frequencies refer to peak-flow magnitudes, in cubic feet per second associated with given annual exceedance probabilities (AEPs), in percent. Preliminary to the investigation of peak-flow frequency analyses, a large-scale study was done to investigate general patterns in peak-flow temporal trends and stationarity for Montana gaging stations. Temporal trends were analyzed for two hydrologic variables: annual peak flow and peak-flow timing. Annual peak flow is the annual series of maximum instantaneous discharge in cubic feet per second, which is recorded for each water year that a gaging station is operated. Peak-flow timing is the annual series of the day of the annual peak flow (hereinafter referred to as day of peak). The primary focus of the study was to identify general patterns in peak-flow temporal trends and stationarity through water year 2011 that are relevant to application of peak-flow frequency analyses within a statewide gaging-station network; a water year is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. Emphasis is placed on annual peak flow because of direct relevance to peak-flow frequency analysis; however, peak-flow timing was included in the study because although peak-flow timing data are not directly relevant to peak-flow frequency analysis, peak-flow timing is of interest to many users of peak-flow frequency data.

Purpose and Scope

The study described in Chapter B 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 primary purpose of Chapter B is to present the results of a large-scale study to investigate general patterns in peak-flow temporal trends and stationarity through water year 2011 for Montana gaging stations; hereinafter, all references to specific years refer to water years in this report chapter. Temporal trends in annual peak flow and peak-flow timing for 24 long-term gaging stations are reported and described. The primary focus of the study was to identify general patterns in peak-flow temporal trends and stationarity that are relevant to application of peak-flow frequency analyses within a statewide gaging-station network.

Selection of Streamflow-Gaging Stations

More than 700 gaging stations with 10 or more years of annual peak-flow records have been operated by the USGS in Montana and for which peak-flow frequency analyses are reported. Initially, 725 gaging stations were screened for inclusion in this study based on the following selection criteria: (1) at least 75 years of annual peak-flow records with largely unbroken series (that is, generally few missing years in the systematic record), (2) at least 5 years of data in the 1930s (a particularly dry period that can substantially affect the peak-flow characteristics of an individual gaging station), and (3) generally small effects from urbanization or large reservoir storage. The screening process resulted in selection of 24 long-term gaging stations (fig. 1, table 1; map numbers assigned according to McCarthy and others, 2016) for inclusion in the study of peak-flow temporal trends and stationarity. The selected 24 long-term gaging stations represent the only gaging stations out of the 725 screened gaging stations that met all of the selection criteria.

Several of the gaging stations with large drainage basins contain large urban areas that have substantially increased in size during the periods of data collection. Urbanization can affect hydrologic characteristics in several ways, with increases in impervious area and runoff potential being a primary factor. Geographic information system (GIS) analysis of the 2001 National Land Cover Dataset (Homer and others, 2007) was done to estimate the urban area (as determined by the area of high-intensity residential development) within the drainage basin for each of the gaging stations. In no case did the urban area account for more than about 3 percent of the drainage basin of an individual gaging station; therefore, it was presumed that temporal variability in urbanization within relatively small areas would have small effects on temporal trends in streamflow characteristics.

Reservoir storage and operations have the potential to affect temporal variability in streamflow characteristics. The current (2015) criterion used by the USGS in this study classifies a gaging station as affected by major dam regulation if the drainage area upstream from a single upstream dam exceeds 20 percent of the drainage area for the gaging station. Specific methods used to determine the regulation classification of a gaging station are described by McCarthy and others (2016). Based on the regulation-classification criterion, none of the 24 long-term gaging stations included in this study are considered to be affected by major dam regulation. Furthermore, in previous peak-flow frequency studies for Montana (for example, Parrett and Johnson, 2004), all of the selected long-term gaging stations were considered to be unregulated.

The datasets of the 24 gaging stations are somewhat diverse, both with respect to the represented hydrologic regimes and the temporal data-collection characteristics. The study was restricted to long-term gaging stations to ensure representation of a substantial time period before and after the mid 1970s. This key breakpoint (the mid-1970s) was based on increasing global temperatures since the mid-1970s (National Aeronautics and Space Administration Goddard Institute for Space Studies, 2013) and various reported hydrologic effects (for example, Wahl, 1992; Westmacott and Burn, 1997; McCabe and Clark, 2005; Aziz and Burn, 2006; Pederson and others, 2011) associated with reported changes in climatic conditions. The key mid-1970s breakpoint also was generally identified as a transition point in large-scale temporal patterns of peak flows for long-term Montana gaging stations (as further described in the section "Methods of Analysis"). The long record-length requirement allows thorough evaluation of potential changes in peak-flow characteristics after the mid-1970s in relation to temporal patterns in characteristics before the mid-1970s.

Although there is some hydrologic and topographic diversity among the 24 long-term gaging stations, they provide poor representation of the entirety of Montana. Most of the 24 gaging stations are high elevation (mean basin elevation greater than about 6,000 feet [ft]), whereas much of Montana is below 6,000 ft. Furthermore, most of the gaging stations have relatively large drainage basins (greater than about 1,000 square miles [mi^2]). These large drainage basins serve as integrators of climatic effects over large areas but probably do not provide good representation of the larger variability in peak-flow characteristics that is typical for smaller drainage basins. This study represents an initial effort to evaluate general patterns in peak-flow temporal trends and stationarity that are relevant to application of peak-flow frequency analyses within a statewide gaging-station network. As such, there was purposeful emphasis on long-term datasets to allow full temporal representation within the period of peak-flow record collection in Montana; however, the rigorous dataset requirements result in poor representation of the entirety of Montana. Future studies on peak-flow temporal trends and stationarity might include relaxing the dataset requirements to provide representation of a broader range in areal, hydrologic, and topographic characteristics.

The 24 long-term gaging stations are grouped according to the following major river basins: Saskatchewan River Basin (2 gaging stations); Missouri River Basin (16 gaging stations); and Columbia River Basin (6 gaging stations). Gaging stations in the Missouri River are subgrouped according to the following descriptive classes: (1) Missouri River headwaters tributaries (three gaging stations); (2) upper Missouri River tributaries (two gaging stations); (3) Musselshell River Basin (one gaging station); (4) upper Milk River Basin (one gaging station); (4) lower Missouri River tributary (one gaging station); and (5) Yellowstone River Basin (eight gaging stations).

Several factors contribute to difficulties in making rigorous statistical comparisons among gaging stations and among groups of gaging stations. The 24 gaging stations represent somewhat of a diversity in hydrologic regimes that have relatively large variability in temporal patterns in peak-flow characteristics. The numbers of gaging stations vary substantially among groups. Within groups, there also is variation in the temporal data-collection characteristics among the gaging stations. In some cases, multiple gaging stations are located on the same channel. In most of these cases, there is at least a two-fold increase in drainage area between the gaging stations; however, in a few cases, the increase in drainage area between the gaging stations is less than two fold and there is potential for introduction of redundant information. Given these factors, the datasets are not well suited for a rigorous statistical analysis focused on detailed definition and evaluation of temporal trends in peak-flow characteristics. Rather,

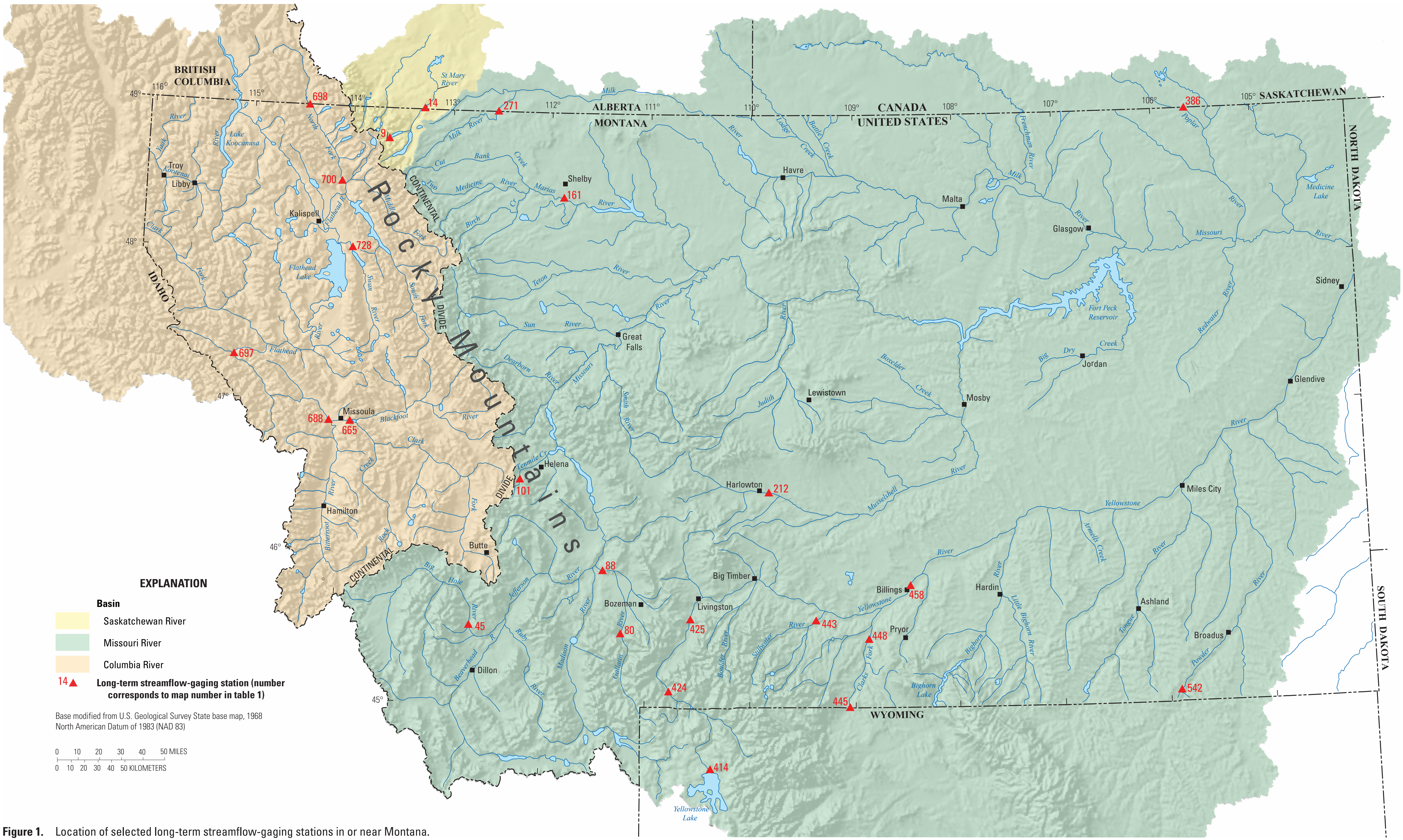

Figure 1. Location of selected long-term streamflow-gaging stations in or near Montana.

Table 1. Information for selected long-term gaging stations in or near Montana.

[NAD 83, North American Datum of 1983; NAVD 88, North American Vertical Datum of 1988]

Map number (fig. 1)	Station identification number	Station name	Latitude, in decimal degrees (NAD 83)	Longitude, in decimal degrees (NAD 83)	Contributing drainage area, in square miles	Percent of drainage basin affected by dams	Mean basin elevation, in feet above NAVD 88	Number of years of annual peak-flow records	Annual peak flows period of record through water year 2011
Streamflow-gaging stations in the Saskatchewan River Basin									
9	05014500	Swiftcurrent Creek at Many Glacier, Montana	48.7988	-113.6567	31.2	0.0	6,435	99	1913–2011
14	05020500	St. Mary River at international boundary	49.0114	-113.2995	462	13.8	5,745	107	1903–71, 1973, 1975–2011
Streamflow-gaging stations in the Missouri River Basin									
Missouri River headwaters tributaries									
45	06025500	Big Hole River near Melrose, Montana	45.5266	-112.7017	2,472	0.6	7,111	87	1924–40, 1942–2011
80	06043500	Gallatin River near Gallatin Gateway, Montana	45.4973	-111.2707	819	0.6	7,894	83	1890–1894, 1931–81, 1985–2011
88	06052500	Gallatin River at Logan, Montana	45.8854	-111.4383	1,789	1.5	6,635	92	1895–1900, 1902–05, 1929–33, 1935–2011
Upper Missouri River tributaries									
101	06062500	Tenmile Creek near Rimini, Montana	46.5239	-112.2566	33.0	3.8	6,541	95	1915–94, 1997–2011
161	06099500	Marias River near Shelby, Montana	48.4272	-111.8898	2,716	6.8	4,509	105	1902–04, 1906–07, 1911–46, 1948–2011
Musselshell River Basin									
212	06120500	Musselshell River at Harlowton, Montana	46.4288	-109.8412	1,108	5.5	5,713	103	1909–2011
Upper Milk River Basin									
271	06133000	Milk River at western crossing of international boundary	49.0075	-112.5453	405	0.0	4,734	80	1931–38, 1940–2011
Lower Missouri River tributary									
386	06178000	Poplar River at international boundary	48.9903	-105.6969	358	0.0	2,885	80	1931, 1933–2011

Table 1. Information for selected long-term gaging stations in or near Montana.—Continued

[NAD 83, North American Datum of 1983; NAVD 88, North American Vertical Datum of 1988]

Map number (fig. 1)	Station identification number	Station name	Latitude, in decimal degrees (NAD 83)	Longitude, in decimal degrees (NAD 83)	Contributing drainage area, in square miles	Percent of drainage basin affected by dams	Mean basin elevation, in feet above NAVD 88	Number of years of annual peak-flow records	Annual peak flows period of record through water year 2011
Streamflow-gaging stations in the Missouri River Basin—Continued									
Yellowstone River Basin									
414	06186500	Yellowstone River at Yellowstone Lake outlet, Yellowstone National Park, Wyoming	44.5671	-110.3804	995	0.0	8,699	86	1923–82, 1984–86, 1989–2011
424	06191500	Yellowstone River at Corwin Springs, Montana	45.1121	-110.7937	2,616	0.0	8,343	105	1890–1893, 1911–2011
425	06192500	Yellowstone River near Livingston, Montana	45.5972	-110.5665	3,551	0.3	8,012	87	1897–1905, 1929–32, 1938–2011
443	06205000	Stillwater River near Absarokee, Montana	45.5514	-109.3880	976	5.0	7,204	81	1911–14, 1935–2011
445	06207500	Clarks Fork Yellowstone River near Belfry, Montana	45.0099	-109.0654	1,152	0.0	7,761	90	1922–2011
448	06208500	Clarks Fork Yellowstone River at Edgar, Montana	45.4657	-108.8441	2,034	0.2	6,322	98	1905–13, 1922–32, 1934–2011
458	06214500	Yellowstone River at Billings, Montana	45.8001	-108.4680	11,414	1.8	6,544	86	1904–05, 1918, 1929–2011
542	06324500	Powder River at Moorhead, Montana	45.0572	-105.8784	8,029	0.0	5,250	82	1923, 1929–72, 1975–2011
Streamflow-gaging stations in the Columbia River Basin									
665	12340500	Clark Fork above Missoula, Montana	46.8772	-113.9319	6,021	7.8	5,765	83	1908, 1930–2011
688	12353000	Clark Fork below Missoula, Montana	46.8686	-114.1277	9,017	5.2	5,742	82	1930–2011
697	12354500	Clark Fork at St. Regis, Montana	47.3016	-115.0869	10,728	4.4	5,571	96	1911–23, 1929–2011
698	12355000	Flathead River at Flathead, British Columbia	49.0012	-114.4757	429	0.0	5,753	77	1929–94, 2001–2011
700	12355500	North Fork Flathead River near Columbia Falls, Montana	48.4958	-114.1268	1,556	0.0	5,399	90	1911–17, 1929–2011
728	12370000	Swan River near Bigfork, Montana	48.0242	-113.9788	672	0.0	5,012	90	1922–2011

this study is intended to provide an initial assessment of general large-scale patterns in peak-flow temporal variability and stationarity for long-term gaging stations in Montana. Primary considerations in the study were whether the analyses for the long-term gaging stations indicate potential changes in peak-flow characteristics after the mid-1970s and whether the potential changes might be relevant to stationarity issues in the application of peak-flow frequency analyses within a statewide gaging-station network.

Methods of Analysis

Hydrographic information presented in this report chapter (including drainage area, basin-elevation data, and percentage of basin greater than 6,000 ft) was determined by GIS analysis of medium resolution (1:100,000 scale and 30 meter) digital datasets. The digital datasets include National Elevation Dataset (Gesch and others, 2002), the National Hydrography Dataset (U.S. Geological Survey, 2015), and the National Hydrography Dataset Plus Version 2 (Horizon Systems Corporation, 2013).

Extensive preliminary exploratory analyses were done to develop a consistent general approach for investigating peak-flow temporal characteristics among the diverse gaging stations. Initially, for each gaging station, scatterplots of the annual peak-flow time series in conjunction with locally weighted scatterplot smooths (LOWESS; Cleveland, 1985) were investigated to assist in identifying dominant trend periods. Also, all possible 10-, 20-, 30-, 40-, and 50-year trends were plotted and examined for each gaging station. The exploratory analyses indicated that peak flows for most gaging stations generally were lower than median peak flow (determined for the entire period of record through 2011) from about 1930 to the early 1940s and generally were higher than median peak flow from about the mid- to late 1960s to the mid- to late 1970s. These generally consistent large-scale patterns served as the basis for defining four trend analysis periods that were applied for each gaging station: (1) from the start of systematic data collection through 1940 (for gaging stations with at least 15 years of systematic record during the period); (2) from 1930 to 1976; (3) from 1967 to 2011; and (4) from the start of systematic data collection through 2011. The trend-analysis periods were purposely overlapped to better define the full extent of temporal changes from dry periods to wet periods or, conversely, from wet periods to dry periods. Definition of the trend-analysis periods primarily was based on examination of annual peak flow with less consideration given to peak-flow timing; however, for many gaging stations, the defined trend analysis periods also provided reasonable representation of dominant trend periods for peak-flow timing.

For the defined trend analysis periods, trend magnitudes were computed using the Sen slope estimator (Sen, 1968), generally following methods used by Hodgkins and others (2007) and Holmes and others (2010). The Sen slope, also known as the Kendall-Theil robust line, is a nonparametric estimator of trend slope for a univariate time series when the time interval is constant (equally spaced). The fitted trend line produced by the Sen slope estimator provides an estimate of the change in the median value of a variable through time. Null hypothesis significance testing was done using the nonparametric Mann-Kendall test (Mann, 1945) to identify significant trends; however, it is notable that much discussion in recent literature has focused on problems with null hypothesis significance testing (Nichols, 2001) and the issue of long-term persistence (Cohn and Lins, 2005) that might be misinterpreted as significant trends. Thus, the statistical significance of trend results are reported but are qualified as being potentially misleading if considered as a primary factor in interpreting trend patterns. Descriptions of trend results in this report chapter focus more heavily on patterns in trend magnitudes than statistical significance.

Statistical distributions of peak-flow characteristics were compiled for selected data summary periods for each gaging station. The data summary periods were (1) 1930–78, (2) 1979–2011, and (3) the entire period of record. The 1930–78 summary period was selected to represent peak-flow characteristics during a period before the mid-1970s that generally ranged from an unusually dry period to an unusually wet period and typically encompassed the full range in historical variability; the summary period purposely extends slightly past the mid-1970s to include transition years. The 1979–2011 summary period was selected to represent the period after the mid-1970s that might be affected by reported changes in hydrologic regimes associated with changes in climatic conditions. The entire period of record (including any pre-1930 data) also was statistically summarized. For annual peak flow, the entire period of record represents the data that are typically used to calculate peak-flow frequencies.

The data summary periods purposely differ from the trend-analysis periods, based on the specific objectives of the analyses applied to the periods. The data summary periods were selected to allow characterization and comparison of peak flows before and after the key mid-1970s breakpoint. The data summary period before the key breakpoint was extended slightly past the mid-1970s to include transition years. Assigning the transition data into the data summary period before the mid-1970s would presumably accentuate the differences between the two summary periods. This conservative approach was applied to avoid the possibility of not distinguishing actual changes in peak-flow characteristics after the mid-1970s. In contrast, the trend-analysis periods were selected to quantify and statistically evaluate changes in peak-flow characteristics from dry periods to wet periods or, conversely, from wet periods to dry periods. The trend-analysis periods were purposely overlapped to better define the full extent of temporal changes from dry periods to wet periods or, conversely, from wet periods to dry periods.

For a given gaging station, stationarity of annual peak flow requires that all the data represent a consistent hydrologic regime within the same (albeit highly variable) fundamental climatic system. As such, a primary consideration in this study is whether annual-peak-flow data after the mid-1970s are substantially different from data for the entire period of record and thus might result in substantially different peak-flow frequencies. Peak-flow timing data are not directly incorporated in calculation of peak-flow frequencies and have less direct relevance than annual-peak-flow data in this study. The nonparametric Wilcoxon rank sum procedure (Wilcoxon, 1945) was used to test for significant differences between the annual-peak-flow median for 1979–2011 in relation to medians for 1930–78 and for the entire period of record. The nonparametric Wilcoxon rank sum procedure (Wilcoxon, 1945) also was used to test for significant changes in peak-flow timing, with the test applied to the day-of-peak median for 1979–2011 in relation to medians for 1930–78 and for the entire period of record. In this study, a significance level (*p*-value) less than 0.05 indicates statistical significance.

Factors that Affect Interpretation of Results

The fitted trend lines provide estimates of the changes in median values through time. Trend-magnitude values are considered semiquantitative estimates determined by statistical analysis. Throughout this report chapter, trend-magnitude values (reported to two significant figures) sometimes are referred to in discussion of temporal changes in peak-flow characteristics. Reference to specific trend-magnitude values is intended to facilitate discussion of temporal changes, but is not intended to represent absolute accuracy at two significant figures. The discussion of trend results focuses on the trend-magnitude values. The *p*-values associated with the trend results are indicated in the tables and figures that present trend results but not emphasized in the discussion.

In the discussion of temporal trends in annual peak flow, qualitative observations on trend magnitudes are made. Trend magnitudes are considered to be (1) substantial, if the deviation from zero was larger than about 1 percent per year; (2) moderate, if the deviation from zero was about 0.2–1 percent per year; and (3) small, if the deviation from zero was less than about 0.2 percent per year. The qualitative descriptions were subjectively defined and are intended to facilitate discussion of trend patterns among gaging stations and groups of gaging stations.

Among the diverse gaging stations, trend magnitudes for peak-flow timing are more difficult to consistently interpret than trend magnitudes for annual peak flow. Multiple distinct populations of day-of-peak values for some individual gaging stations contribute to this issue. A brief overview of major causal factors of peak flows is relevant to understanding multiple populations in day-of-peak data. Throughout this report chapter, general observations are made on relations among causal factors of peak flows and peak-flow timing. The observations generally 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), Zelt and others (1999), Knowles and others (2006), Pederson and others (2011), and Shinker (2010).

In much of Montana, especially areas east of the Rocky Mountain front, May and June typically have higher mean monthly precipitation than most other months, and the May and June precipitation typically (primarily depending on elevation) is in the form of rainfall. During the spring (typically May and June), two major sources provide moisture for the region: (1) warm moist air masses are advected into the region because of the formation of the low-level jet, which advects moisture northward from the Gulf of Mexico (Mock, 1996; Shinker, 2010); and (2) northwesterly flows of moisture from the northern Pacific Ocean in conjunction with the formation of major frontal systems and unstable air masses, all of which result from cool season atmospheric circulation patterns (Mock, 1996; Shinker, 2010). Convective storms also can develop behind the cyclonic frontal systems and further contribute to spring precipitation. Runoff from spring rainfall is a major causal factor contributing to many peak flows in Montana. Monthly mean precipitation typically decreases (sometimes sharply) as warm stable air masses build across the Pacific Northwest and northern Rocky Mountains from June through September (Mock, 1996; Shinker, 2010).

In the western part of Montana, cyclonic systems commonly referred to as atmospheric rivers can deliver large amounts of moisture from the Pacific Ocean in the late summer and fall, occasionally resulting in flooding. In high-elevation areas of western Montana, the cool season (fall and winter) precipitation totals usually exceed the spring (May and June) precipitation totals, which can result in large accumulated mountain snowpacks. Much lower precipitation totals and smaller amounts of accumulated snowpack, however, are common in lower elevation areas. The timing and relative contribution of snowmelt runoff to streamflow is strongly dependent on spring temperatures, which reflect the importance of elevation and, to a lesser extent, latitude on snowmelt timing (Pederson and others, 2011). In low-elevation areas, snowmelt runoff generally is in late winter through early spring (Zelt and others, 1999), typically before May, and the timing of annual peaks that result from low-elevation snowmelt runoff typically is somewhat distinctly separated from the timing of annual peaks that result from spring precipitation or summer convective storms. With increase in elevation, the time of snowmelt runoff is later in the year. In high-elevation areas, most snowmelt typically is from May through mid-July (Pederson and others, 2011); the typical snowmelt runoff period and the typical spring rainfall period are somewhat synchronized, and the relative contributions of snowmelt and rainfall runoff are difficult to distinguish. Difficulties in distinguishing the effects of snowmelt and rainfall on peak flows in high-elevation areas also have been noted by Pederson and others (2011).

For most of the long-term gaging stations in this study that have relatively high mean basin elevations (that is, greater than about 6,000 ft) peak flows typically are during the snowmelt runoff period and result from snowmelt only or a combination of rainfall on snowmelt. Peak flows that are outside of the snowmelt runoff period (May through mid-July) and result from rainfall only are somewhat infrequent. For the high-elevation gaging stations, the day-of-peak data typically are well (approximately continuously and normally) distributed within the snowmelt period. Among the high-elevation gaging stations, trend magnitudes for peak-flow timing can be reasonably consistently interpreted and compared. Upward trends in peak-flow timing indicate that the timing of annual peak flows changed from earlier in the year to later in the year. Conversely, downward trends in peak-flow timing indicate that the timing of annual peak flows changed from later in the year to earlier in the year. In the discussion, trend magnitudes for peak-flow timing for high-elevation gaging stations are qualitatively considered to be (1) substantial, if the deviation from zero was larger than about 0.20 percent per year; (2) moderate, if the deviation from zero was about 0.10–0.20 percent per year; and (3) small, if the deviation from zero was less than about 0.10 percent per year. The criteria for qualitative observations on trend magnitudes for peak-flow timing purposely differ from the criteria for trend magnitudes for annual peak flow because of large differences in units of measurement and scaling between day of peak and annual peak flow.

Many of the long-term gaging stations in this study that have relatively low mean basin elevations (less than about 6,000 ft) have bimodal (and sometimes trimodal) distributions of day-of-peak data. The multiple populations of day-of-peak values for individual low-elevation gaging stations primarily result from the following major causal factors: low-elevation snowmelt (possibly with associated rainfall) and rainfall only outside of the snowmelt period. Furthermore, rainfall-only events can result from cyclonic storms (and convective storms that sometimes follow behind cyclonic systems) that typically are in May and June and intense convective and cyclonic summer storms that typically are from July through September. Each of these causal factors might account for a considerable proportion of the day-of-peak values in the annual series. For some gaging stations, there is somewhat distinct and relatively large separation in the ranges of day-of-peak values between the various causal factors. Rigorous statistical analysis of day-of-peak data for gaging stations with multiple populations would involve segregating the data into the individual populations for separate analysis; however, this detailed approach was beyond the scope of this study. In the simplified approach of this study, all day-of-peak data for an individual gaging station were treated as coming from a single population. The fitted trend lines generally are within or near the day-of-peak values representing the dominant causal factor population. The temporal changes in median peak flow indicated by the fitted trend lines might represent changes in timing within the dominant causal factor or shifts in dominance between causal factors. As such, trend magnitudes for peak-flow timing for low-elevation gaging stations are somewhat variable and more difficult to interpret than for high-elevation gaging stations. Discussion of trend magnitudes for peak-flow timing for low-elevation gaging stations focuses on general patterns in directions of trends.

A detailed analysis of causal factors for individual peak flows was not done for this study; however, results are described based on principles that peak flows in high-elevation areas (greater than about 6,000 ft) generally occur during the high-elevation snowmelt runoff period (May through mid-July) and primarily are affected by snowmelt runoff. Peak flows in low-elevation areas (less than about 6,000 ft) somewhat frequently occur outside of the low-elevation snowmelt runoff period (late winter through early spring, typically before May), and rainfall-only events account for a larger proportion of peak flows in low-elevation areas than in high-elevation areas. However, in both high- and low-elevation areas, a combination of rainfall and snowmelt events can occur within the snowmelt runoff period.

Temporal Trends and Stationarity in Annual Peak Flow and Peak-Flow Timing

Results of analysis of temporal trends are presented in table 2 for annual peak flow and in table 3 for day of peak. Statistical summaries of annual peak flow and peak-flow timing for summary time periods are presented in table 4. Study results are discussed according to the groups of gaging stations.

For stations that have at least 15 years of peak-flow records before 1940, trend results for the period from the start of systematic data collection to 1940 are presented in tables and figures for informational purposes. However, because less than 50 percent of the gaging stations have adequate pre-1940 data, trend results for the period from the start of systematic data collection to 1940 are not discussed.

Streamflow-Gaging Stations in the Saskatchewan River Basin

Fitted trends for annual peak flow and peak-flow timing, and statistical distributions for summary time periods for the two gaging stations in the Saskatchewan River Basin are presented in figure 2. The two gaging stations in the Saskatchewan River Basin (Swiftcurrent Creek at Many Glacier, Montana [gaging station 05014500; map number 9; fig. 1, table 1] and St. Mary River at international boundary [gaging station 05020500; map number 14; fig. 1, table 1]) have mean basin elevations of 6,435 and 5,745 ft, respectively. For both gaging stations, nearly all peak flows are during May and June, likely caused by snowmelt runoff (possibly with associated spring rainfall). Day-of-peak values generally are uniformly distributed during May and June (fig. 2).

Table 2. Results of analysis of temporal trends in annual peak flow (the annual series of maximum instantaneous discharge, in cubic feet per second).

[All years refer to water year, which is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. Gray shading indicates statistical significance (*p*-value less than 0.05). *p*-value, statistical significance; —, not applicable]

Map number (fig. 1)	Station identification number	Station name	Trend results for the period from the start of systematic data collection through 1940 (for stations with at least 15 years of systematic record during the period)						
			Number of years with data	Start-year	Fitted trend value, in cubic feet per second	End-year	Fitted trend value, in cubic feet per second	Trend magnitude, in percent per year	*p*-value
		Streamflow-gaging stations in the Saskatchewan River Basin							
9	05014500	Swiftcurrent Creek at Many Glacier, Montana	28	1913	1,050	1940	1,120	0.21	0.57
14	05020500	St. Mary River at international boundary	26	1915	5,460	1940	3,100	-1.66	0.06
		Streamflow-gaging stations in the Missouri River Basin							
		Missouri River headwaters tributaries							
45	06025500	Big Hole River near Melrose, Montana	—	—	—	—	—	—	—
80	06043500	Gallatin River near Gallatin Gateway, Montana	—	—	—	—	—	—	—
88	06052500	Gallatin River at Logan, Montana	—	—	—	—	—	—	—
		Upper Missouri River tributaries							
101	06062500	Tenmile Creek near Rimini, Montana	26	1915	317	1940	78	-2.90	0.03
161	06099500	Marias River near Shelby, Montana	35	1902	8,300	1940	3,230	-1.57	0.01
		Musselshell River Basin							
212	06120500	Musselshell River at Harlowton, Montana	32	1909	1,712	1940	898	-1.49	0.14
		Upper Milk River Basin							
271	06133000	Milk River at western crossing of international boundary	—	—	—	—	—	—	—
		Lower Missouri River tributary							
386	06178000	Poplar River at international boundary	—	—	—	—	—	—	—
		Yellowstone River Basin							
414	06186500	Yellowstone River at Yellowstone Lake outlet, Yellowstone National Park, Wyoming	18	1923	4,590	1940	3,800	-0.97	0.54
424	06191500	Yellowstone River at Corwin Springs, Montana	30	1911	19,100	1940	12,500	-1.15	0.09
425	06192500	Yellowstone River near Livingston, Montana	—	—	—	—	—	—	—
443	06205000	Stillwater River near Absarokee, Montana	—	—	—	—	—	—	—
445	06207500	Clarks Fork Yellowstone River near Belfry, Montana	19	1922	7,560	1940	7,900	0.24	0.86
448	06208500	Clarks Fork Yellowstone River at Edgar, Montana	18	1922	7,590	1940	7,410	-0.12	0.97
458	06214500	Yellowstone River at Billings, Montana	—	—	—	—	—	—	—
542	06324500	Powder River at Moorhead, Montana	—	—	—	—	—	—	—
		Streamflow-gaging stations in the Columbia River Basin							
665	12340500	Clark Fork above Missoula, Montana	—	—	—	—	—	—	—
688	12353000	Clark Fork below Missoula, Montana	—	—	—	—	—	—	—
697	12354500	Clark Fork at St. Regis, Montana	25	1911	41,100	1940	23,400	-1.43	0.04
698	12355000	Flathead River at Flathead, British Columbia	—	—	—	—	—	—	—
700	12355500	North Fork Flathead River near Columbia Falls, Montana	—	—	—	—	—	—	—
728	12370000	Swan River near Bigfork, Montana	19	1922	5,860	1940	4,420	-1.29	0.10

Table 2. Results of analysis of temporal trends in annual peak flow (the annual series of maximum instantaneous discharge, in cubic feet per second).–Continued

[All years refer to water year, which is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. Gray shading indicates statistical significance (*p*-value less than 0.05). *p*-value, statistical significance; —, not applicable]

Map number (fig. 1)	Station identification number	Station name	Trend results for the period from 1930 through 1976: Number of years with data	Start-year	Fitted trend value, in cubic feet per second	End-year	Fitted trend value, in cubic feet per second	Trend magnitude, in percent per year	*p*-value
		Streamflow-gaging stations in the Saskatchewan River Basin							
9	05014500	Swiftcurrent Creek at Many Glacier, Montana	47	1930	1,020	1976	1,060	0.06	0.80
14	05020500	St. Mary River at international boundary	45	1930	2,900	1976	4,660	1.29	0.05
		Streamflow-gaging stations in the Missouri River Basin							
		Missouri River headwaters tributaries							
45	06025500	Big Hole River near Melrose, Montana	46	1930	5,560	1976	10,100	1.73	0.01
80	06043500	Gallatin River near Gallatin Gateway, Montana	46	1931	3,350	1976	6,690	2.17	0.00
88	06052500	Gallatin River at Logan, Montana	46	1930	3,180	1976	6,400	2.15	0.00
		Upper Missouri River tributaries							
101	06062500	Tenmile Creek near Rimini, Montana	46	1931	161	1976	276	1.55	0.05
161	06099500	Marias River near Shelby, Montana	45	1931	4,980	1976	7,000	0.88	0.23
		Musselshell River Basin							
212	06120500	Musselshell River at Harlowton, Montana	47	1930	850	1976	1,310	1.15	0.24
		Upper Milk River Basin							
271	06133000	Milk River at western crossing of international boundary	45	1931	696	1976	1,290	1.86	0.12
		Lower Missouri River tributary							
386	06178000	Poplar River at international boundary	45	1931	496	1976	935	1.92	0.18
		Yellowstone River Basin							
414	06186500	Yellowstone River at Yellowstone Lake outlet, Yellowstone National Park, Wyoming	47	1930	3,370	1976	6,010	1.67	0.00
424	06191500	Yellowstone River at Corwin Springs, Montana	47	1930	14,100	1976	22,100	1.20	0.00
425	06192500	Yellowstone River near Livingston, Montana	42	1930	15,200	1976	24,800	1.34	0.00
443	06205000	Stillwater River near Absarokee, Montana	42	1935	6,105	1976	7,805	0.66	0.17
445	06207500	Clarks Fork Yellowstone River near Belfry, Montana	47	1930	6,840	1976	8,800	0.61	0.03
448	06208500	Clarks Fork Yellowstone River at Edgar, Montana	46	1930	6,921	1976	8,838	0.59	0.10
458	06214500	Yellowstone River at Billings, Montana	47	1930	33,200	1976	49,600	1.05	0.00
542	06324500	Powder River at Moorhead, Montana	45	1930	6,420	1976	8,050	0.54	0.41
		Streamflow-gaging stations in the Columbia River Basin							
665	12340500	Clark Fork above Missoula, Montana	47	1930	11,100	1976	20,500	1.82	0.01
688	12353000	Clark Fork below Missoula, Montana	47	1930	21,400	1976	39,600	1.80	0.00
697	12354500	Clark Fork at St. Regis, Montana	47	1930	28,700	1976	49,900	1.57	0.00
698	12355000	Flathead River at Flathead, British Columbia	47	1930	6,220	1976	9,840	1.24	0.01
700	12355500	North Fork Flathead River near Columbia Falls, Montana	47	1930	16,200	1976	25,200	1.19	0.01
728	12370000	Swan River near Bigfork, Montana	47	1930	4,470	1976	5,790	0.63	0.11

Table 2. Results of analysis of temporal trends in annual peak flow (the annual series of maximum instantaneous discharge, in cubic feet per second).–Continued

[All years refer to water year, which is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. Gray shading indicates statistical significance (*p*-value less than 0.05). *p*-value, statistical significance; —, not applicable]

Map number (fig. 1)	Station identification number	Station name	Trend results for the period from 1967 through 2011: Number of years with data	Start-year	Fitted trend value, in cubic feet per second	End-year	Fitted trend value, in cubic feet per second	Trend magnitude, in percent per year	*p*-value
		Streamflow-gaging stations in the Saskatchewan River Basin							
9	05014500	Swiftcurrent Creek at Many Glacier, Montana	45	1967	1,010	2011	1,070	0.12	0.81
14	05020500	St. Mary River at international boundary	43	1967	3,700	2011	3,830	0.08	0.83
		Streamflow-gaging stations in the Missouri River Basin							
		Missouri River headwaters tributaries							
45	06025500	Big Hole River near Melrose, Montana	45	1967	9,020	2011	6,080	-0.72	0.18
80	06043500	Gallatin River near Gallatin Gateway, Montana	42	1967	6,000	2011	4,970	-0.38	0.22
88	06052500	Gallatin River at Logan, Montana	45	1967	6,430	2011	4,770	-0.58	0.11
		Upper Missouri River tributaries							
101	06062500	Tenmile Creek near Rimini, Montana	43	1967	231	2011	183	-0.47	0.27
161	06099500	Marias River near Shelby, Montana	45	1967	6,400	2011	4,760	-0.57	0.40
		Musselshell River Basin							
212	06120500	Musselshell River at Harlowton, Montana	45	1967	1,086	2011	686	-0.82	0.25
		Upper Milk River Basin							
271	06133000	Milk River at western crossing of international boundary	45	1967	1,000	2011	1,100	0.21	0.84
		Lower Missouri River tributary							
386	06178000	Poplar River at international boundary	45	1967	934	2011	296	-1.52	0.04
		Yellowstone River Basin							
414	06186500	Yellowstone River at Yellowstone Lake outlet, Yellowstone National Park, Wyoming	42	1967	5,330	2011	4,840	-0.21	0.72
424	06191500	Yellowstone River at Corwin Springs, Montana	45	1967	19,300	2011	19,700	0.06	0.87
425	06192500	Yellowstone River near Livingston, Montana	45	1967	23,600	2011	22,400	-0.11	0.73
443	06205000	Stillwater River near Absarokee, Montana	45	1967	7,411	2011	5,449	-0.59	0.08
445	06207500	Clarks Fork Yellowstone River near Belfry, Montana	45	1967	8,320	2011	7,880	-0.12	0.74
448	06208500	Clarks Fork Yellowstone River at Edgar, Montana	45	1967	8,455	2011	7,205	-0.33	0.29
458	06214500	Yellowstone River at Billings, Montana	45	1967	43,900	2011	35,900	-0.41	0.20
542	06324500	Powder River at Moorhead, Montana	43	1967	6,840	2011	2,440	-1.43	0.01
		Streamflow-gaging stations in the Columbia River Basin							
665	12340500	Clark Fork above Missoula, Montana	45	1967	16,200	2011	11,400	-0.66	0.07
688	12353000	Clark Fork below Missoula, Montana	45	1967	33,300	2011	23,700	-0.64	0.16
697	12354500	Clark Fork at St. Regis, Montana	45	1967	42,900	2011	30,300	-0.65	0.12
698	12355000	Flathead River at Flathead, British Columbia	39	1967	7,520	2011	6,060	-0.43	0.27
700	12355500	North Fork Flathead River near Columbia Falls, Montana	45	1967	20,300	2011	16,900	-0.37	0.29
728	12370000	Swan River near Bigfork, Montana	45	1967	5,280	2011	4,440	-0.35	0.16

Table 2. Results of analysis of temporal trends in annual peak flow (the annual series of maximum instantaneous discharge, in cubic feet per second).–Continued

[All years refer to water year, which is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. Gray shading indicates statistical significance (*p*-value less than 0.05). *p*-value, statistical significance; —, not applicable]

Map number (fig. 1)	Station identification number	Station name	Trend results for the period from the start of systematic data collection through 2011						
			Number of years with data	Start-year	Fitted trend value, in cubic feet per second	End-year	Fitted trend value, in cubic feet per second	Trend magnitude, in percent per year	*p*-value
Streamflow-gaging stations in the Saskatchewan River Basin									
9	05014500	Swiftcurrent Creek at Many Glacier, Montana	99	1913	1,010	2011	1,070	0.06	0.57
14	05020500	St. Mary River at international boundary	95	1915	4,050	2011	3,900	-0.04	0.79
Streamflow-gaging stations in the Missouri River Basin									
Missouri River headwaters tributaries									
45	06025500	Big Hole River near Melrose, Montana	87	1924	7,570	2011	7,430	-0.02	0.93
80	06043500	Gallatin River near Gallatin Gateway, Montana	78	1931	4,440	2011	5,780	0.37	0.03
88	06052500	Gallatin River at Logan, Montana	82	1929	4,160	2011	5,780	0.47	0.02
Upper Missouri River tributaries									
101	06062500	Tenmile Creek near Rimini, Montana	95	1915	241	2011	186	-0.23	0.20
161	06099500	Marias River near Shelby, Montana	105	1902	6,480	2011	5,160	-0.19	0.29
Musselshell River Basin									
212	06120500	Musselshell River at Harlowton, Montana	103	1909	1,300	2011	840	-0.34	0.09
Upper Milk River Basin									
271	06133000	Milk River at western crossing of international boundary	80	1931	919	2011	1,130	0.28	0.51
Lower Missouri River tributary									
386	06178000	Poplar River at international boundary	80	1931	698	2011	490	-0.37	0.25
Yellowstone River Basin									
414	06186500	Yellowstone River at Yellowstone Lake outlet, Yellowstone National Park, Wyoming	86	1923	4,160	2011	5,340	0.32	0.09
424	06191500	Yellowstone River at Corwin Springs, Montana	101	1911	16,000	2011	19,600	0.22	0.08
425	06192500	Yellowstone River near Livingston, Montana	78	1929	17,600	2011	22,800	0.35	0.04
443	06205000	Stillwater River near Absarokee, Montana	77	1935	6,818	2011	6,162	-0.12	0.48
445	06207500	Clarks Fork Yellowstone River near Belfry, Montana	90	1922	7,280	2011	8,270	0.15	0.20
448	06208500	Clarks Fork Yellowstone River at Edgar, Montana	89	1922	7,723	2011	7,935	0.03	0.77
458	06214500	Yellowstone River at Billings, Montana	83	1929	37,600	2011	41,800	0.14	0.34
542	06324500	Powder River at Moorhead, Montana	81	1929	7,870	2011	3,470	-0.67	0.00
Streamflow-gaging stations in the Columbia River Basin									
665	12340500	Clark Fork above Missoula, Montana	82	1930	15,000	2011	13,400	-0.13	0.55
688	12353000	Clark Fork below Missoula, Montana	82	1930	27,700	2011	28,300	0.03	0.89
697	12354500	Clark Fork at St. Regis, Montana	96	1911	38,200	2011	34,200	-0.10	0.46
698	12355000	Flathead River at Flathead, British Columbia	77	1929	7,180	2011	7,150	-0.01	0.96
700	12355500	North Fork Flathead River near Columbia Falls, Montana	83	1929	19,700	2011	18,900	-0.05	0.72
728	12370000	Swan River near Bigfork, Montana	90	1922	5,310	2011	4,730	-0.12	0.25

Table 3. Results of analysis of temporal trends in peak-flow timing (the annual series of the day of the annual peak flow).

[All years refer to water year, which is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. Gray shading indicates statistical significance (*p*-value less than 0.05). p-value, statistical significance; —, not applicable]

Map number (fig. 1)	Station identification number	Station name	Trend results for the period from the start of systematic data collection through 1940 (for stations with at least 15 years of systematic record during the period)						
			Number of years with data	Start-year	Fitted trend value, calendar day (Julian day)	End-year	Fitted trend value, calendar day (Julian day)	Trend magnitude, in percent per year	*p*-value
Streamflow-gaging stations in the Saskatchewan River Basin									
9	05014500	Swiftcurrent Creek at Many Glacier, Montana	28	1913	May 30 (150)	1940	May 22 (143)	-0.18	0.24
14	05020500	St. Mary River at international boundary	26	1915	June 19 (170)	1940	May 29 (149)	-0.47	0.01
Streamflow-gaging stations in the Missouri River Basin									
Missouri River headwaters tributaries									
45	06025500	Big Hole River near Melrose, Montana	—	—	—	—	—	—	—
80	06043500	Gallatin River near Gallatin Gateway, Montana	—	—	—	—	—	—	—
88	06052500	Gallatin River at Logan, Montana	—	—	—	—	—	—	—
Upper Missouri River tributaries									
101	06062500	Tenmile Creek near Rimini, Montana	26	1915	June 1 (153)	1940	May 13 (133)	-0.49	0.06
161	06099500	Marias River near Shelby, Montana	35	1902	May 30 (151)	1940	May 25 (146)	-0.08	0.72
Musselshell River Basin									
212	06120500	Musselshell River at Harlowton, Montana	32	1909	June 1 (152)	1940	June 4 (156)	0.06	0.90
Upper Milk River Basin									
271	06133000	Milk River at western crossing of international boundary	—	—	—	—	—	—	—
Lower Missouri River tributary									
386	06178000	Poplar River at international boundary	—	—	—	—	—	—	—
Yellowstone River Basin									
414	06186500	Yellowstone River at Yellowstone Lake outlet, Yellowstone National Park, Wyoming	18	1923	July 1 (183)	1940	June 26 (177)	-0.17	0.32
424	06191500	Yellowstone River at Corwin Springs, Montana	30	1911	June 13 (165)	1940	June 1 (152)	-0.25	0.12
425	06192500	Yellowstone River near Livingston, Montana	—	—	—	—	—	—	—
443	06205000	Stillwater River near Absarokee, Montana	—	—	—	—	—	—	—
445	06207500	Clarks Fork Yellowstone River near Belfry, Montana	19	1922	June 15 (167)	1940	June 10 (161)	-0.19	0.48
448	06208500	Clarks Fork Yellowstone River at Edgar, Montana	18	1922	June 15 (166)	1940	June 9 (161)	-0.18	0.57
458	06214500	Yellowstone River at Billings, Montana	—	—	—	—	—	—	—
542	06324500	Powder River at Moorhead, Montana	—	—	—	—	—	—	—
Streamflow-gaging stations in the Columbia River Basin									
665	12340500	Clark Fork above Missoula, Montana	—	—	—	—	—	—	—
688	12353000	Clark Fork below Missoula, Montana	—	—	—	—	—	—	—
697	12354500	Clark Fork at St. Regis, Montana	25	1911	June 7 (158)	1940	May 13 (134)	-0.52	0.01
698	12355000	Flathead River at Flathead, British Columbia	—	—	—	—	—	—	—
700	12355500	North Fork Flathead River near Columbia Falls, Montana	—	—	—	—	—	—	—
728	12370000	Swan River near Bigfork, Montana	19	1922	May 30 (150)	1940	May 25 (146)	-0.16	0.70

Table 3. Results of analysis of temporal trends in peak-flow timing (the annual series of the day of the annual peak flow).—Continued

[All years refer to water year, which is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. Gray shading indicates statistical significance (*p*-value less than 0.05). *p*-value, statistical significance; —, not applicable]

Map number (fig. 1)	Station identification number	Station name	Trend results for the period from 1930 through 1976						
			Number of years with data	Start-year	Fitted trend value, calendar day (Julian day)	End-year	Fitted trend value, calendar day (Julian day)	Trend magnitude, in percent per year	*p*-value
Streamflow-gaging stations in the Saskatchewan River Basin									
9	05014500	Swiftcurrent Creek at Many Glacier, Montana	47	1930	May 27 (148)	1976	June 13 (164)	0.24	0.04
14	05020500	St. Mary River at international boundary	45	1930	June 7 (158)	1976	June 9 (160)	0.03	0.72
Streamflow-gaging stations in the Missouri River Basin									
Missouri River headwaters tributaries									
45	06025500	Big Hole River near Melrose, Montana	46	1930	May 31 (151)	1976	June 7 (159)	0.10	0.35
80	06043500	Gallatin River near Gallatin Gateway, Montana	46	1931	June 4 (156)	1976	June 15 (166)	0.15	0.06
88	06052500	Gallatin River at Logan, Montana	46	1930	June 6 (158)	1976	June 17 (168)	0.14	0.06
Upper Missouri River tributaries									
101	06062500	Tenmile Creek near Rimini, Montana	46	1931	May 22 (143)	1976	May 29 (149)	0.11	0.31
161	06099500	Marias River near Shelby, Montana	45	1931	May 27 (148)	1976	June 2 (154)	0.09	0.49
Musselshell River Basin									
212	06120500	Musselshell River at Harlowton, Montana	47	1930	June 3 (154)	1976	June 7 (158)	0.06	0.77
Upper Milk River Basin									
271	06133000	Milk River at western crossing of international boundary	45	1931	May 17 (137)	1976	April 25 (115)	-0.34	0.21
Lower Missouri River tributary									
386	06178000	Poplar River at international boundary	45	1931	April 9 (99)	1976	March 28 (87)	-0.27	0.29
Yellowstone River Basin									
414	06186500	Yellowstone River at Yellowstone Lake outlet, Yellowstone National Park, Wyoming	47	1930	June 26 (177)	1976	July 1 (183)	0.06	0.28
424	06191500	Yellowstone River at Corwin Springs, Montana	47	1930	June 7 (158)	1976	June 16 (168)	0.12	0.10
425	06192500	Yellowstone River near Livingston, Montana	42	1930	June 9 (160)	1976	June 15 (166)	0.08	0.31
443	06205000	Stillwater River near Absarokee, Montana	42	1935	June 13 (164)	1976	June 16 (167)	0.04	0.52
445	06207500	Clarks Fork Yellowstone River near Belfry, Montana	47	1930	June 10 (161)	1976	June 19 (171)	0.12	0.11
448	06208500	Clarks Fork Yellowstone River at Edgar, Montana	46	1930	June 9 (160)	1976	June 22 (173)	0.17	0.02
458	06214500	Yellowstone River at Billings, Montana	47	1930	June 13 (165)	1976	June 18 (169)	0.06	0.29
542	06324500	Powder River at Moorhead, Montana	45	1930	June 10 (162)	1976	June 7 (158)	-0.04	0.81
Streamflow-gaging stations in the Columbia River Basin									
665	12340500	Clark Fork above Missoula, Montana	47	1930	May 14 (135)	1976	June 2 (153)	0.29	0.04
688	12353000	Clark Fork below Missoula, Montana	47	1930	May 18 (138)	1976	June 4 (156)	0.27	0.05
697	12354500	Clark Fork at St. Regis, Montana	47	1930	May 20 (140)	1976	June 4 (156)	0.23	0.06
698	12355000	Flathead River at Flathead, British Columbia	47	1930	May 19 (139)	1976	May 28 (149)	0.15	0.17
700	12355500	North Fork Flathead River near Columbia Falls, Montana	47	1930	May 20 (140)	1976	June 2 (154)	0.21	0.06
728	12370000	Swan River near Bigfork, Montana	47	1930	May 25 (146)	1976	June 5 (156)	0.15	0.12

Table 3. Results of analysis of temporal trends in peak-flow timing (the annual series of the day of the annual peak flow).—Continued

[All years refer to water year, which is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. Gray shading indicates statistical significance (*p*-value less than 0.05). *p*-value, statistical significance; —, not applicable]

Map number (fig. 1)	Station identification number	Station name	Trend results for the period from 1967 through 2011: Number of years with data	Start-year	Fitted trend value, calendar day (Julian day)	End-year	Fitted trend value, calendar day (Julian day)	Trend magnitude, in percent per year	*p*-value
		Streamflow-gaging stations in the Saskatchewan River Basin							
9	05014500	Swiftcurrent Creek at Many Glacier, Montana	45	1967	June 1 (152)	2011	June 4 (156)	0.05	0.72
14	05020500	St. Mary River at international boundary	43	1967	June 4 (156)	2011	June 10 (162)	0.08	0.36
		Streamflow-gaging stations in the Missouri River Basin							
		Missouri River headwaters tributaries							
45	06025500	Big Hole River near Melrose, Montana	45	1967	June 6 (157)	2011	June 6 (157)	0.00	0.93
80	06043500	Gallatin River near Gallatin Gateway, Montana	42	1967	June 13 (165)	2011	June 1 (153)	-0.16	0.13
88	06052500	Gallatin River at Logan, Montana	45	1967	June 13 (165)	2011	June 6 (157)	-0.10	0.30
		Upper Missouri River tributaries							
101	06062500	Tenmile Creek near Rimini, Montana	43	1967	May 24 (144)	2011	May 29 (150)	0.08	0.43
161	06099500	Marias River near Shelby, Montana	45	1967	May 24 (145)	2011	May 31 (151)	0.09	0.56
		Musselshell River Basin							
212	06120500	Musselshell River at Harlowton, Montana	45	1967	May 28 (148)	2011	June 2 (154)	0.07	0.56
		Upper Milk River Basin							
271	06133000	Milk River at western crossing of international boundary	45	1967	April 21 (111)	2011	May 10 (131)	0.38	0.45
		Lower Missouri River tributary							
386	06178000	Poplar River at international boundary	45	1967	March 26 (85)	2011	April 16 (107)	0.55	0.21
		Yellowstone River Basin							
414	06186500	Yellowstone River at Yellowstone Lake outlet, Yellowstone National Park, Wyoming	42	1967	July 1 (183)	2011	June 26 (178)	-0.06	0.30
424	06191500	Yellowstone River at Corwin Springs, Montana	45	1967	June 17 (168)	2011	May 26 (146)	-0.29	0.01
425	06192500	Yellowstone River near Livingston, Montana	45	1967	June 15 (166)	2011	May 31 (152)	-0.20	0.02
443	06205000	Stillwater River near Absarokee, Montana	45	1967	June 14 (165)	2011	June 7 (159)	-0.09	0.17
445	06207500	Clarks Fork Yellowstone River near Belfry, Montana	45	1967	June 16 (168)	2011	June 3 (154)	-0.18	0.06
448	06208500	Clarks Fork Yellowstone River at Edgar, Montana	45	1967	June 18 (169)	2011	June 3 (155)	-0.19	0.07
458	06214500	Yellowstone River at Billings, Montana	45	1967	June 15 (166)	2011	June 6 (158)	-0.12	0.13
542	06324500	Powder River at Moorhead, Montana	43	1967	June 8 (159)	2011	May 25 (145)	-0.19	0.54
		Streamflow-gaging stations in the Columbia River Basin							
665	12340500	Clark Fork above Missoula, Montana	45	1967	May 27 (148)	2011	May 26 (146)	-0.02	0.85
688	12353000	Clark Fork below Missoula, Montana	45	1967	June 2 (154)	2011	May 28 (148)	-0.08	0.42
697	12354500	Clark Fork at St. Regis, Montana	45	1967	May 31 (151)	2011	May 24 (145)	-0.09	0.41
698	12355000	Flathead River at Flathead, British Columbia	39	1967	May 25 (145)	2011	May 25 (145)	0.00	0.87
700	12355500	North Fork Flathead River near Columbia Falls, Montana	45	1967	May 24 (145)	2011	May 29 (149)	0.06	0.47
728	12370000	Swan River near Bigfork, Montana	45	1967	May 31 (151)	2011	June 3 (155)	0.05	0.60

Table 3. Results of analysis of temporal trends in peak-flow timing (the annual series of the day of the annual peak flow).—Continued

[All years refer to water year, which is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. Gray shading indicates statistical significance (*p*-value less than 0.05). p-value, statistical significance; —, not applicable]

Map number (fig. 1)	Station identification number	Station name	Trend results for the period from the start of systematic data collection through 2011: Number of years with data	Start-year	Fitted trend value, calendar day (Julian day)	End-year	Fitted trend value, calendar day (Julian day)	Trend magnitude, in percent per year	*p*-value
Streamflow-gaging stations in the Saskatchewan River Basin									
9	05014500	Swiftcurrent Creek at Many Glacier, Montana	99	1913	May 27 (148)	2011	June 5 (156)	0.06	0.16
14	05020500	St. Mary River at international boundary	95	1915	June 8 (159)	2011	June 8 (159)	0.00	0.92
Streamflow-gaging stations in the Missouri River Basin									
Missouri River headwaters tributaries									
45	06025500	Big Hole River near Melrose, Montana	87	1924	June 1 (153)	2011	June 6 (157)	0.03	0.32
80	06043500	Gallatin River near Gallatin Gateway, Montana	78	1931	June 11 (162)	2011	June 6 (158)	-0.03	0.42
88	06052500	Gallatin River at Logan, Montana	82	1929	June 11 (162)	2011	June 7 (159)	-0.03	0.47
Upper Missouri River tributaries									
101	06062500	Tenmile Creek near Rimini, Montana	95	1915	May 22 (143)	2011	May 29 (150)	0.05	0.14
161	06099500	Marias River near Shelby, Montana	105	1902	May 28 (148)	2011	June 2 (154)	0.03	0.42
Musselshell River Basin									
212	06120500	Musselshell River at Harlowton, Montana	103	1909	June 1 (153)	2011	June 4 (155)	0.01	0.75
Upper Milk River Basin									
271	06133000	Milk River at western crossing of international boundary	80	1931	May 9 (130)	2011	April 26 (116)	-0.13	0.30
Lower Missouri River tributary									
386	06178000	Poplar River at international boundary	80	1931	March 31 (90)	2011	April 5 (96)	0.07	0.70
Yellowstone River Basin									
414	06186500	Yellowstone River at Yellowstone Lake outlet, Yellowstone National Park, Wyoming	86	1923	June 29 (181)	2011	June 28 (179)	-0.01	0.60
424	06191500	Yellowstone River at Corwin Springs, Montana	101	1911	June 12 (164)	2011	June 3 (154)	-0.06	0.03
425	06192500	Yellowstone River near Livingston, Montana	78	1929	June 15 (167)	2011	June 2 (154)	-0.09	0.02
443	06205000	Stillwater River near Absarokee, Montana	77	1935	June 13 (165)	2011	June 10 (161)	-0.02	0.55
445	06207500	Clarks Fork Yellowstone River near Belfry, Montana	90	1922	June 15 (167)	2011	June 8 (159)	-0.05	0.14
448	06208500	Clarks Fork Yellowstone River at Edgar, Montana	89	1922	June 14 (166)	2011	June 9 (160)	-0.04	0.28
458	06214500	Yellowstone River at Billings, Montana	83	1929	June 15 (166)	2011	June 8 (160)	-0.05	0.14
542	06324500	Powder River at Moorhead, Montana	81	1929	June 8 (159)	2011	May 30 (150)	-0.07	0.45
Streamflow-gaging stations in the Columbia River Basin									
665	12340500	Clark Fork above Missoula, Montana	82	1930	May 20 (140)	2011	May 28 (148)	0.07	0.21
688	12353000	Clark Fork below Missoula, Montana	82	1930	May 25 (146)	2011	May 30 (150)	0.04	0.40
697	12354500	Clark Fork at St. Regis, Montana	96	1911	May 30 (150)	2011	May 26 (146)	-0.03	0.41
698	12355000	Flathead River at Flathead, British Columbia	77	1929	May 24 (144)	2011	May 24 (144)	0.00	0.84
700	12355500	North Fork Flathead River near Columbia Falls, Montana	83	1929	May 24 (144)	2011	May 30 (150)	0.05	0.21
728	12370000	Swan River near Bigfork, Montana	90	1922	May 27 (148)	2011	June 4 (156)	0.06	0.11

Table 4. Statistical summaries of annual peak flow (the annual series of maximum instantaneous discharge, in cubic feet per second) and peak-flow timing (the annual series of the day of the annual peak flow) for summary time periods.

[All years refer to water year, which is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. Gray shading indicates statistical significance (*p*-value less than 0.05). p-value, statistical significance]

Map number (fig. 1)	Station identification number	Station name	Median for indicated period, cubic feet per second			Results of Wilcoxon rank sum test[1] for differences in medians among periods (*p*-value)	
			1930–78	1979–2011	Period of record	Median for 1979–2011 compared to median for 1930–78	Median for 1979–2011 compared to median for period of record
Streamflow-gaging stations in the Saskatchewan River Basin							
9	05014500	Swiftcurrent Creek at Many Glacier, Montana	1,010	1,040	1,040	0.78	0.72
14	05020500	St. Mary River at international boundary	3,740	3,610	3,980	0.64	0.58
Streamflow-gaging stations in the Missouri River Basin							
Missouri River headwaters tributaries							
45	06025500	Big Hole River near Melrose, Montana	7,760	6,610	7,500	0.20	0.39
80	06043500	Gallatin River near Gallatin Gateway, Montana	5,020	5,200	5,140	0.97	0.97
88	06052500	Gallatin River at Logan, Montana	4,820	5,580	4,980	0.25	0.54
Upper Missouri River tributaries							
101	06062500	Tenmile Creek near Rimini, Montana	218	202	214	0.50	0.36
161	06099500	Marias River near Shelby, Montana	5,950	5,160	5,700	0.56	0.48
Musselshell River Basin							
212	06120500	Musselshell River at Harlowton, Montana	1,080	739	1,070	0.52	0.25
Upper Milk River Basin							
271	06133000	Milk River at western crossing of international boundary	1,000	1,050	1,020	0.74	0.83
Lower Missouri River tributary							
386	06178000	Poplar River at international boundary	720	350	592	0.07	0.24
Yellowstone River Basin							
414	06186500	Yellowstone River at Yellowstone Lake outlet, Yellowstone National Park, Wyoming	4,690	4,780	4,730	0.77	0.83
424	06191500	Yellowstone River at Corwin Springs, Montana	18,100	17,500	17,700	0.48	0.53
425	06192500	Yellowstone River near Livingston, Montana	20,500	20,100	20,600	0.84	0.95
443	06205000	Stillwater River near Absarokee, Montana	6,905	6,250	6,470	0.26	0.49
445	06207500	Clarks Fork Yellowstone River near Belfry, Montana	7,820	7,470	7,780	0.85	0.84
448	06208500	Clarks Fork Yellowstone River at Edgar, Montana	7,900	7,440	7,890	0.43	0.43
458	06214500	Yellowstone River at Billings, Montana	41,400	37,600	39,400	0.51	0.71
542	06324500	Powder River at Moorhead, Montana	7,200	3,730	5,730	0.00	0.00
Streamflow-gaging stations in the Columbia River Basin							
665	12340500	Clark Fork above Missoula, Montana	15,500	13,400	14,200	0.12	0.27
688	12353000	Clark Fork below Missoula, Montana	30,500	27,200	28,000	0.27	0.48
697	12354500	Clark Fork at St. Regis, Montana	37,400	34,400	36,100	0.16	0.24
698	12355000	Flathead River at Flathead, British Columbia	7,960	6,710	7,170	0.17	0.33
700	12355500	North Fork Flathead River near Columbia Falls, Montana	20,400	18,600	19,200	0.15	0.40
728	12370000	Swan River near Bigfork, Montana	5,130	4,820	5,020	0.29	0.34

Table 4. Statistical summaries of annual peak flow (the annual series of maximum instantaneous discharge, in cubic feet per second) and peak-flow timing (the annual series of the day of the annual peak flow) for summary time periods.—Continued

[All years refer to water year, which is the 12-month period from October 1 through September 30 and is designated by the year in which it ends. Gray shading indicates statistical significance (*p*-value less than 0.05). p-value, statistical significance]

Map number (fig. 1)	Station identification number	Station name	Median for indicated period,calendar day (Julian day)			Results of Wilcoxon rank sum test[1] for differences in medians among periods (*p*-value)	
			1930–78	1979–2011	Period of record	Median for 1979–2011 compared to median for 1930–78	Median for 1979–2011 compared to median for period of record
Streamflow-gaging stations in the Saskatchewan River Basin							
9	05014500	Swiftcurrent Creek at Many Glacier, Montana	June 5 (156)	June 1 (152)	June 1 (152)	0.99	0.84
14	05020500	St. Mary River at international boundary	June 8 (159)	June 7 (158)	June 8 (159)	0.82	0.97
Streamflow-gaging stations in the Missouri River Basin							
Missouri River headwaters tributaries							
45	06025500	Big Hole River near Melrose, Montana	June 4 (156)	June 3 (154)	June 4 (155)	0.90	0.89
80	06043500	Gallatin River near Gallatin Gateway, Montana	June 10 (161)	June 3 (155)	June 9 (160)	0.03	0.12
88	06052500	Gallatin River at Logan, Montana	June 11 (162)	June 5 (156)	June 10 (161)	0.03	0.12
Upper Missouri River tributaries							
101	06062500	Tenmile Creek near Rimini, Montana	May 26 (146)	May 28 (148)	May 26 (146)	0.21	0.34
161	06099500	Marias River near Shelby, Montana	May 30 (150)	May 31 (151)	May 31 (151)	0.73	0.76
Musselshell River Basin							
212	06120500	Musselshell River at Harlowton, Montana	June 5 (156)	May 31 (151)	June 3 (154)	0.92	0.93
Upper Milk River Basin							
271	06133000	Milk River at western crossing of international boundary	May 1 (121)	May 5 (125)	May 3 (123)	0.50	0.67
Lower Missouri River tributary							
386	06178000	Poplar River at international boundary	April 3 (93)	April 9 (99)	April 3 (93)	0.61	0.74
Yellowstone River Basin							
414	06186500	Yellowstone River at Yellowstone Lake outlet, Yellowstone National Park, Wyoming	June 29 (180)	June 28 (180)	June 29 (180)	0.34	0.50
424	06191500	Yellowstone River at Corwin Springs, Montana	June 11 (162)	June 2 (153)	June 8 (159)	0.00	0.02
425	06192500	Yellowstone River near Livingston, Montana	June 11 (163)	June 6 (157)	June 9 (160)	0.01	0.07
443	06205000	Stillwater River near Absarokee, Montana	June 14 (166)	June 11 (162)	June 11 (162)	0.47	0.73
445	06207500	Clarks Fork Yellowstone River near Belfry, Montana	June 14 (165)	June 7 (158)	June 12 (163)	0.03	0.14
448	06208500	Clarks Fork Yellowstone River at Edgar, Montana	June 15 (166)	June 9 (160)	June 13 (164)	0.07	0.15
458	06214500	Yellowstone River at Billings, Montana	June 15 (166)	June 10 (161)	June 12 (163)	0.08	0.22
542	06324500	Powder River at Moorhead, Montana	June 7 (158)	May 31 (151)	June 5 (156)	0.74	0.75
Streamflow-gaging stations in the Columbia River Basin							
665	12340500	Clark Fork above Missoula, Montana	May 24 (144)	May 25 (145)	May 24 (144)	0.73	0.87
688	12353000	Clark Fork below Missoula, Montana	May 27 (147)	May 30 (150)	May 28 (148)	0.66	0.78
697	12354500	Clark Fork at St. Regis, Montana	May 28 (148)	May 28 (148)	May 28 (148)	0.48	0.38
698	12355000	Flathead River at Flathead, British Columbia	May 24 (144)	May 25 (145)	May 24 (144)	0.51	0.66
700	12355500	North Fork Flathead River near Columbia Falls, Montana	May 27 (147)	May 26 (146)	May 27 (147)	1.00	0.70
728	12370000	Swan River near Bigfork, Montana	May 31 (151)	June 2 (153)	June 1 (152)	0.54	0.62

[1]The Wilcoxon rank sum test was used to test for significant differences between the median for the period 1979 through 2011 and the medians for 1930 through 1978 and the entire period of record.

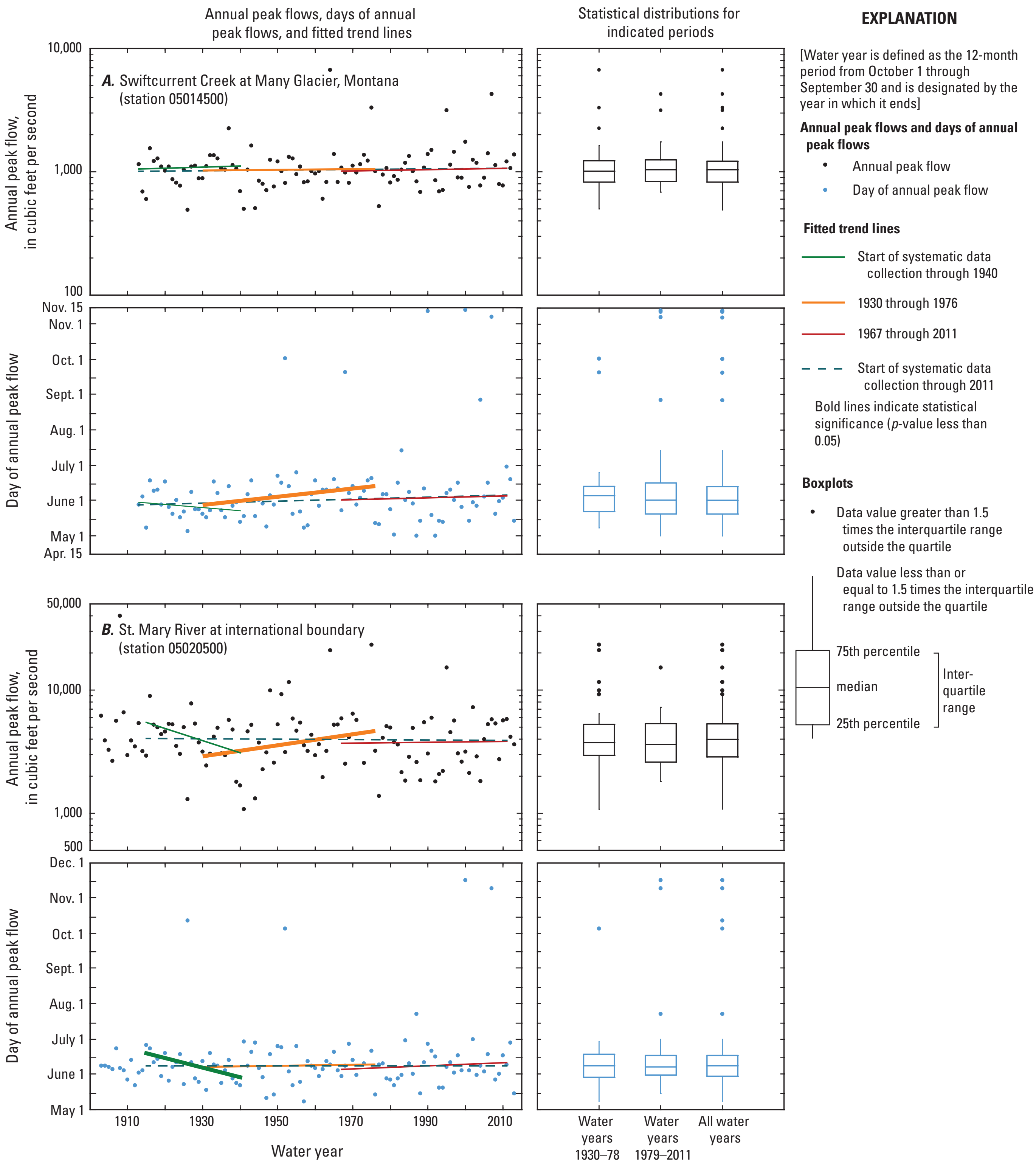

Figure 2. Fitted trends for annual peak flow (the annual series of maximum instantaneous discharge, in cubic feet per second) and peak-flow timing (the annual series of the day of the annual peak flow), and statistical distributions for summary time periods for streamflow-gaging stations in the Saskatchewan River Basin: *A*, Swiftcurrent Creek at Many Glacier, Montana (gaging station 05014500); and *B*, St. Mary River at international boundary (gaging station 05020500).

Peak flows for St. Mary River at international boundary are potentially affected by the St. Mary diversion canal, which transfers water from the St. Mary River into the North Fork of the Milk River. The canal was constructed in 1915 and has a diversion capacity of 850 cubic feet per second (ft^3/s; Bureau of Reclamation, 2013). Because of the potential effect of the St. Mary diversion on the trend results, the trend analyses for this station were restricted to the post-diversion period (1915–2011); it was presumed that the operation of the diversion was reasonably similar during the post-diversion period.

Temporal trends in peak-flow characteristics are variable among the two gaging stations in the Saskatchewan River Basin but generally are small to moderate. However, the study results indicate a substantial upward trend in peak-flow timing during 1930–76 for Swiftcurrent Creek at Many Glacier, Montana (fig. 2*A*; table 3), which indicates that the timing of annual peak flows changed from earlier in the year to later in the year. Also, the study results indicate a substantial upward trend in annual peak flow during 1930–76 for St. Mary River at international boundary (fig. 2*B*; table 2).

Differences between the medians for 1979–2011 and the medians for the other summary time periods were not significantly different for annual peak flow and day of peak (table 4). For annual peak flow and day of peak, statistical distributions among the summary time periods generally are similar (fig. 2). Study results provide evidence that annual peak flow for the long-term gaging stations in the Saskatchewan River Basin can be reasonably considered as stationary for application of peak-flow frequency analyses within a statewide gaging-station network.

Streamflow-Gaging Stations in the Missouri River Basin

Gaging stations in the Missouri River are subgrouped according to the following descriptive classes: (1) Missouri River headwaters tributaries (three gaging stations); (2) upper Missouri River tributaries (two gaging stations); (3) Musselshell River Basin (one gaging station); (4) upper Milk River Basin (one gaging station); (4) lower Missouri River tributary (one gaging station); and (5) Yellowstone River Basin (eight gaging stations). Study results are discussed according to the descriptive classes.

Missouri River Headwaters Tributaries

The three gaging stations on Missouri River headwaters tributaries (Big Hole River near Melrose, Montana [gaging station 06025500; map number 45; fig. 1, table 1], Gallatin River near Gallatin Gateway, Montana [gaging station 06043500; map number 80; fig. 1, table 1], and Gallatin River at Logan, Montana [gaging station 06052500; map number 88; fig. 1, table 1]) have mean basin elevations that range from 6,635 to 7,894 ft. For all of the gaging stations, nearly all day-of-peak values are during May and June, likely caused by snowmelt runoff (possibly with associated spring rainfall). Day-of-peak values generally are uniformly distributed (centered at times that are variable among gaging stations and time periods) within May and June (fig. 3).

Fitted trends for annual peak flow and peak-flow timing, and statistical distributions for summary time periods for the three gaging stations on Missouri River headwaters tributaries are presented in figure 3. The study results for all gaging stations indicate substantial upward trends in annual peak flow during 1930–76 and moderate downward trends in annual peak flow during 1967–2011 (fig. 3; table 2). Big Hole River near Melrose, Montana, has a small downward trend in annual peak flow during the entire period of record, and the Gallatin River gaging stations have moderate upward trends in annual peak flow during the entire period of record. The study results also indicate moderate upward trends in peak-flow timing for all gaging stations during 1930–76, but variable changes (in trend direction and magnitude) among gaging stations during 1967–2011 (fig. 3; table 3). The gaging stations have small changes in peak-flow timing during the entire period of record that are variable in direction.

Significant differences between the day-of-peak medians for 1979–2011 and the medians for 1930–78 were determined for Gallatin River near Gallatin Gateway, Montana, and Gallatin River at Logan, Montana (table 4). The day-of-peak medians for 1979–2011 (Julian day 155 and 156 for Gallatin River near Gallatin Gateway, Montana, and Gallatin River at Logan, Montana, respectively) are significantly less than medians for 1930–78 (Julian day 161 and 162, respectively; table 4).

For annual peak flow, statistical distributions among the summary time periods generally are similar (fig. 3). However, for the Bighole River near Melrose, Montana, (fig. 3*A*), the interquartile range of peak flows for 1979–2011 is considerably larger than the interquartile range for 1930–1978 and for the entire period of record. For day of peak, the statistical distributions for the Gallatin River gaging stations for 1979–2011 are shifted downward in relation to distributions for 1930–78.

For annual peak flow for the Missouri River headwater tributaries, upward trends during 1930–76 generally were stronger than downward trends during 1967–2011, and statistical distributions generally were similar among summary time periods. Study results provide evidence that annual peak flow for the long-term gaging stations can be reasonably considered as stationary for application of peak-flow frequency analyses within a statewide gaging-station network. However, for peak-flow timing for the two Gallatin River gaging stations, moderate upward trends during 1930–76 were generally similar in magnitude to moderate downward trends during 1967–2011; also, day-of-peak medians for 1979–2011 were significantly less than medians for 1930–78 (table 4). For the Gallatin River gaging stations, the moderate downward trends in peak-flow timing for 1967–2011 indicate that the timing of annual peak flows changed (by 8 to 12 days) from later in the year to earlier in the year.

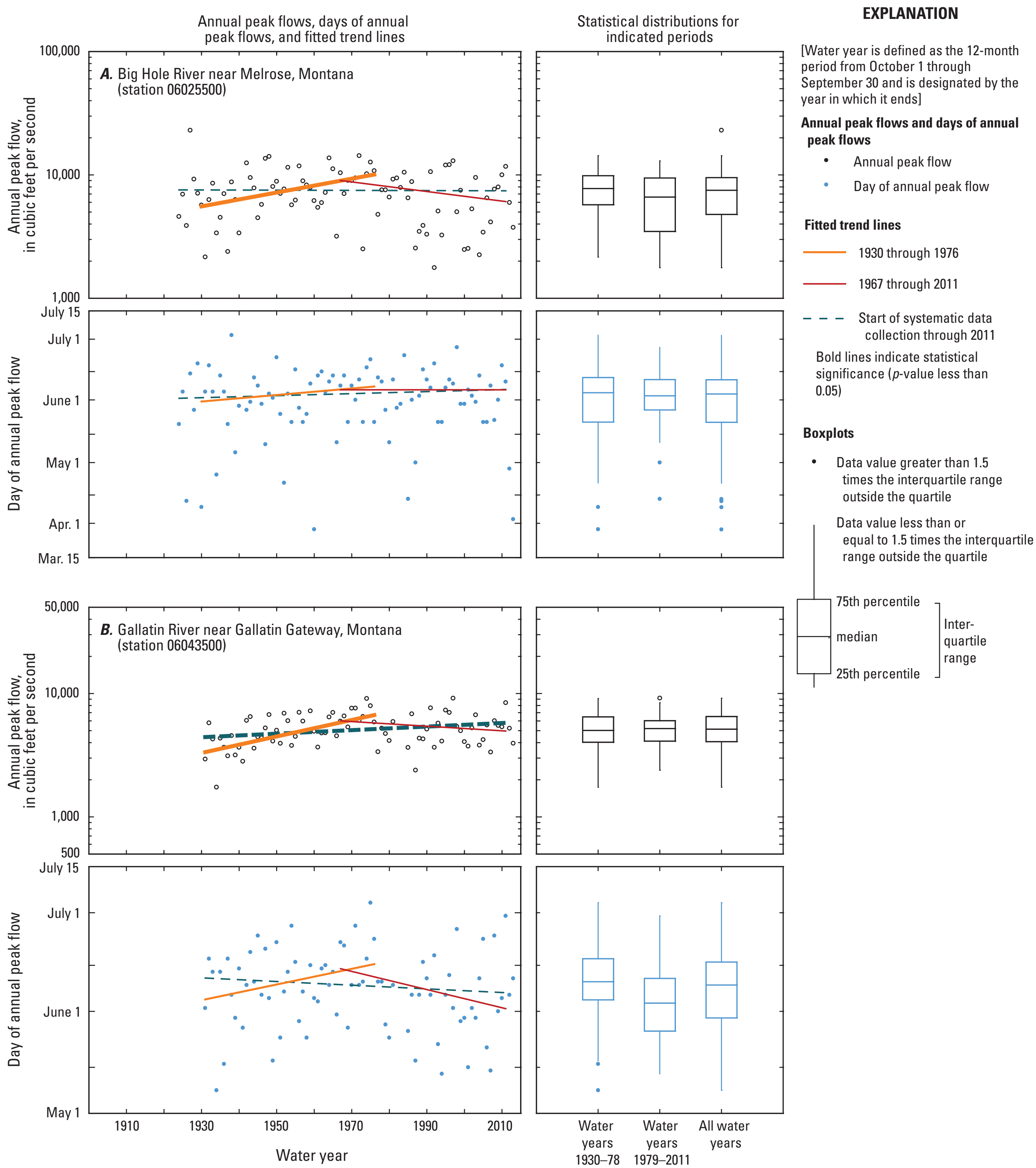

Figure 3. Fitted trends for annual peak flow (the annual series of maximum instantaneous discharge, in cubic feet per second) and peak-flow timing (the annual series of the day of the annual peak flow), and statistical distributions for summary time periods for streamflow-gaging stations on Missouri River headwaters tributaries: *A*, Big Hole River near Melrose, Montana (gaging station 06025500); *B*, Gallatin River near Gallatin Gateway, Montana (gaging station 06043500); and *C*, Gallatin River at Logan, Montana (gaging station 06052500).

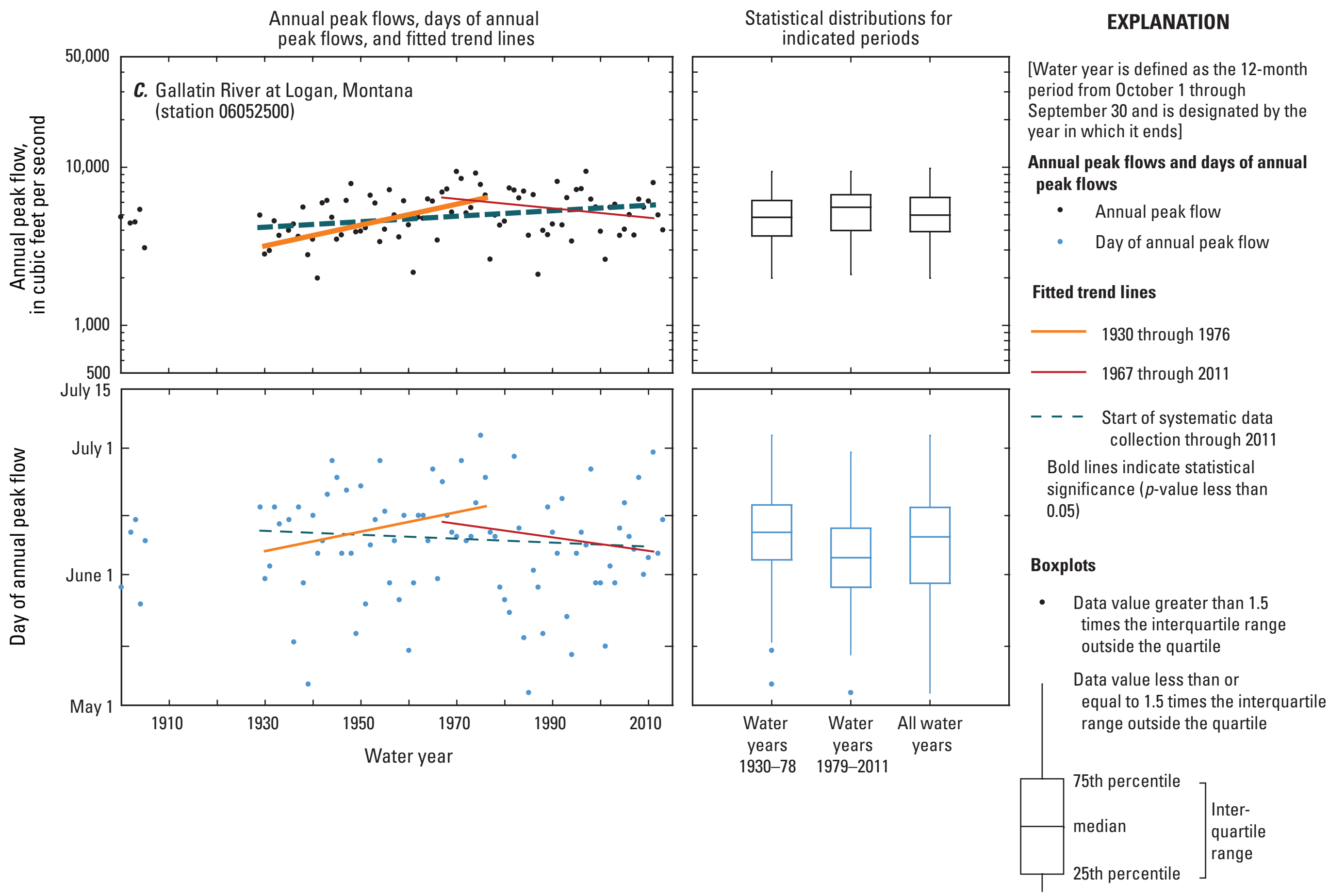

Figure 3. Graphs showing fFitted trends for annual peak flow (the annual series of maximum instantaneous discharge, in cubic feet per second) and peak-flow timing (the annual series of the day of the annual peak flow), and statistical distributions for summary time periods for streamflow-gaging stations on Missouri River headwaters tributaries: *A*, Big Hole River near Melrose, Montana (gaging station 06025500); *B*, Gallatin River near Gallatin Gateway, Montana (gaging station 06043500); and *C*, Gallatin River at Logan, Montana (gaging station 06052500).—Continued

Upper Missouri River Tributaries

The two gaging stations on upper Missouri River tributaries (Tenmile Creek near Rimini, Montana [gaging station 06062500; map number 101; fig. 1, table 1], and Marias River near Shelby, Montana [gaging station 06099500; map number 161; fig. 1, table 1]) have relatively large variability in mean basin elevations. For Tenmile Creek near Rimini, Montana (mean basin elevation 6,541 ft), nearly all peak flows are during May and June, likely caused by snowmelt runoff (possibly with associated spring rainfall). Day-of-peak values generally are uniformly distributed during May and June (fig. 4). For Marias River near Shelby, Montana (mean basin elevation 4,509 ft; range in elevation from 3,096–9,472 ft), most peak flows are during May and June, likely caused by high-elevation snowmelt runoff and spring rainfall. The few peak flows that are during March and April likely are caused by low-elevation snowmelt runoff. The few peak flows that are in November likely are caused by rainfall. Day-of-peak values that are outside of May and June account for less than 10 percent of peak flows; thus, most day-of-peak values are uniformly distributed during May and June (fig. 4).

Fitted trends for annual peak flow and peak-flow timing, and statistical distributions for summary time periods for the two gaging stations on upper Missouri River tributaries are presented in figure 4. The study results indicate moderate to substantial upward trends in annual peak flow for the gaging stations during 1930–76 and moderate downward trends in annual peak flow during 1967–2011 (fig. 4; table 2). The gaging stations have small downward trends in annual peak flow during the entire period of record. The study results also indicate small to moderate upward trends in peak-flow timing for the gaging stations during 1930–76 and small upward trends in peak-flow timing during 1967–2011 (fig. 4; table 3). The gaging stations have small upward trends in peak-flow timing during the entire period of record.

Differences between the medians for 1979–2011 and the medians for the other summary time periods were not significant for annual peak flow and day of peak (table 4). For both

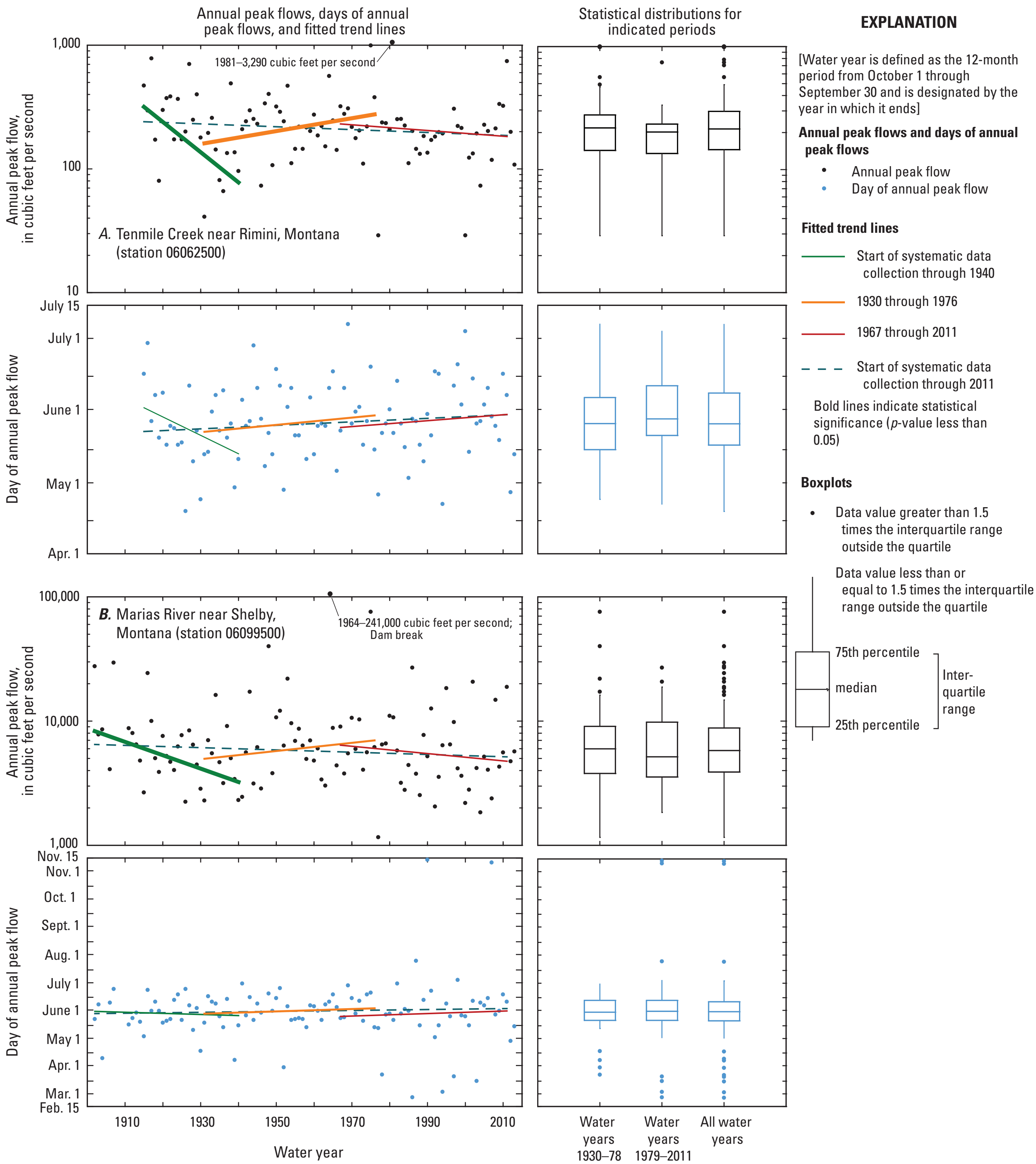

Figure 4. Fitted trends for annual peak flow (the annual series of maximum instantaneous discharge, in cubic feet per second) and peak-flow timing (the annual series of the day of the annual peak flow), and statistical distributions for summary time periods for streamflow-gaging stations on upper Missouri River tributaries: *A*, Tenmile Creek near Rimini, Montana (gaging station 06062500); and *B*, Marias River near Shelby, Montana (gaging station 06099500).

annual peak flow and day of peak, statistical distributions among the summary time periods generally are similar (fig. 4).

For annual peak flow for the upper Missouri River tributaries, upward trends during 1930–76 generally were stronger than downward trends during 1967–2011, and statistical distributions generally were similar among summary time periods. Study results provide evidence that annual peak flow for the long-term gaging stations can be reasonably considered as stationary for application of peak-flow frequency analyses within a statewide gaging-station network.

Musselshell River Basin

The gaging station in the Musselshell River Basin (Musselshell River at Harlowton, Montana [gaging station 06120500; map number 212; fig. 1, table 1]) has a mean basin elevation of 5,713 ft. About 85 percent of peak flows are during May and June, likely caused by snowmelt runoff (possibly with associated spring rainfall). The few peak flows that are during March and April likely are caused by low-elevation snowmelt runoff (possibly with associated rainfall). The few peak flows that are in July are caused by rainfall. Peak flows that are outside of May and June account for less than 15 percent of peak flows; thus, most day-of-peak values generally are uniformly distributed during May and June (fig. 5).

Fitted trends for annual peak flow and peak-flow timing, and statistical distributions for summary time periods for Musselshell River at Harlowton, Montana, are presented in figure 5. The study results indicate a substantial upward trend in annual peak flow during 1930–76 and a moderate downward trend during 1967–2011 (fig. 5; table 2). There is a moderate downward trend in annual peak flow during the entire period of record. Study results also indicate a small upward trend in peak-flow timing during 1930–76, and a small upward trend in peak-flow timing during 1967–2011 (fig. 5; table 3). There is a small upward trend in peak-flow timing during the entire period of record.

Differences between the median for 1979–2011 and the medians for the other summary time periods were not significant for annual peak flow and day of peak (table 4). For both annual peak flow and day of peak, statistical distributions among the summary time periods generally are similar (fig. 5).

For annual peak flow for Musselshell River at Harlowton, Montana, the upward trend during 1930–1976 was stronger than the downward trend during 1967–2011, and statistical distributions generally were similar among summary time periods. Study results provide evidence that annual peak flow for the long-term gaging station can be reasonably considered as stationary for application of peak-flow frequency analyses within a statewide gaging-station network.

Upper Milk River Basin

The gaging station in the upper Milk River Basin (Milk River at western crossing of international boundary [gaging station 06133000; map number 271; fig. 1, table 1]) has a mean basin elevation of 4,734 ft. Although the maximum basin elevation exceeds 8,500 ft, greater than 97 percent of the basin is less than 6,000 ft in elevation. A considerable proportion (about 35 percent) of peak flows that are during March through mid-April likely are caused by low-elevation snowmelt runoff (sometimes with associated early spring rainfall). A considerable proportion of peak flows (about 40 percent) during mid-May through mid-July likely also are caused by spring and summer rainfall (possibly with associated high-elevation snowmelt runoff). Day-of-peak values are considered bimodally distributed.

Fitted trends for annual peak flow and peak-flow timing, and statistical distributions for summary time periods for Milk River at western crossing of international boundary are presented in figure 6. The study results indicate a substantial upward trend in annual peak flow during 1930–76 and a small upward trend during 1967–2011 (fig. 6; table 2). There is a moderate upward trend in annual peak flow during the entire period of record. The study results also indicate a downward trend in peak-flow timing during 1930–76, and an upward trend in peak-flow timing during 1967–2011 (fig. 6; table 3). There is a downward trend in peak-flow timing during the entire period of record. Day-of-peak values for Milk River at western crossing of international boundary are considered to be bimodally distributed. Thus, caution should be used in interpreting the temporal trends in peak-flow timing because of the simplified handling of the multiple populations.

Differences between the median for 1979–2011 and the medians for the other summary time periods were not significant for annual peak flow and day of peak (table 4). For both annual peak flow and day of peak, statistical distributions among the summary time periods generally are similar (fig. 6).

For annual peak flow for Milk River at western crossing of international boundary, the upward trend during 1930–1976 was stronger than the upward trend during 1967–2011, and statistical distributions generally were similar among summary time periods. Study results provide evidence that annual peak flow for the long-term gaging station can be reasonably considered as stationary for application of peak-flow frequency analyses within a statewide gaging-station network.

Lower Missouri River Tributary

The gaging station on a lower Missouri River tributary (Poplar River at international boundary [gaging station 06178000; map number 386; fig. 1, table 1]) has a mean basin elevation of 2,885 ft. Most peak flows are during March and April and likely are caused by snowmelt runoff (possibly with associated spring rainfall). However, a considerable proportion of peak flows (greater than 20 percent) are during mid-May through August, likely caused by spring and summer rainfall. Day-of-peak values are considered bimodally distributed.

Fitted trends for annual peak flow and peak-flow timing, and statistical distributions for summary time periods for Poplar River at international boundary are presented in figure 7.

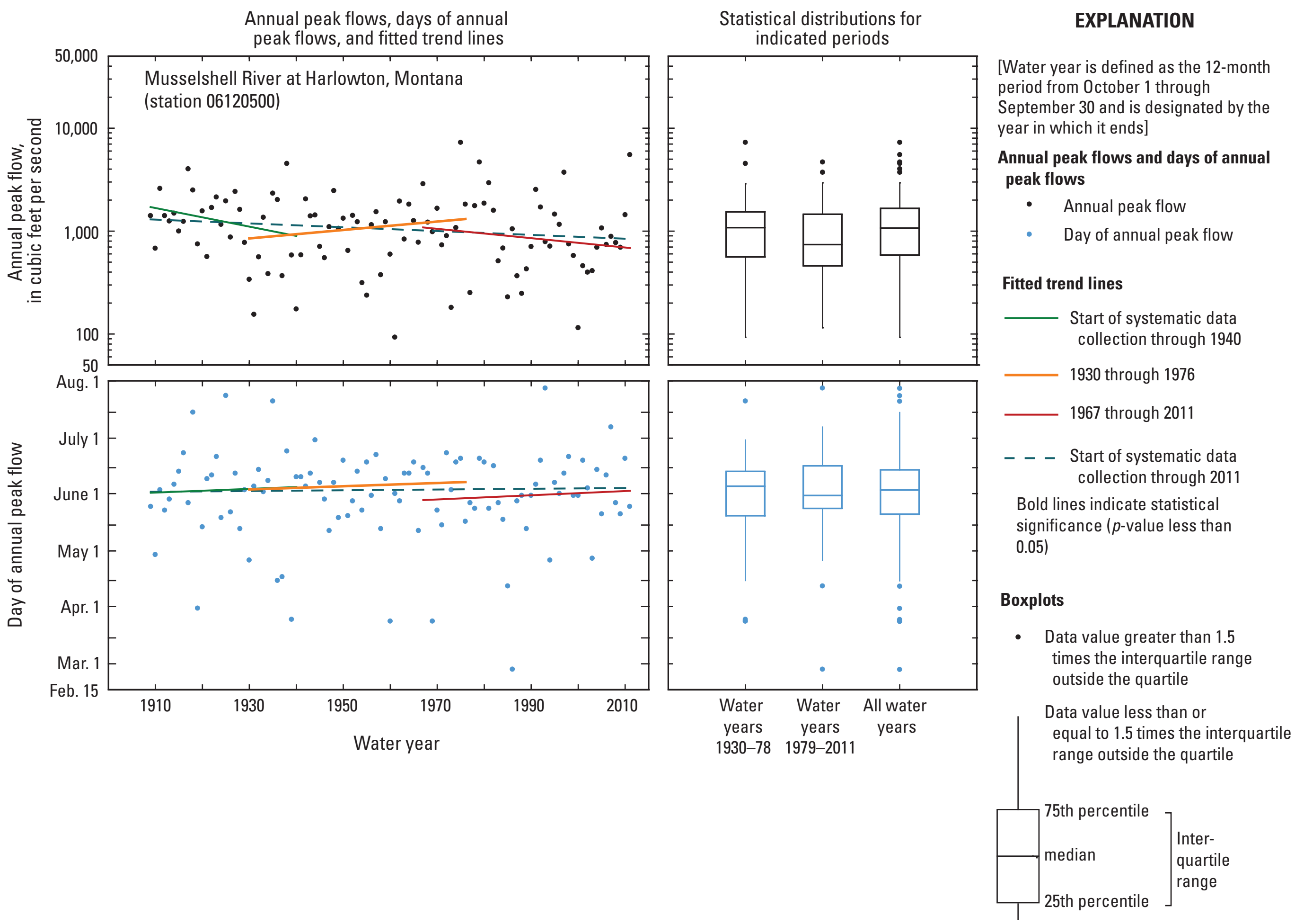

Figure 5. Fitted trends for annual peak flow (the annual series of maximum instantaneous discharge, in cubic feet per second) and peak-flow timing (the annual series of the day of the annual peak flow), and statistical distributions for summary time periods for the streamflow-gaging station in the Musselshell River Basin.

The study results indicate a substantial upward trend in annual peak flow during 1930–76 and a substantial downward trend during 1967–2011 (fig. 7; table 2). Poplar River at international boundary has a moderate downward trend in annual peak flow during the entire period of record. The study results also indicate a downward trend in peak-flow timing during 1930–76, and an upward trend in peak-flow timing during 1967–2011 (fig. 7; table 3). There is an upward trend in peak-flow timing during the entire period of record. Day-of-peak values for Poplar River at international boundary are considered to be bimodally distributed. Thus, caution should be used in interpreting the temporal trends in peak-flow timing because of the simplified handling of the multiple populations.

Differences between the medians for 1979–2011 and the medians for the other summary time periods were not significant for annual peak flow and day of peak (table 4); however, there is a downward shift in the statistical distribution of peak flows for 1979–2011 in relation to the distributions for 1930–78 and for the entire period of record. The annual-peak-flow median for 1979–2011 (350 ft^3/s) is about 40 percent lower than the median for the period of record (592 ft^3/s). Also, the interquartile range of day-of-peak values for 1979–2011 is considerably larger than for 1930–78. During 1979–2011, spring and summer peak flows were more frequent than during 1930–78.

For annual peak flow for the Poplar River at international boundary, the substantial upward trend during 1930–76 was of similar magnitude to the substantial downward trend during 1967–2011, and the annual-peak-flow median for 1979–2011 was substantially lower than the median for the entire period of record. Thus, study results indicate some potential changes in peak-flow characteristics after the mid 1970s, which is further discussed in the section "Discussion of Stationarity Issues for Low-Elevation Gaging Stations in Eastern Montana."

Yellowstone River Basin

The eight gaging stations in the Yellowstone River Basin have relatively large variability in mean basin elevations (ranging from 5,250 to 8,699 ft). Seven of the gaging stations

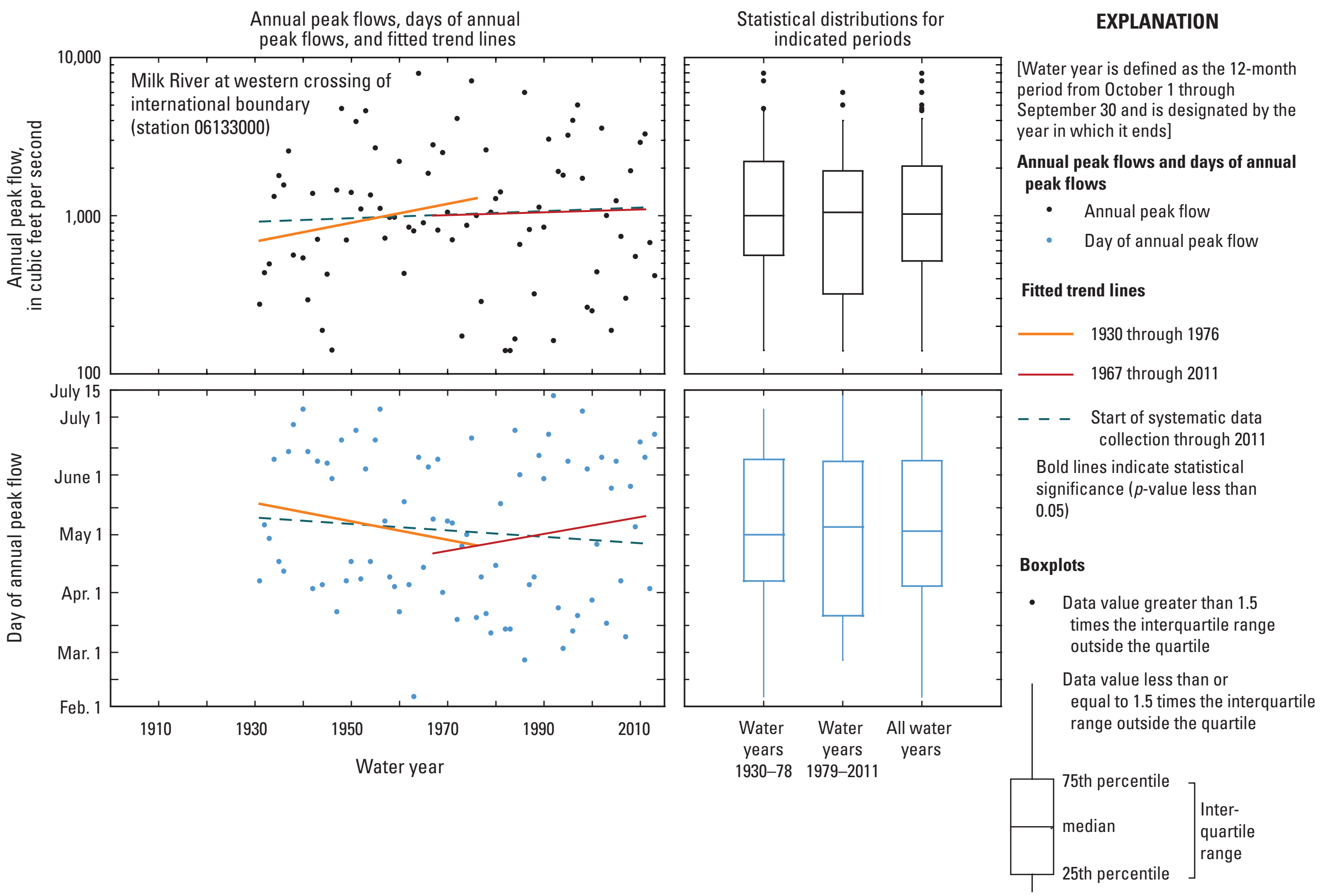

Figure 6. Fitted trends for annual peak flow (the annual series of maximum instantaneous discharge, in cubic feet per second) and peak-flow timing (the annual series of the day of the annual peak flow), and statistical distributions for summary time periods for the streamflow-gaging station in the upper Milk River Basin.

in the Yellowstone River Basin have mean basin elevations greater than 6,000 ft (fig. 1, table 1):

- Yellowstone River at Yellowstone Lake outlet, Yellowstone National Park, Wyoming (gaging station 06186500; map number 414);
- Yellowstone River at Corwin Springs, Montana (gaging station 06191500; map number 424);
- Yellowstone River near Livingston, Montana (gaging station 06192500; map number 425);
- Stillwater River near Absarokee, Montana (gaging station 06205000; map number 443);
- Clarks Fork Yellowstone River near Belfry, Montana (gaging station 06207500; map number 445);
- Clarks Fork Yellowstone River at Edgar, Montana (gaging station 06208500; map number 448); and
- Yellowstone River at Billings, Montana (gaging station 06214500; map number 458).

For all of these high-elevation gaging stations except Yellowstone River at Yellowstone Lake outlet, Yellowstone National Park, Wyoming, nearly all peak flows are during May and June, likely caused by snowmelt runoff (possibly with associated spring rainfall). Day-of-peak values generally are uniformly distributed (centered at times that are variable among gaging stations) within May and June (fig. 8). The high mean basin elevation (8,699 ft) for Yellowstone River at Yellowstone Lake outlet, Yellowstone National Park, Wyoming, results in day-of-peak values being generally uniformly distributed during mid-June through mid-July.

One of the gaging stations in the Yellowstone River Basin (Powder River at Moorhead, Montana [gaging station 06324500; map number 542; fig. 1, table 1]) has a mean basin elevation of 5,250 ft and less than 20 percent of the basin area is higher than 6,000 ft. Day-of-peak values for Powder River at Moorhead, Montana, are more variable than for the high-elevation gaging stations. Most peak flows are during May and June, likely caused by spring rainfall and high-elevation snowmelt runoff. A considerable proportion of peak flows (about 15–20 percent) are during March and probably are caused by low-elevation snowmelt runoff (possibly with associated

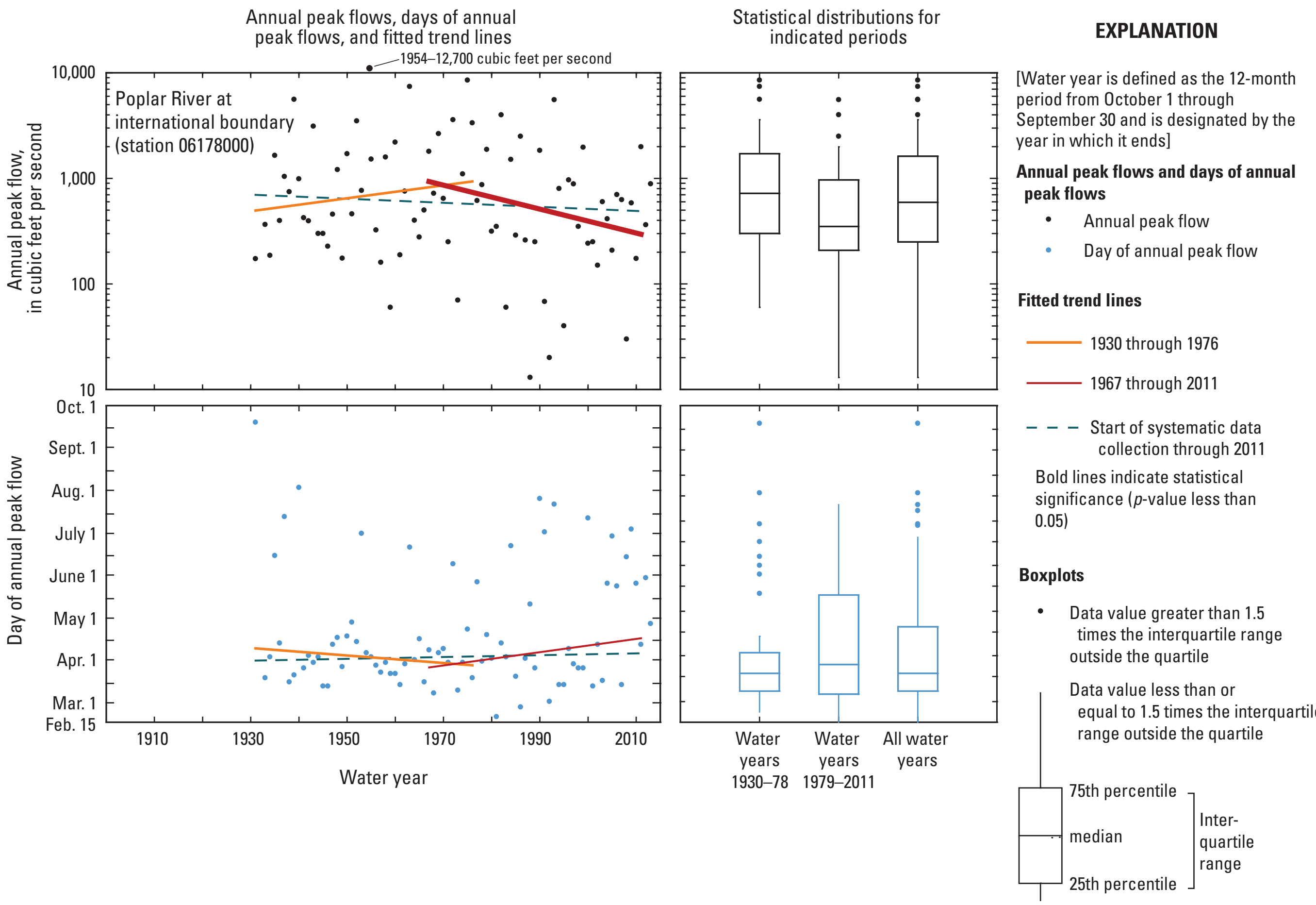

Figure 7. Fitted trends for annual peak flow (the annual series of maximum instantaneous discharge, in cubic feet per second) and peak-flow timing (the annual series of the day of the annual peak flow), and statistical distributions for summary time periods for the streamflow-gaging station on a lower Missouri River tributary.

spring rainfall). Furthermore, a considerable proportion of peak flows (greater than about 20 percent) are after July 1 and are caused by summer rainfall. Day-of-peak values for Powder River at Moorhead, Montana, are considered trimodally distributed.

Fitted trends for annual peak flow and peak-flow timing, and statistical distributions for summary time periods for the eight gaging stations in the Yellowstone River Basin are presented in figure 8. For the seven high-elevation gaging stations, the study results indicate moderate to substantial upward trends in annual peak flow during 1930–76 and generally small to moderate downward trends in annual peak flow during 1967–2011 (fig. 8; table 2). The high-elevation gaging stations generally have small to moderate upward trends in annual peak flow during the entire period of record. The study results also indicate variable (small to moderate) upward trends in peak-flow timing during 1930–76, and variable (small to substantial) downward trends in peak-flow timing during 1967–2011 (fig. 8; table 3). The substantial downward trends in peak-flow timing during 1967–2011 for Yellowstone River at Corwin Springs, Montana (-0.29 percent per year) and Yellowstone River near Livingston, Montana (-0.20 percent per year) are notable. All of the high-elevation gaging stations have small downward trends in peak-flow timing during the entire period of record. Overall, trend results for the high-elevation stations in the Yellowstone River Basin are somewhat similar to results for the Missouri River headwaters tributaries.

For annual peak flow for the seven high-elevation gaging stations in the Yellowstone River Basin, differences between the medians for 1979–2011 and the medians for the other summary time periods were not significant (table 4), and statistical distributions among the summary time periods generally are similar (fig. 8). However, for three of the high-elevation gaging stations, the day-of-peak medians for 1979–2011 were significantly less than the medians for 1930–78, and for all of the high-elevation gaging stations, statistical distributions of day-of-peak values for 1979–2011 are shifted downward in relation to distributions for 1930–78.

For the low-elevation gaging station in the Yellowstone River Basin (Powder River at Moorhead, Montana), study results indicate a moderate upward trend in annual peak flow during 1930–76 and a substantial downward trend in annual peak flow during 1967–2011 (fig. 8*H*; table 2). For Powder River at Moorhead, Montana, there is a moderate downward

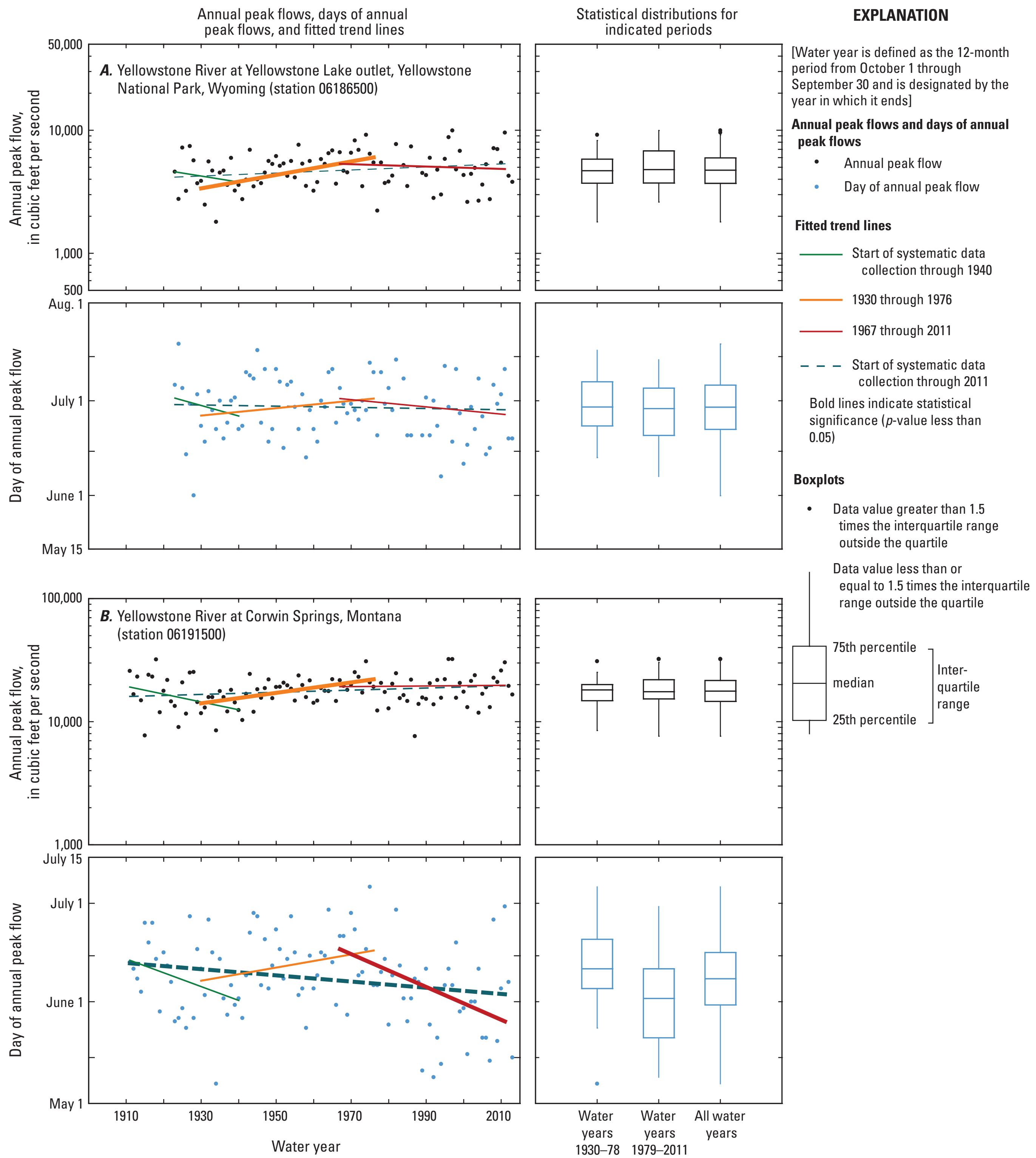

Figure 8. Fitted trends for annual peak flow (the annual series of maximum instantaneous discharge, in cubic feet per second) and peak-flow timing (the annual series of the day of the annual peak flow), and statistical distributions for summary time periods for streamflow-gaging stations in the Yellowstone River Basin: *A*, Yellowstone River at Yellowstone Lake outlet, Yellowstone National Park, Wyoming (gaging station 06186500); *B*, Yellowstone River at Corwin Springs, Montana (gaging station 06191500); *C*, Yellowstone River near Livingston, Montana (gaging station 06192500); *D*, Stillwater River near Absarokee, Montana (gaging station 06205000); *E*, Clarks Fork Yellowstone River near Belfry, Montana (gaging station 06207500); *F*, Clarks Fork Yellowstone River at Edgar, Montana (gaging station 06208500); *G*, Yellowstone River at Billings, Montana (gaging station 06214500); and *H*, Powder River at Moorhead, Montana (gaging station 06324500).

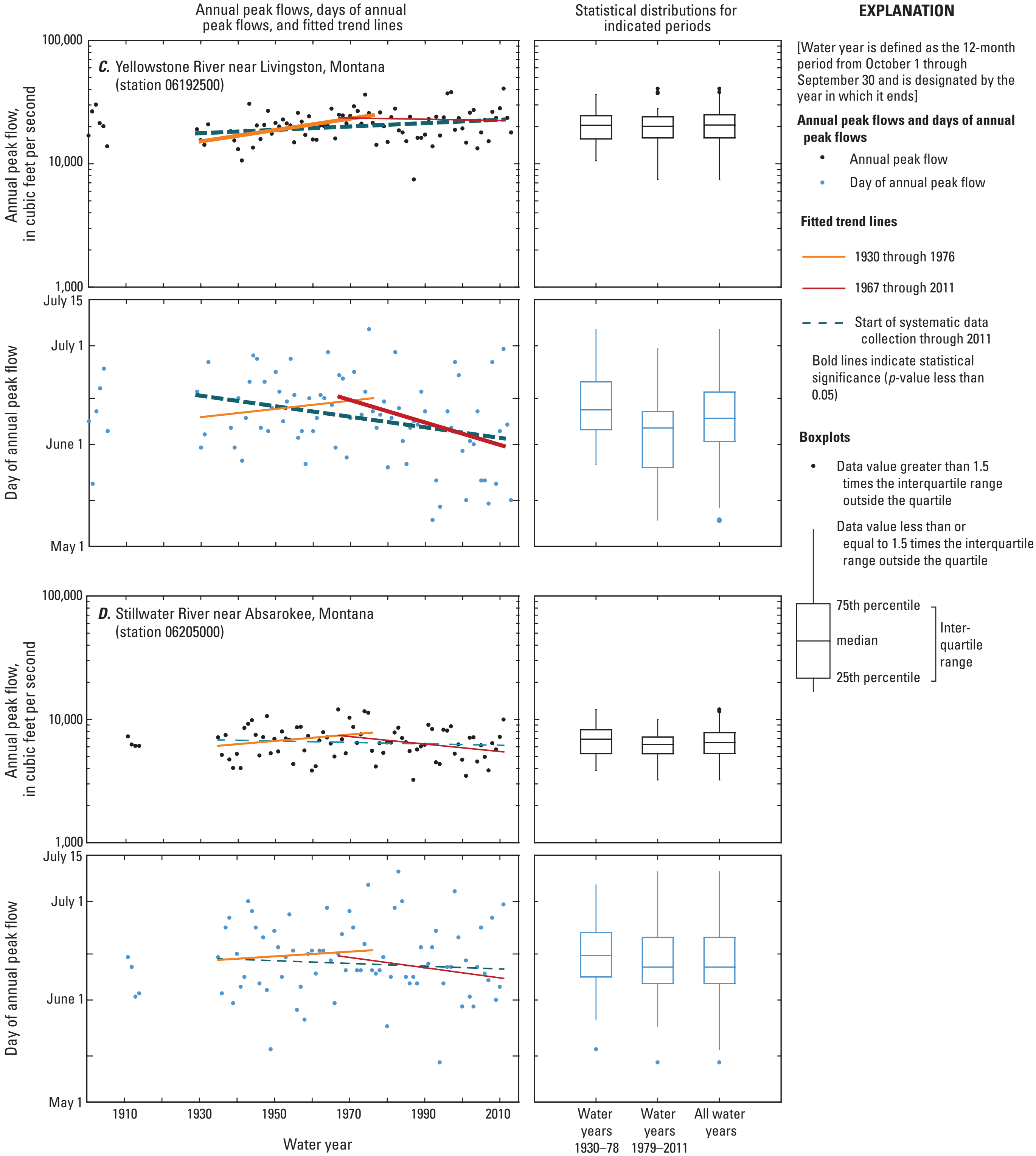

Figure 8. Graphs showing fFitted trends for annual peak flow (the annual series of maximum instantaneous discharge, in cubic feet per second) and peak-flow timing (the annual series of the day of the annual peak flow), and statistical distributions for summary time periods for streamflow-gaging stations in the Yellowstone River Basin: *A*, Yellowstone River at Yellowstone Lake outlet, Yellowstone National Park, Wyoming (gaging station 06186500); *B*, Yellowstone River at Corwin Springs, Montana (gaging station 06191500); *C*, Yellowstone River near Livingston, Montana (gaging station 06192500); *D*, Stillwater River near Absarokee, Montana (gaging station 06205000); *E*, Clarks Fork Yellowstone River near Belfry, Montana (gaging station 06207500); *F*, Clarks Fork Yellowstone River at Edgar, Montana (gaging station 06208500); *G*, Yellowstone River at Billings, Montana (gaging station 06214500); and *H*, Powder River at Moorhead, Montana (gaging station 06324500).—Continued

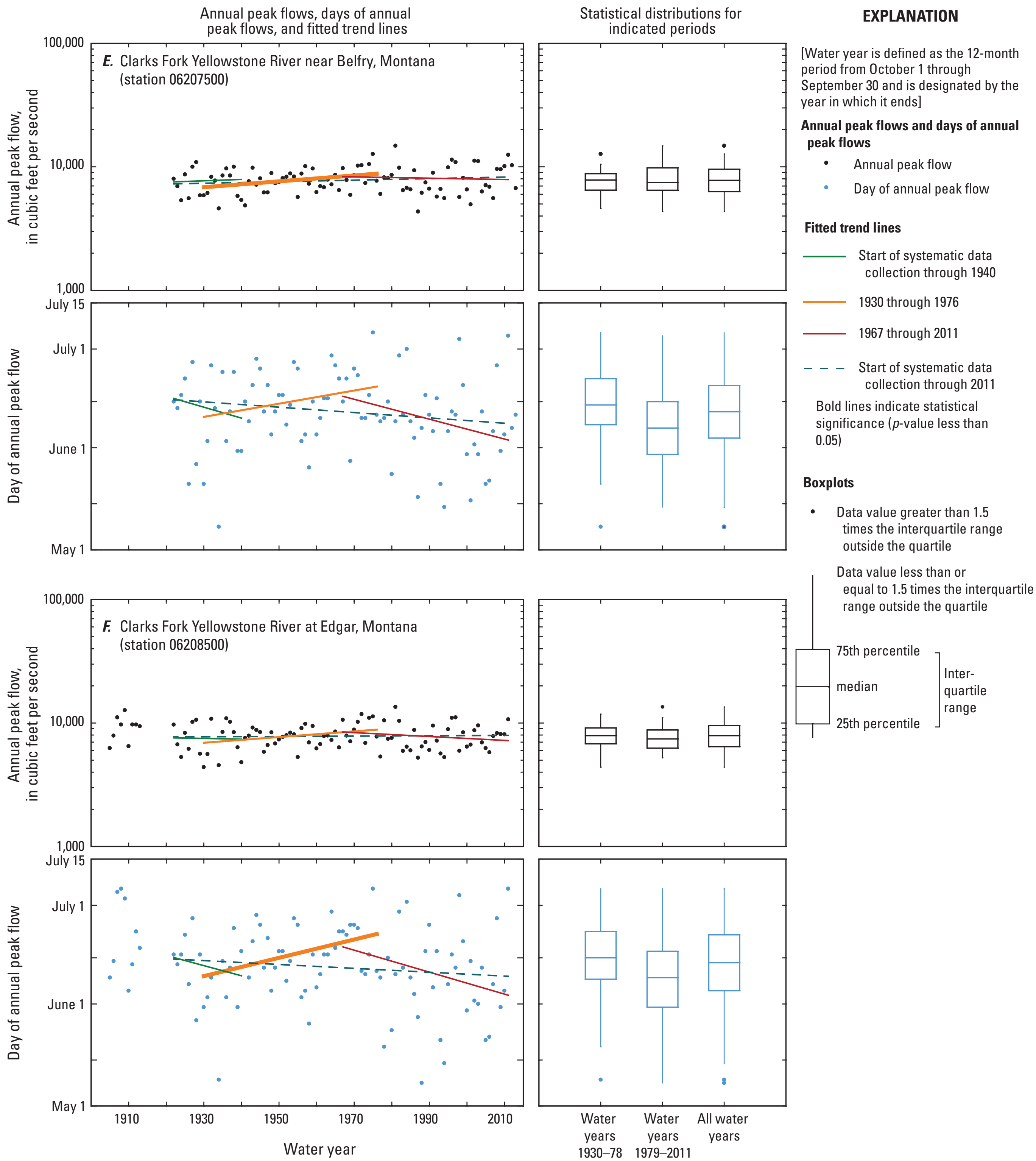

Figure 8. Graphs showing fFitted trends for annual peak flow (the annual series of maximum instantaneous discharge, in cubic feet per second) and peak-flow timing (the annual series of the day of the annual peak flow), and statistical distributions for summary time periods for streamflow-gaging stations in the Yellowstone River Basin: *A*, Yellowstone River at Yellowstone Lake outlet, Yellowstone National Park, Wyoming (gaging station 06186500); *B*, Yellowstone River at Corwin Springs, Montana (gaging station 06191500); *C*, Yellowstone River near Livingston, Montana (gaging station 06192500); *D*, Stillwater River near Absarokee, Montana (gaging station 06205000); *E*, Clarks Fork Yellowstone River near Belfry, Montana (gaging station 06207500); *F*, Clarks Fork Yellowstone River at Edgar, Montana (gaging station 06208500); *G*, Yellowstone River at Billings, Montana (gaging station 06214500); and *H*, Powder River at Moorhead, Montana (gaging station 06324500).—Continued

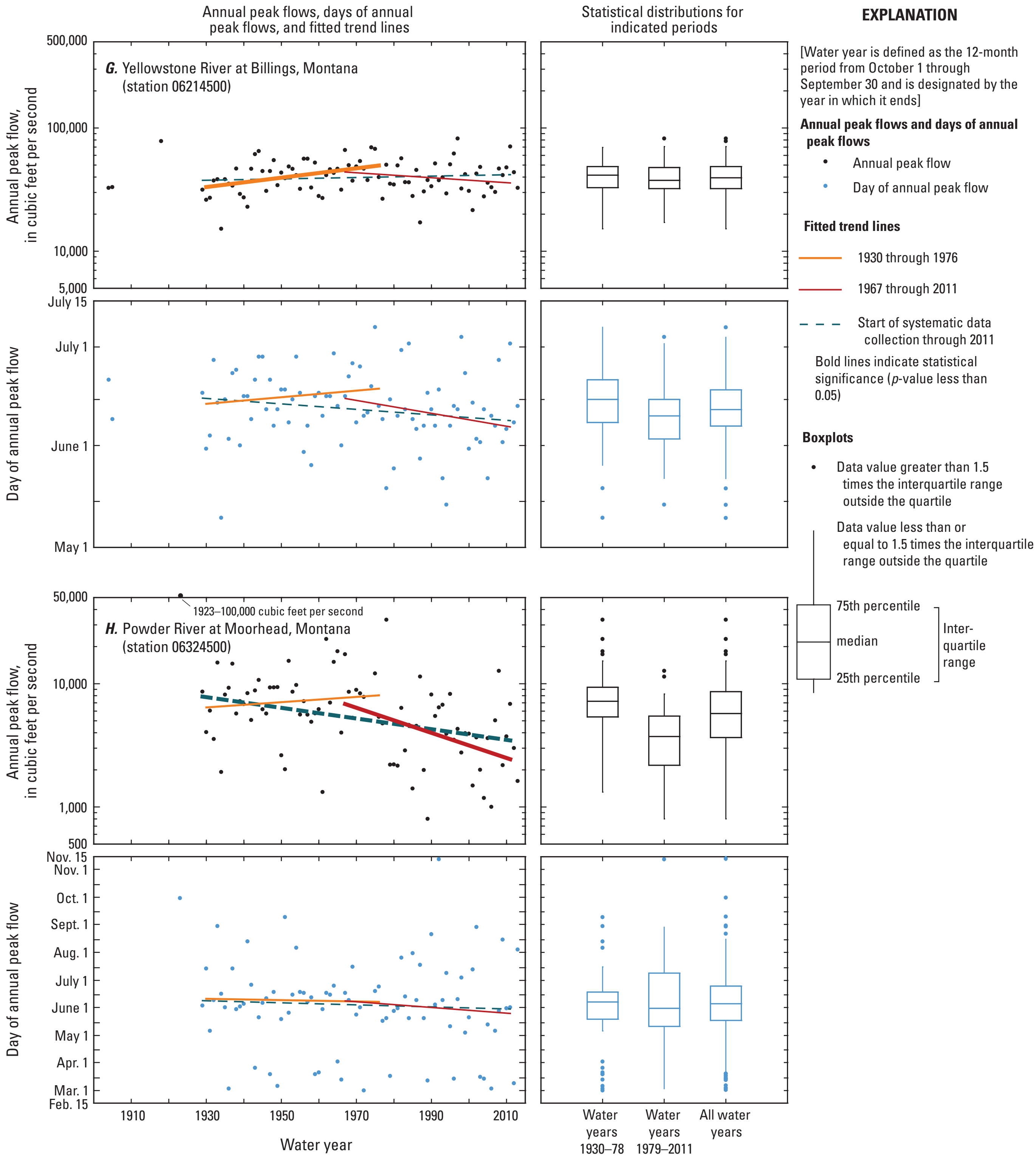

Figure 8. Graphs showing fFitted trends for annual peak flow (the annual series of maximum instantaneous discharge, in cubic feet per second) and peak-flow timing (the annual series of the day of the annual peak flow), and statistical distributions for summary time periods for streamflow-gaging stations in the Yellowstone River Basin: *A*, Yellowstone River at Yellowstone Lake outlet, Yellowstone National Park, Wyoming (gaging station 06186500); *B*, Yellowstone River at Corwin Springs, Montana (gaging station 06191500); *C*, Yellowstone River near Livingston, Montana (gaging station 06192500); *D*, Stillwater River near Absarokee, Montana (gaging station 06205000); *E*, Clarks Fork Yellowstone River near Belfry, Montana (gaging station 06207500); *F*, Clarks Fork Yellowstone River at Edgar, Montana (gaging station 06208500); *G*, Yellowstone River at Billings, Montana (gaging station 06214500); and *H*, Powder River at Moorhead, Montana (gaging station 06324500).—Continued

trend in annual peak flow during the entire period of record. The study results also indicate a downward trend in peak-flow timing during 1930–76, during 1967–2011, and also during the entire period of record (fig. 8*H*; table 3). Day-of-peak values for Powder River at Moorhead, Montana, are considered to be trimodally distributed. Thus, caution should be used in interpreting the temporal trends in peak-flow timing because of the simplified handling of the multiple populations.

For Powder River at Moorhead, Montana, the annual-peak-flow median for 1979–2011 was significantly less than the medians for 1930–78 and for the entire period of record; statistical distributions for 1979–2011 are shifted downward in relation to distributions for 1930–78 and for the entire period of record (fig. 8*H*; table 4). The annual-peak-flow median for 1979–2011 (3,730 ft^3/s) is about 35 percent lower than the median for the period of record (5,730 ft^3/s). For day of peak, differences between the median for 1979–2011 and the medians for the other summary time periods were not significant (table 4); however, the interquartile range of day-of-peak values for 1979–2011 is considerably larger than the interquartile range for 1930–78.

For annual peak flow for the high-elevation gaging stations in the Yellowstone River Basin, upward trends during 1930–76 generally were stronger than downward trends during 1967–2011, and statistical distributions generally were similar among summary time periods. Study results provide evidence that annual peak flow for the high-elevation long-term gaging stations can be reasonably considered as stationary for application of peak-flow frequency analyses within a statewide gaging-station network. For peak-flow timing, all of the seven high-elevation gaging stations have downward trends during 1967–2011, and three of those stations have day-of-peak medians for 1979–2011 that are significantly less than medians for 1930–78 (table 4).

For annual peak flow for the low-elevation gaging station (Powder River at Moorhead, Montana), the upward trend during 1930–76 was weaker than the substantial downward trend during 1967–2011, and the annual-peak-flow median for 1979–2011 was substantially lower than the median for the entire period of record. Thus, study results indicate some potential changes in peak-flow characteristics after the mid-1970s, which is further discussed in the section "Discussion of Stationarity Issues for Low-Elevation Gaging Stations in Eastern Montana."

Streamflow-Gaging Stations in the Columbia River Basin

The six gaging stations in the Columbia River Basin have mean basin elevations that range from 5,012 to 5,765 ft (fig. 1, table 1):

- Clark Fork above Missoula, Montana (gaging station 12340500; map number 665);
- Clark Fork below Missoula, Montana (gaging station 12353000; map number 688);
- Clark Fork at St. Regis, Montana (gaging station 12354500; map number 697);
- Flathead River at Flathead, British Columbia (gaging station 12355000; map number 698);
- North Fork Flathead River near Columbia Falls, Montana (gaging station 12355500; map number 700); and
- Swan River near Bigfork, Montana (gaging station 12370000; map number 728).

For all of the gaging stations, nearly all peak flows are during May and June, likely caused by snowmelt runoff (possibly with associated spring rainfall). Day-of-peak values generally are uniformly distributed during May and June (fig. 9).

Fitted trends for annual peak flow and peak-flow timing, and statistical distributions for summary time periods for the six gaging stations in the Columbia River Basin are presented in figure 9. The study results indicate substantial upward trends in annual peak flow for most gaging stations during 1930–76 and moderate downward trends in annual peak flow for all gaging stations during 1967–2011 (fig. 9; table 2). Most gaging stations have small to moderate downward trends in annual peak flow during the entire period of record. The study results also indicate variable (moderate to substantial) upward trends in peak-flow timing for all gaging stations during 1930–76, but small changes that are variable in trend direction among gaging stations during 1967–2011 (fig. 9; table 3). Most gaging stations have small changes in peak-flow timing during the entire period of record that are variable in trend direction.

Differences between the medians for 1979–2011 and the medians for the other summary time periods were not significant for annual peak flow and day of peak (table 4). For both annual peak flow and day of peak, statistical distributions among the summary time periods generally are similar (fig. 9).

For annual peak flow for the Columbia River Basin, upward trends during 1930–76 generally were stronger than downward trends during 1967–2011, and statistical distributions generally were similar among summary time periods. Study results provide evidence that annual peak flow for the long-term gaging stations can be reasonably considered as stationary for application of peak-flow frequency analyses within a statewide gaging-station network.

Summary Observations

For annual peak flow for most long-term gaging stations, upward trends during 1930–76 generally were stronger than downward trends during 1967–2011 and statistical distributions generally were similar among summary time periods. Study results provide evidence that annual peak flow for most of the long-term gaging stations can be reasonably considered

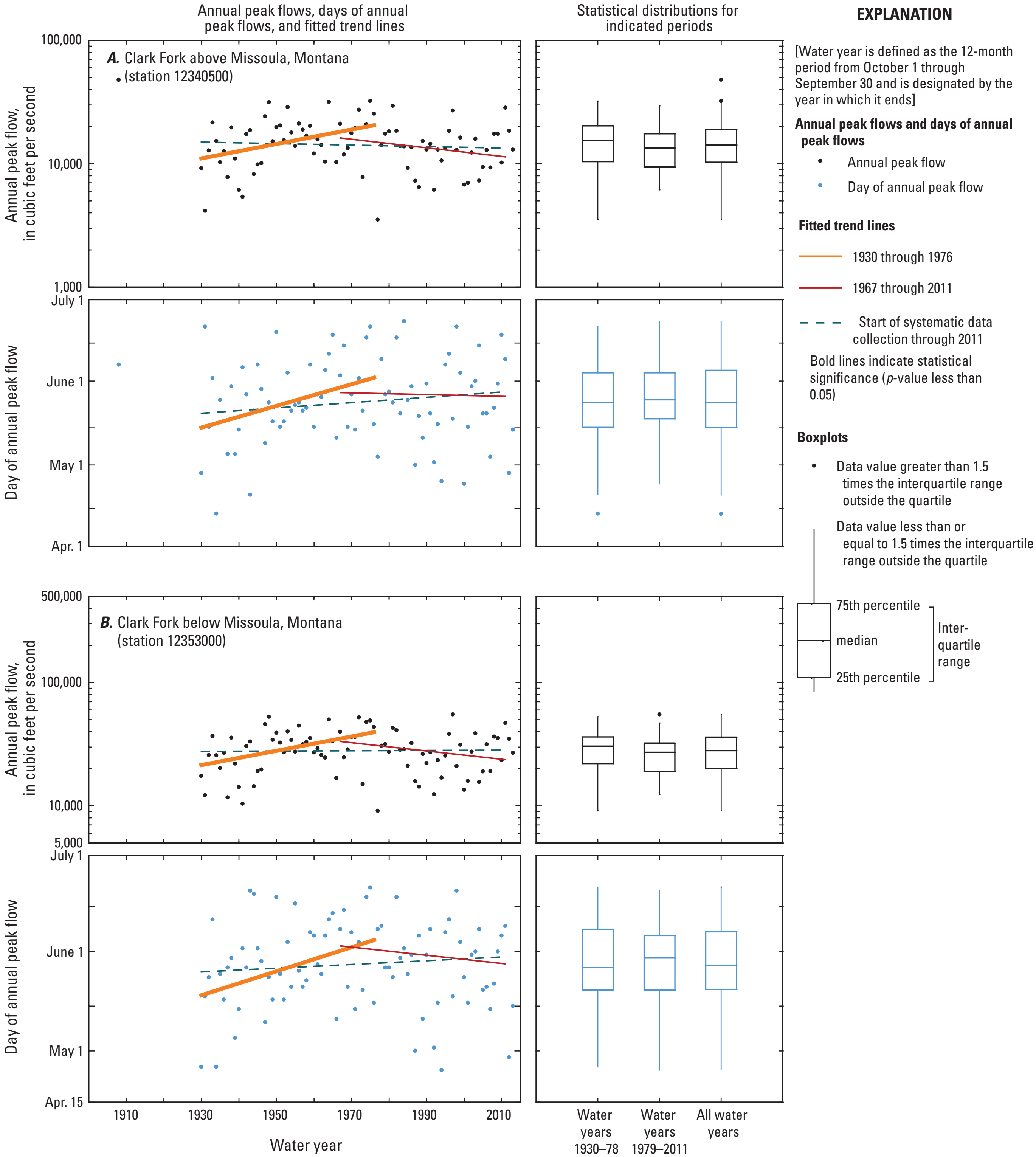

Figure 9. Fitted trends for annual peak flow (the annual series of maximum instantaneous discharge, in cubic feet per second) and peak-flow timing (the annual series of the day of the annual peak flow), and statistical distributions for summary time periods for streamflow-gaging stations in the Columbia River Basin: *A*, Clark Fork above Missoula, Montana (gaging station 12340500); *B*, Clark Fork below Missoula, Montana (gaging station 12353000); *C*, Clark Fork at St. Regis, Montana (gaging station 12354500); *D*, Flathead River at Flathead, British Columbia (gaging station 12355000); *E*, North Fork Flathead River near Columbia Falls, Montana (gaging station 12355500); and *F*, Swan River near Bigfork, Montana (gaging station 12370000).

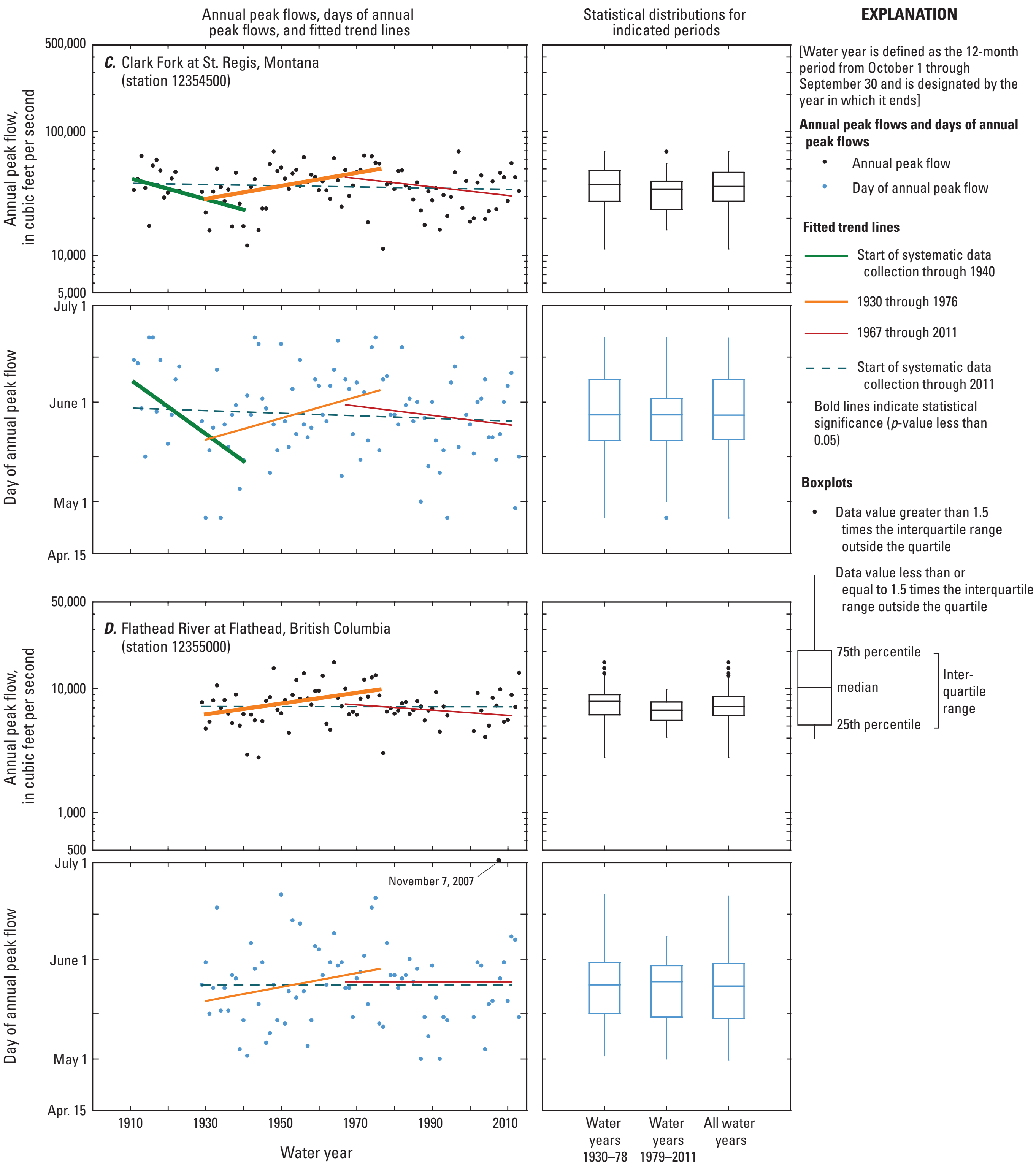

Figure 9. Fitted trends for annual peak flow (the annual series of maximum instantaneous discharge, in cubic feet per second) and peak-flow timing (the annual series of the day of the annual peak flow), and statistical distributions for summary time periods for streamflow-gaging stations in the Columbia River Basin: *A*, Clark Fork above Missoula, Montana (gaging station 12340500); *B*, Clark Fork below Missoula, Montana (gaging station 12353000); *C*, Clark Fork at St. Regis, Montana (gaging station 12354500); *D*, Flathead River at Flathead, British Columbia (gaging station 12355000); *E*, North Fork Flathead River near Columbia Falls, Montana (gaging station 12355500); and *F*, Swan River near Bigfork, Montana (gaging station 12370000).—Continued

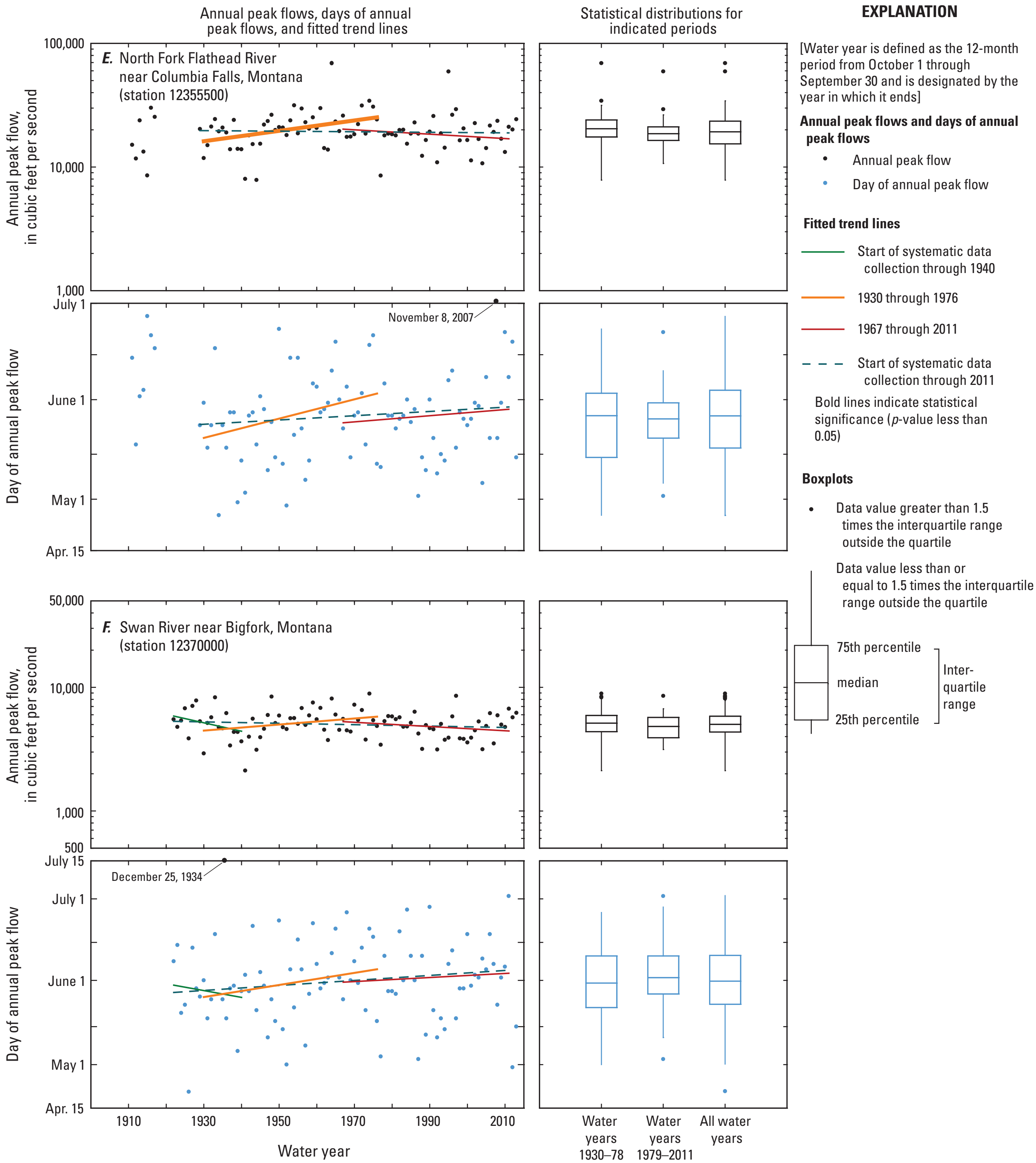

Figure 9. Fitted trends for annual peak flow (the annual series of maximum instantaneous discharge, in cubic feet per second) and peak-flow timing (the annual series of the day of the annual peak flow), and statistical distributions for summary time periods for streamflow-gaging stations in the Columbia River Basin: *A*, Clark Fork above Missoula, Montana (gaging station 12340500); *B*, Clark Fork below Missoula, Montana (gaging station 12353000); *C*, Clark Fork at St. Regis, Montana (gaging station 12354500); *D*, Flathead River at Flathead, British Columbia (gaging station 12355000); *E*, North Fork Flathead River near Columbia Falls, Montana (gaging station 12355500); and *F*, Swan River near Bigfork, Montana (gaging station 12370000).—Continued

as stationary for application of peak-flow frequency analyses within a statewide gaging-station network; however, for two low-elevation gaging stations (Poplar River at international boundary [gaging station 06178000; map number 386; fig. 1, table 1] and Powder River at Moorhead, Montana [gaging station 06324500; map number 542; fig. 1, table 1]), substantial downward trends in annual peak flow during 1967–2011 were of similar or stronger magnitude than the upward trends during 1930–76, and the annual-peak-flow medians for 1979–2011 were substantially lower than the medians for the entire period of record. These issues are further discussed in the section "Discussion of Stationarity Issues for Low-Elevation Gaging Stations in Eastern Montana."

For peak-flow timing for most long-term gaging stations, differences in trends between the periods 1930–76 and 1967–2011 are variable and not particularly strong, and statistical distributions generally are similar among the summary time periods. However, for two gaging stations on a Missouri River headwater tributary (Gallatin River near Gallatin Gateway, Montana [gaging station 06043500; map number 80; fig. 1, table 1] and Gallatin River at Logan, Montana [gaging station 06052500; map number 88; fig. 1, table 1]), and for five of the seven high-elevation gaging stations in the Yellowstone River Basin (Yellowstone River at Corwin Springs, Montana [gaging station 06191500; map number 424; fig. 1, table 1], Yellowstone River near Livingston, Montana [gaging station 06192500; map number 425; fig. 1, table 1], Clarks Fork Yellowstone River near Belfry, Montana [gaging station 06207500; map number 445; fig.1, table 1], Clarks Fork Yellowstone River at Edgar, Montana [gaging station 06208500; map number 448; fig. 1, table 1], Yellowstone River at Billings, Montana [gaging station 06214500; map number 458; fig. 1, table 1]), downward trends in peak-flow timing during 1967–2011 generally were stronger than upward trends during 1930–1976 and day-of-peak medians for 1979–2011 were considerably less than day-of-peak medians for 1930–78. The downward trends in peak-flow timing for 1967–2011 indicate that the timing of annual peak flows changed from later in the year to earlier in the year. For the seven high-elevation gaging stations, the mean change during 1967–2011 was about 13 days (range of 8 to 22 days).

For most of the high-elevation gaging stations on the Missouri River headwaters tributaries and in the Yellowstone River and Columbia River Basins, there was general correspondence between trend patterns for annual peak flow and trend patterns for peak-flow timing. That is, during periods when there were upward trends in annual peak flow, there also generally were upward trends peak-flow timing. Conversely, during periods when there were downward trends in annual peak flow, there generally were downward trends in peak-flow timing. Moore and others (2007) also reported general correspondence between trend patterns in runoff variables and timing variables.

Discussion of Stationarity Issues for Low-Elevation Streamflow-Gaging Stations in Eastern Montana

The two low-elevation gaging stations in eastern Montana (Poplar River at international boundary [gaging station 06178000; map number 386; fig. 1, table 1] and Powder River at Moorhead, Montana [gaging station 06324500; map number 542; fig. 1, table 1]) had considerable changes in annual peak-flow characteristics after the mid-1970s, which might provide evidence of potential nonstationarity in the peak-flow records. Although a small number of stations are represented, additional investigation was considered to be warranted.

Peak-flow frequencies for the two gaging stations based on data collected during 1979–2011 were compared to peak-flow frequencies based on the entire period of record. Documentation concerning development of the peak-flow frequencies is presented in appendix 1 (at the back of this report chapter). Documentation regarding analytical procedures for the peak-flow frequency analyses is presented in table 1–1. Peak-flow frequency results are presented in table 1-2 and figure 1–1.

For Poplar River at international boundary, peak-flow frequencies for the period 1979–2011 were somewhat lower than peak-flow frequencies for the entire period of record (fig. 1–1*A*, table 1–2). For individual annual exceedance probabilities (AEPs), peak-flow frequencies for the period 1979–2011 ranged from 19 to 50 percent lower than peak-flow frequencies for the entire period of record. For most AEPs, the peak-flow frequencies for the period 1979–2011 were lower than the lower 95-percent confidence level of the peak-flow frequency curve for the entire period of record.

For Powder River at Moorhead, Montana, peak-flow frequencies for the period 1979–2011 were substantially lower than peak-flow frequencies for the entire period of record (fig. 1–1*B*, table 1–1). For individual AEPs, peak-flow frequencies for the period 1979–2011 ranged from 32 to 65 percent lower than peak-flow frequencies for the entire period of record (table 1–2). For all AEPs, the peak-flow frequencies for the period 1979–2011 were lower than the lower 95-percent confidence level of the peak-flow frequency curve for the entire period of record. Furthermore, for all AEPs, the upper 95-percent confidence level for the period 1979–2011 was lower than the lower 95-percent confidence level of the peak-flow frequency curve for the entire period of record.

The differences between peak-flow frequencies based on 1979–2011 data and peak-flow frequencies based on the entire period of record provide additional information on potential nonstationarity in annual peak flow for the two low-elevation gaging stations in eastern Montana. The observed differences could have large effects on some uses of peak-flow frequency information.

It is difficult to accurately determine the possible causes of the potential nonstationarity in annual peak flow. Consequently, it also is difficult to develop a clear approach for handling this potential nonstationarity issue within the context of application of peak-flow frequency analyses within a statewide gaging-station network.

The two low-elevation gaging stations that exhibit potential nonstationarity are located in drainage basins that are strongly affected by agricultural activities that potentially affect the hydrologic regimes. Primary agricultural activities that might alter natural hydrologic conditions include construction of small impoundments (primarily for stock-watering purposes) and irrigation diversions. Because of the extensive data requirements of the trend analysis, a small number of stations in low-elevation agriculture-dominated basins are represented; however, the potential nonstationarity issues represented by the two low-elevation gaging stations might have application to a large number of gaging stations in Montana.

As previously discussed in the section “Selection of Streamflow-Gaging Stations,” the current (2015) criterion used by the USGS classifies a gaging station as affected by major dam regulation if the drainage area upstream from a single upstream dam exceeds 20 percent of the drainage area for the gaging station. Additionally, the USGS classifies a gaging station as affected by minor dam regulation if the drainage area upstream from all upstream dams exceeds 20 percent of the drainage area for the gaging station (McCarthy and others, 2016). According to these criteria, the two low-elevation gaging stations are not classified as affected by major or minor regulation. However, for the two low-elevation gaging stations, additional considerations might affect their regulation status.

Much of the drainage basins of the two low-elevation gaging stations are located in either Saskatchewan, Canada (for Poplar River at international boundary) or Wyoming (for Powder River at Moorhead, Montana). The geospatial data for small impoundments used by the USGS for regulation classification (McCarthy and others, 2016) were not available for Canada and Wyoming, and quantitative assessment of potential effects of small-impoundment development was difficult. However, some qualitative information might be relevant to evaluating potential effects of small-impoundment development for the two gaging stations.

For Poplar River at international boundary, a second gaging station (Poplar River near Bredette, Montana [gaging station 06180500]) is downstream. Within the intervening drainage area in Montana between the two gaging stations, there was small-impoundment development during about 1950–65 that affects about 13 percent of the intervening drainage area. The somewhat small amount of small-impoundment development in the intervening drainage area might indicate that small-impoundment development was not a large contributor to nonstationarity issues for Poplar River at international boundary.

For Powder River at Moorhead, a second gaging station (Powder River near Locate, Montana [gaging station 06326500]) is downstream. Within the intervening drainage area in Montana between the two gaging stations, there was small-impoundment development during about 1940–61 that affects about 20 percent of the intervening drainage area. Also, small-impoundment development probably was extensive in the Powder River Basin in Wyoming during about 1997–2010 when coalbed methane extraction activities were extensive (National Research Council, 2010); therefore, small-impoundment development might be a contributor to nonstationarity issues for Powder River at Moorhead, Montana.

The criteria used by the USGS for regulation classification do not incorporate assessment of irrigation diversions. Datasets for irrigation diversions are not readily available at sufficient scale and coverage for assessing effects on the application of peak-flow 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. Lacking suitable data, it is difficult to assess potential effects of irrigation diversions on the potential nonstationarity issues for the two low-elevation gaging stations.

Changes in climatic characteristics after the mid-1970s possibly contributed to the potential nonstationarity issues. Lack of considerable indication of potential nonstationarity in annual peak flow for the other long-term gaging stations in this study might indicate that climatic changes have been more pronounced with respect to effects on peak flows in low-elevation areas in eastern Montana than in areas represented by the other long-term gaging stations. Another possibility is that climatic changes after the mid-1970s are exacerbated in low-elevation areas where small-impoundment development and potential effects of irrigation diversions might be more extensive.

Potential nonstationarity issues for peak flows have been considered in other parts of the United States. Increasing peak flows have been observed in recent years (after the 1970s) in Maine (Hodgkins, 2010) and North Dakota (Williams-Sether, 2015). In Maine, Hodgkins (2010) suggested a conservative approach of computing peak-flow frequencies from datasets restricted to recent years and also datasets that include the entire period of record and then selecting the higher computed peak-flow frequencies. In North Dakota, peak-flow frequencies have been calculated using generalized skew values determined from the truncated period 1960–2009 (Williams-Sether, 2015). For the two low-elevation gaging stations in eastern Montana with indication of decreasing peak flows after the mid-1970s, a conservative approach would be to compute peak-flow frequencies based on the entire period of record.

The issue of potential nonstationarity of annual peak flow in low-elevation areas of eastern Montana might be clarified by additional future research. Research activities might include (1) detailed analysis of effects of changes in climatic characteristics after the mid-1970s on hydrologic regimes in eastern Montana; (2) detailed documentation of locations and capacities of irrigation diversion canals in eastern Montana; (3) detailed documentation of locations, storage capacities, and operations of small impoundments in eastern Montana; (4) analysis of effects of irrigation diversion canals and small impoundments on peak-flow characteristics; and (5) analysis of the combined effects of changes in climatic characteristics, diversions, and small impoundments on peak-flow characteristics in eastern Montana. A possible initial follow-up study might involve relaxing the rigorous dataset requirements that were used in this study to include additional low-elevation gaging stations in eastern Montana. This expanded study might provide information on the areal extent of the observed trend patterns for the two low-elevation gaging stations.

Summary and Conclusions

The primary purpose of Chapter B of this Scientific Investigations Report is to present the results of a large-scale study by the U.S. Geological Survey, in cooperation with the Montana Department of Transportation and the Montana Department of Natural Resources and Conservation to investigate general patterns in peak-flow temporal trends and stationarity through water year 2011 for 24 long-term streamflow-gaging stations (hereinafter referred to as gaging stations) in Montana. Hereinafter, all years refer 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. Temporal trends were analyzed for two hydrologic variables: annual peak flow and peak-flow timing. Annual peak flow is the annual series of maximum instantaneous discharge in cubic feet per second. Peak-flow timing is the annual series of the day of the annual peak flow (hereinafter referred to as day of peak).

The 24 long-term gaging stations are grouped according to the following major river basins: Saskatchewan River Basin (2 gaging stations); Missouri River Basin (16 gaging stations); and Columbia River Basin (6 gaging stations). Gaging stations in the Missouri River are subgrouped according to the following descriptive classes: (1) Missouri River headwaters tributaries (three gaging stations); (2) upper Missouri River tributaries (two gaging stations); (3) Musselshell River Basin (one gaging station); (4) upper Milk River Basin (one gaging station); (4) lower Missouri River tributary (one gaging station); and (5) Yellowstone River Basin (eight gaging stations).

Exploratory analyses indicated that peak flows for most sites generally were lower than median peak flow (determined for the entire period of record through 2011) from about 1930 to the early 1940s and generally were higher than median peak flow from the mid- to late 1960s to the mid- to late 1970s. These generally consistent large-scale patterns served as the basis for defining four trend analysis periods that were applied for each gaging station: (1) from the start of systematic data collection through 1940 (for gaging stations with at least 15 years of systematic record during the period); (2) from 1930 to 1976; (3) from 1967 to 2011; and (4) from the start of systematic data collection through 2011.

For the defined trend analysis periods, trend magnitudes were computed using the Sen slope estimator. Statistical distributions of peak-flow characteristics were compiled for selected data summary periods for each gaging station. The data summary periods were (1) 1930–78, (2) 1979–2011, and (3) the entire period of record. The 1930–78 summary period was selected to represent peak-flow characteristics during a period before the mid-1970s that generally ranged from an unusually dry period to an unusually wet period and typically encompassed the full range in historical variability; the summary period purposely extends slightly past the mid-1970s to include transition years. The 1979–2011 summary period was selected to represent the period after the mid 1970s that might be affected by reported changes in hydrologic regimes associated with changes in climatic conditions. The entire period of record (including any pre-1930 data) also was statistically summarized. For annual peak flow, the entire period of record represents the data that are typically used to calculate peak-flow frequencies. For a given gaging station, stationarity of annual peak flow requires that all of the data represent a consistent hydrologic regime within the same (albeit highly variable) fundamental climatic system. As such, a primary consideration in this study is whether annual peak flow data after the mid-1970s are substantially different from data for the entire period of record and thus might result in substantially different peak-flow frequencies. The nonparametric Wilcoxon rank sum procedure was used to test for significant differences between the annual-peak-flow median for 1979–2011 in relation to medians for 1930–78 and for the entire period of record. The nonparametric Wilcoxon rank sum procedure also was used to test for significant changes in peak-flow timing, with the test applied to the day-of-peak median for 1979–2011 in relation to medians for 1930–78 and for the entire period of record. In this study, a significance level (p-value) less than 0.05 indicates statistical significance.

For annual peak flow for most long-term gaging stations, upward trends during 1930–76 generally were stronger than downward trends during 1967–2011, and statistical distributions generally were similar among summary time periods. Study results provide evidence that annual peak flow for most of the long-term gaging stations can 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 (Poplar River at international boundary [gaging station 06178000] and Powder River at Moorhead, Montana [gaging station 06324500]), substantial downward trends in annual peak flow during 1967–2011 were of similar or stronger magnitude than the upward trends during 1930–76, and the annual-peak-flow medians for 1979–2011 were substantially lower than the medians for the entire period of record.

For peak-flow timing for most long-term gaging stations, differences in trending between the periods 1930–76 and 1967–2011 are variable and not particularly strong, and statistical distributions generally are similar among the summary time periods. However, for two gaging stations on a Missouri River headwater tributary (Gallatin River near Gallatin Gateway, Montana [gaging station 06043500] and Gallatin River at Logan, Montana [gaging station 06052500]) and for five high-elevation gaging stations in the Yellowstone River Basin (Yellowstone River at Corwin Springs, Montana [gaging station 06191500], Yellowstone River near Livingston, Montana [gaging station 06192500], Clarks Fork Yellowstone River near Belfry, Montana [gaging station 06207500], Clarks Fork Yellowstone River at Edgar, Montana [gaging station 06208500], and Yellowstone River at Billings, Montana [gaging station 06214500]), downward trends in peak-flow timing during 1967–2011 generally were stronger than upward trends during 1930–76, and day-of-peak medians for 1979–2011 were considerably less than medians for 1930–78.

For most of the high-elevation gaging stations on the Missouri River headwaters tributaries and in the Yellowstone River and Columbia River Basins, there was general correspondence between trend patterns for annual peak flow and trend patterns for peak-flow timing. That is, during periods when there were upward trends in annual peak flow, there also generally were upward trends in peak-flow timing. Conversely, during periods when there were downward trends in annual peak flow, there generally were downward trends in peak-flow timing.

The two low-elevation gaging stations in eastern Montana (Poplar River at international boundary [gaging station 06178000] and Powder River at Moorhead, Montana [gaging station 06324500]) have had considerable changes in annual-peak-flow characteristics after the mid-1970s, which might provide evidence of potential nonstationarity in the peak-flow records. Peak-flow frequencies for the two gaging stations based on data collected during 1979–2011 were compared to peak-flow frequencies based on the entire period of record. For Poplar River at international boundary, peak-flow frequencies for the period 1979–2011 were somewhat lower than peak-flow frequencies for the entire period of record. For individual annual exceedance probabilities (AEPs), peak-flow frequencies for the period 1979–2011 ranged from 19 to 50 percent lower than peak-flow frequencies for the entire period of record. For most AEPs, the peak-flow frequencies for the period 1979–2011 were lower than the lower 95-percent confidence level of the peak-flow frequency curve for the entire period of record. For Powder River at Moorhead, Montana, peak-flow frequencies for the period 1979–2011 were substantially lower than peak-flow frequencies for the entire period of record. For individual AEPs, peak-flow frequencies for the period 1979–2011 ranged from 32 to 65 percent lower than peak-flow frequencies for the entire period of record. For all AEPs, the peak-flow frequencies for the period 1979–2011 were lower than the lower 95-percent confidence level of the peak-flow frequency curve for the entire period of record. Furthermore, for all AEPs the upper 95-percent confidence level for the period 1979–2011 was lower than the lower 95-percent confidence level of the peak-flow frequency curve for the entire period of record. The differences between peak-flow frequencies based on 1979–2011 data and peak-flow frequencies based on the entire period of record provide additional information on potential nonstationarity in annual peak flow for the two low-elevation gaging stations in eastern Montana. The observed differences could have large effects on some uses of peak-flow frequency information.

It is difficult to accurately determine the possible causes of the potential nonstationarity in annual peak flow. Consequently, it also is difficult to develop a clear approach for handling this potential nonstationarity issue within the context of application of peak-flow frequency analyses within a statewide gaging-station network. The two low-elevation gaging stations that exhibit potential nonstationarity are located in drainage basins that are strongly affected by agricultural activities that potentially affect the hydrologic regimes. Primary agricultural activities that might alter natural hydrologic conditions include construction of small impoundments (primarily for stock-watering purposes) and irrigation diversions. Temporal variability in these activities might contribute to the potential nonstationarity issues. Changes in climatic characteristics after the mid-1970s also possibly contribute to the potential nonstationarity issues. Lack of considerable indication of potential nonstationarity in annual peak flow for the other long-term gaging stations in this study might indicate that climatic changes have been more pronounced with respect to effects on peak flows in low-elevation areas in eastern Montana than in areas represented by the other long-term gaging stations. Another possibility is that climatic changes after the mid-1970s are exacerbated in low-elevation areas where small-impoundment development and potential effects of irrigation diversions might be more extensive.

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Appendix 1

Appendix 1. Information on Peak-Flow Frequency Analyses for Low-Elevation Streamflow-Gaging Stations in Eastern Montana

Peak-flow frequency analyses for Poplar River at international boundary (streamflow-gaging station 06178000; map number 386; fig. 1, table 1) and Powder River at Moorhead, Montana (streamflow-gaging station 06324500; map number 542; fig. 1, table 1) were done using procedures described by Sando and others (2016). 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.

For each of the streamflow-gaging stations, peak-flow frequency analyses were done on two of the data summary periods: (1) 1979–2011, and (2) the entire period of record. Documentation regarding analytical procedures for the peak-flow frequency analyses is presented in table 1–1. Peak-flow frequency results are presented in table 1–2 and figure 1–1.

Table 1–1. Documentation regarding analytical procedures for peak-flow frequency analyses for low-elevation streamflow-gaging stations in eastern Montana.

[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]

Map number (fig. 1)	Station identification number	Station name	Drainage area, in square miles	Number of years of peak-flow records in analysis period	Analysis period of record, water years	Primary reason for deviation from standard Bulletin 17B procedures[1]	Log-distribution information for peak-flow data				
							Mean	Standard deviation	Skew type used in analysis	Station skew	Generalized skew
386	06178000	Poplar River at international boundary	358	80	1931, 1933–2011	low-end	2.817	0.504	WEIGHTED	-0.251	-0.400
				33	1979–2011	--	2.581	0.654	WEIGHTED	-0.436	-0.400
542	06324500	Powder River at Moorhead, Montana	8,029	82	1923, 1929–72, 1975–2011	--	3.743	0.343	WEIGHTED	-0.324	-0.005
				33	1979–2011	--	3.540	0.295	WEIGHTED	-0.216	-0.005

Map number (fig. 1)	Station identification number	Station name	Drainage area, in square miles	Number of years of peak-flow records in analysis period	Analysis period of record, water years	Primary reason for deviation from standard Bulletin 17B procedures[1]	Low-outlier information		
							Low-outlier threshold, in cubic feet per second	Type of low-outlier threshold[2]	Number of systematic peak flows less than or equal to low-outlier threshold
386	06178000	Poplar River at international boundary	358	80	1931, 1933–2011	low-end	160	user	10
				33	1979–2011	--	7.6	default	10
542	06324500	Powder River at Moorhead, Montana	8,029	82	1923, 1929–72, 1975–2011	--	615.8	default	0
				33	1979–2011	--	591.9	default	0

Map number (fig. 1)	Station identification number	Station name	Drainage area, in square miles	Number of years of peak-flow records in analysis period	Analysis period of record, water years	Primary reason for deviation from standard Bulletin 17B procedures[1]	High-outlier and historical adjustment information		
							High-outlier threshold, in cubic feet per second	Type of high-outlier threshold[2]	Water year of peak flow for user or historical high-outlier threshold
386	06178000	Poplar River at international boundary	358	80	1931, 1933–2011	low-end	31,385.2	default	--
				33	1979–2011	--	19,174.0	default	--
542	06324500	Powder River at Moorhead, Montana	8,029	82	1923, 1929–72, 1975–2011	--	33,000	user	1978
				33	1979–2011	--	20,348.5	default	--

Table 1–1. Documentation regarding analytical procedures for peak-flow frequency analyses for low-elevation streamflow-gaging stations in eastern Montana.—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]

Map number (fig. 1)	Station identification number	Station name	Drainage area, in square miles	Number of years of peak-flow records in analysis period	Analysis period of record, water years	Primary reason for deviation from standard Bulletin 17B procedures[1]	High-outlier and historical adjustment information: Number of historical peak flows	Number of systematic peak flows greater than or equal to high-outlier threshold	Length of historic period, in years	Start water year of historic period	End water year of historic period
386 0	06178000	Poplar River at international boundary	358	80	1931, 1933–2011	low-end	0	0	--	--	--
				33	1979–2011	--	0	0	--	--	--
542 0	06324500	Powder River at Moorhead, Montana	8,029	82	1923, 1929–72, 1975–2011	--	1	1	93	1919	2011
				33	1979–2011	--	0	0	--	--	--

[1]Standard Bulletin 17B (U.S. Interagency Advisory Council on Water Data, 1982) procedures are considered to be the use of the weighted skew and the use of the single Grubbs-Beck low-outlier threshold. In cases where either the station skew or a user-selected low-outlier threshold was used, the frequency analysis was considered to deviate from standard Bulletin 17B procedures. The abbreviations for the reasons for deviation from standard Bulletin 17B procedures are defined as follows: low-end: the probability plots of peak-flow records deviate from typical patterns in the lower end of the frequency curve at high annual exceedance probabilities (greater than about 50.0 percent).

[2]Definitions of types of outler thresholds include: default: outlier threshold calculated using Bulletin 17B default procedures (U.S. Interagency Advisory Council on Water Data, 1982); user: outlier threshold based on a systematic peak flow selected by the user (peak-flow frequency analyst).

Table 1–2. Peak-flow frequency results for low-elevation streamflow-gaging stations in eastern Montana.

[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	Drainage area, in square miles	Number of years of peak-flow records in analysis period	Analysis period of record, water years	Data type	Annual peak flow, in cubic feet per second, for indicated annual exceedance probability, in percent				
							66.7	50	42.9	20	10
386	06178000	Poplar River at international boundary	358	80	1931, 1933–2011	frequency-curve estimates	382	622	763	1,710	2,990
						upper 95-percent confidence level	475	771	956	2,230	4,120
						lower 95-percent confidence level	302	501	620	1,350	2,280
				33	1979–2011	frequency-curve estimates	218	424	555	1,380	2,420
						upper 95-percent confidence level	337	662	878	2,460	4,740
						lower 95-percent confidence level	135	274	359	869	1,450
542	06324500	Powder River at Moorhead, Montana	8,029	82	1923, 1929–72, 1975–2011	frequency-curve estimates	3,880	5,420	6,240	10,700	15,400
						upper 95-percent confidence level	4,490	6,270	7,250	12,800	19,100
						lower 95-percent confidence level	3,310	4,690	5,420	9,120	12,800
				33	1979–2011	frequency-curve estimates	2,630	3,530	3,990	6,180	8,190
						upper 95-percent confidence level	3,190	4,300	4,890	8,000	11,200
						lower 95-percent confidence level	2,100	2,890	3,270	5,010	6,490

Map number (fig. 1)	Station identification number	Station name	Drainage area, in square miles	Number of years of peak-flow records in analysis period	Analysis period of record, water years	Data type	Annual peak flow, in cubic feet per second, for indicated annual exceedance probability, in percent				
							4	2	1	0.5	0.2
386	06178000	Poplar River at international boundary	358	80	1931, 1933–2011	frequency-curve estimates	5,550	8,390	12,300	17,500	27,200
						upper 95-percent confidence level	8,230	13,100	20,200	30,200	49,700
						lower 95-percent confidence level	4,030	5,860	8,260	11,400	16,900
				33	1979–2011	frequency-curve estimates	4,210	5,890	7,860	10,100	13,500
						upper 95-percent confidence level	9,220	13,900	19,700	26,800	38,200
						lower 95-percent confidence level	2,380	3,190	4,100	5,090	6,530
542	06324500	Powder River at Moorhead, Montana	8,029	82	1923, 1929–72, 1975–2011	frequency-curve estimates	22,900	29,800	37,800	47,200	61,900
						upper 95-percent confidence level	29,800	40,000	52,400	67,400	91,700
						lower 95-percent confidence level	18,500	23,500	29,200	35,600	45,400
				33	1979–2011	frequency-curve estimates	11,000	13,200	15,600	18,100	21,600
						upper 95-percent confidence level	15,900	20,000	24,600	29,600	36,900
						lower 95-percent confidence level	8,440	9,940	11,500	13,100	15,200

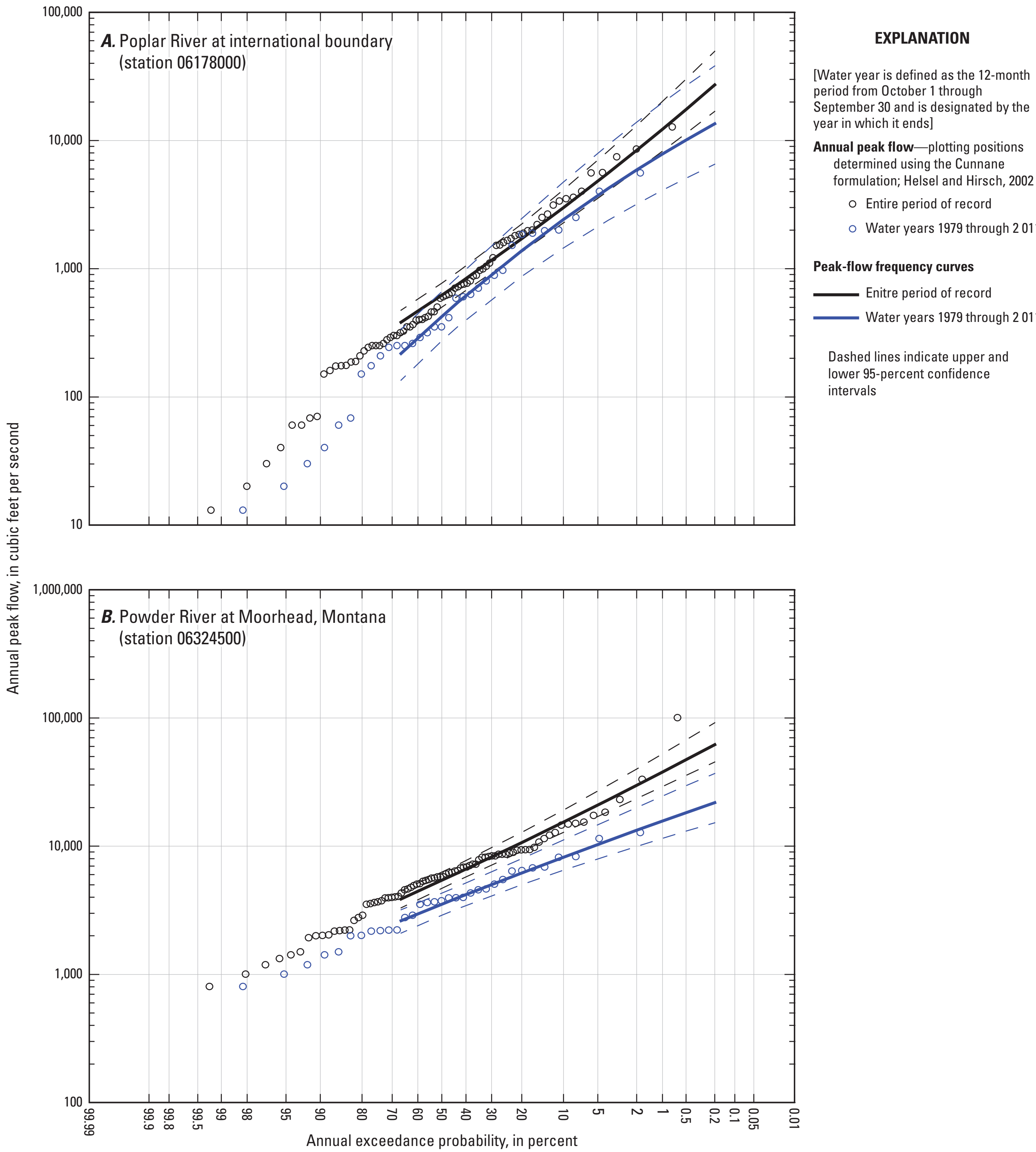

Figure 1–1. Annual peak flows and peak-flow frequency curves for low-elevation streamflow-gaging stations in eastern Montana.

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