USGS
science for a changing world

Prepared in cooperation with the Federal Emergency Management Agency

Characteristics of Peak Streamflows and Extent of Inundation in Areas of West Virginia and Southwestern Virginia Affected by Flooding, June 2016



Open-File Report 2017–1140
Version 1.1, September 2018

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

Cover. Aerial view of the extent of flooding on the Elk River at Clendenin, West Virginia. (Photo by Dan Thom, WOWK CBS 13 News.)

Characteristics of Peak Streamflows and Extent of Inundation in Areas of West Virginia and Southwestern Virginia Affected by Flooding, June 2016

By Samuel H. Austin, Kara M. Watson, R. Russell Lotspeich, Stephen J. Cauller, Jeremy S. White, and Shaun M. Wicklein

Prepared in cooperation with the Federal Emergency Management Agency

Open-File Report 2017–1140
Version 1.1, September 2018

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

U.S. Department of the Interior
RYAN K. ZINKE, Secretary

U.S. Geological Survey
James F. Reilly II, Director

U.S. Geological Survey, Reston, Virginia: 2017
Revised: September 2018 (ver. 1.1)

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment—visit https://www.usgs.gov or call 1–888–ASK–USGS.

For an overview of USGS information products, including maps, imagery, and publications, visit https://store.usgs.gov.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Although this information product, for the most part, is in the public domain, it also may contain copyrighted materials as noted in the text. Permission to reproduce copyrighted items must be secured from the copyright owner.

Suggested citation:
Austin, S.H., Watson, K.M., Lotspeich, R.R., Cauller, S.J., White, J.S., and Wicklein, S.M., 2018, Characteristics of peak streamflows and extent of inundation in areas of West Virginia and southwestern Virginia affected by flood-ing, June 2016 (ver. 1.1, September 2018): U.S. Geological Survey Open-File Report 2017–1140, 35 p., https://doi.org/10.3133/ofr20171140.

ISSN 2331-1258 (online)

Contents

Abstract....1
Introduction....1
    Purpose and Scope....4
    Description of Study Area....4
Weather Conditions Before and During the Flood....6
Methods....6
    Collection of High-Water-Mark Data....6
    Flood-Inundation Mapping....7
    Peak-Flow Data Evaluation....8
    Flood-Frequency Analysis....8
    Flood Probabilities of Peak Streamflows....9
Estimated Magnitudes and Flood Probabilities for Peak Streamflows....22
Flood-Inundation Maps....23
    Elk River Basin....23
    Gauley River Basin....23
    Cherry River Basin....23
    Greenbrier River Basin....27
        Greenbrier River at Alderson....27
        Greenbrier River at Ronceverte....27
        Howard Creek....27
        Meadow River and Sewell Creek....27
    New River Basin....27
Flood Damages....33
Summary....33
References Cited....33
Appendix 1. Graphs Showing Selected Annual Exceedance Probabilities in Relation to Streamflow Using the Expected Moments Algorithm Method for Selected Streamflow-Gaging Stations in West Virginia for the Period of Record through 1990, 2015, and 2016....35
Appendix 2. Graphs Showing Annual Exceedance Probabilities in Relation to Annual Peak Streamflow, Determined Using the Expected Moments Algorithm and Bulletin 17B Methods, for Selected Streamflow-Gaging Stations for the Period of Record through 1990, 2015, and 2016 and Annual Peak Streamflow, by Water Year 1900–2016....35
Appendix 3. Three Tables Listing Expanded Summaries of Site Descriptions, Exceedance Probabilities, Equivalent Recurrence Intervals, Statistics, and Percent Change Since 1990 in Estimated Peak-Flow Annual Exceedance Probabilities for 18 Streamflow-Gaging Stations Associated with June 2016 Flooding in West Virginia and Southwestern Virginia Using Data for the Period of Record through 1990, 2015, and 2016....35

Figures

1. Map showing total precipitation for June 23–24, 2016, and location of U.S. Geological Survey streamflow-gaging stations in West Virginia and southwestern Virginia used to calculate annual exceedance probabilities 2
2. Map showing location of streams, cities, and basins within the study area in West Virginia and southwestern Virginia 3
3. Photos of flood damage *A*, on the Elk River at Clay, West Virginia and *B*, on the Gauley River near Craigsville, West Virginia....5
4. Photo showing aerial view of the extent of flooding on the Elk River at Clendenin, West Virginia 5
5. Graphs showing percent change in peak flows at selected annual exceedance probabilities using the Expected Moments Algorithm method for eight streamflow-gaging stations in West Virginia for 1990–2016 21
6. Flood-documentation map of inundated area along the Elk River in Kanawha and Clay Counties, West Virginia, June 23–24, 2016....24
7. Flood-documentation map of inundated area along the Gauley River in Camden-on-Gauley, West Virginia, June 23–24, 2016 25
8. Flood-documentation map of inundated area along the Cherry River from Richwood to Fenwick, West Virginia, June 23–24, 2016....26
9. Flood-documentation map of inundated area along the Greenbrier River in Alderson, West Virginia, June 23–24, 2016....28
10. Flood-documentation map of inundated area along the Greenbrier River in Ronceverte, West Virginia, June 23–24, 2016 29
11. Flood-documentation map of inundated area along Howard Creek, from White Sulphur Springs to Caldwell, West Virginia, June 23–24, 2016 30
12. Flood-documentation map of inundated area along the Sewell Creek and Meadow River in Rainelle, West Virginia, June 23–24, 2016 31
13. Flood-documentation map of inundated area along the New River in Hinton, West Virginia, June 23–24, 2016 32

Tables

1. Rainfall totals reported from meteorological stations during June 23–24, 2016, floods in West Virginia 6
2. Site description and number of high-water marks in West Virginia used to generate flood-inundation maps for the June 2016 flood 7
3. Site description, exceedance probabilities, equivalent recurrence intervals, and summary statistics for 18 streamflow-gaging stations associated with June 2016 flooding in West Virginia and southwestern Virginia....11
4. Summary of results from six analyses estimating peakflow annual exceedance probabilities at 18 streamflow-gaging stations associated with June 2016 flooding in West Virginia and southwestern Virginia 14
5. Summary of percent changes since 1990 in estimated peak-flow annual exceedance probabilities from six analyses using two methods for 18 streamflow-gaging stations associated with June 2016 flooding in West Virginia and southwestern Virginia for the period of record through 1990, 2015, and 2016....17
6. Description of ungaged stream reaches in West Virginia with peak flood magnitudes for the June 2016 flood....22

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Datum

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

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

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

Abbreviations

AEP	annual exceedance probability
DEM	digital elevation model
EMA	Expected Moments Algorithm
FEMA	Federal Emergency Management Agency
GIS	geographic information system
GPS	Global Positioning System
HWM	high-water mark
LIDAR	light detection and ranging
NAVD 88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
SAMB	State Addressing and Mapping Board
USGS	U.S. Geological Survey

Characteristics of Peak Streamflows and Extent of Inundation in Areas of West Virginia and Southwestern Virginia Affected by Flooding, June 2016

By Samuel H. Austin, Kara M. Watson, R. Russell Lotspeich, Stephen J. Cauller, Jeremy S. White, and Shaun M. Wicklein

Abstract

Heavy rainfall occurred across central and southern West Virginia in June 2016 as a result of repeated rounds of torrential thunderstorms. The storms caused major flooding and flash flooding in central and southern West Virginia with Kanawha, Fayette, Nicholas, and Greenbrier Counties among the hardest hit. Over the duration of the storms, from 8 to 9.37 inches of rain was reported in areas in Greenbrier County. Peak streamflows were the highest on record at 7 locations, and streamflows at 18 locations ranked in the top five for the period of record at U.S. Geological Survey streamflow-gaging stations used in this study. Following the storms, U.S. Geological Survey hydrographers identified and documented 422 high-water marks in West Virginia, noting location and height of the water above land surface. Many of these high-water marks were used to create flood-inundation maps for selected communities of West Virginia that experienced flooding in June 2016. Digital datasets of the inundation areas, mapping boundaries, and water depth rasters are available online.

Introduction

On June 23, 2016, thunderstorms (collectively referred to as "storm") brought torrential rain to much of West Virginia and southwestern Virginia (fig. 1). From June 23 through June 25 historic flooding occurred. Many small streams flooded, and the main stems of the Elk and Gauley Rivers (fig. 2) had record peak flows. A State of Emergency was declared in 44 counties in West Virginia, and the Federal Emergency Management Agency (FEMA) declared 12 West Virginia counties to be disaster areas. Communication and power distribution facilities were disrupted and many roads were damaged. After the event, many creeks and streams were blocked with accumulated debris, which increased the risk of additional flooding until the blockages could be cleared. Damages to agricultural resources were valued in excess of $10 million dollars by the West Virginia State Agriculture Department. Overall damages, when combined with tornado damage in Ohio from the same storm system, were valued in excess of $1 billion dollars (National Oceanic and Atmospheric Administration [NOAA], 2016a).

Moderate flooding was widespread throughout south-central West Virginia. Extreme flooding was localized in the Elk, Gauley, and Greenbrier River Basins in West Virginia, and the James River Basin in Virginia, areas where rainstorm super cells occurred. Floodflows originating in the Greenbrier River Basin resulted in flooding on the New River downstream from Hinton, West Virginia.The National Weather Service (NWS) estimated rainfall return periods in excess of 1,000 years in some of the hardest hit areas of Roane, Kanawha, Clay, Fayette, Nicholas, and Greenbrier Counties in West Virginia (fig. 1). Rainfall exceeding 7.0 inches (in.) was recorded in many areas of West Virginia, including Maxwelton (9.37 in.), Rainelle (7.53 in.), and White Sulphur Springs (9.17 in.) (NOAA, 2016a). Above normal rainfall extended from Charleston, West Virginia to Roanoke, Virginia. Areas hardest hit areas in Virginia are in Alleghany and Bath Counties. The town of Covington, Virginia, received 5.03 in. of rainfall over the 24-hour period (NOAA, 2016b).

In the most severely flooded parts of West Virginia, many water rescues were made. Cars and homes were washed away, and many roads were closed. Several local communities were destroyed, and at least 23 deaths were attributed to the flooding. Parts of West Virginia have experienced flooding in the past. Previous floods include the flood of April 4–5, 1977, in the southern part of West Virginia and the flood of November 4–5, 1985, which superseded the 1977 flood as the most devastating in the State. In the 1985 flood, 47 lives were lost, thousands were left homeless, and approximately 500 bridges were destroyed. Rainfall estimates for November 4–5, 1985, were as much as 20 in. along the Eastern Divide between the Ohio and Potomac Rivers in eastern West Virginia and western Virginia (Paulson and others, 1991). In September 1996, Tropical Storm Fran caused regional flooding on the upper Potomac River. A frontal storm caused flooding on the Cheat and upper Monongahela Rivers in May 1996. In January 1996 about 2 in. of rain fell on a

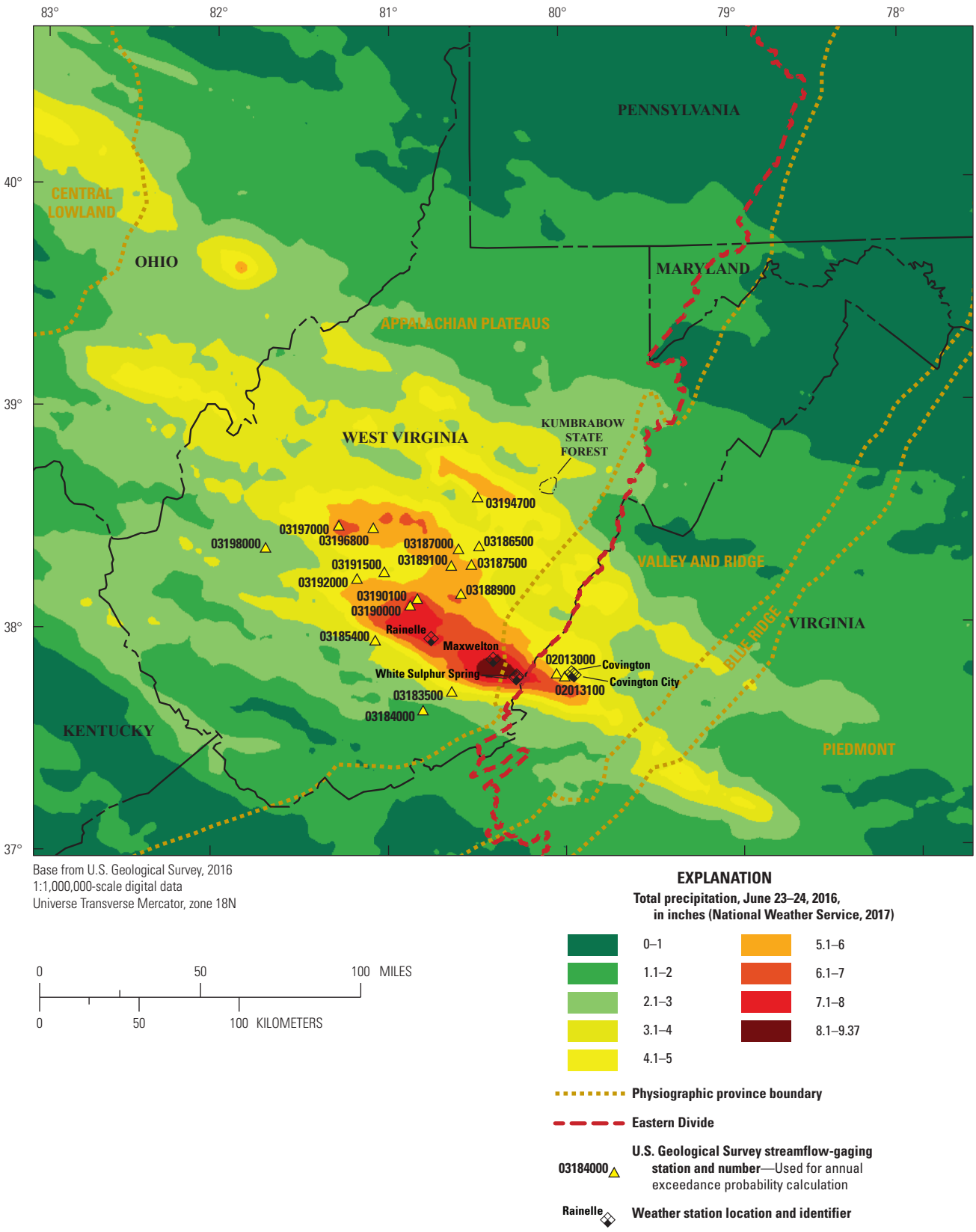


Figure 1. Total precipitation for June 23–24, 2016, and location of U.S. Geological Survey streamflow-gaging stations in West Virginia and southwestern Virginia used to calculate annual exceedance probabilities.

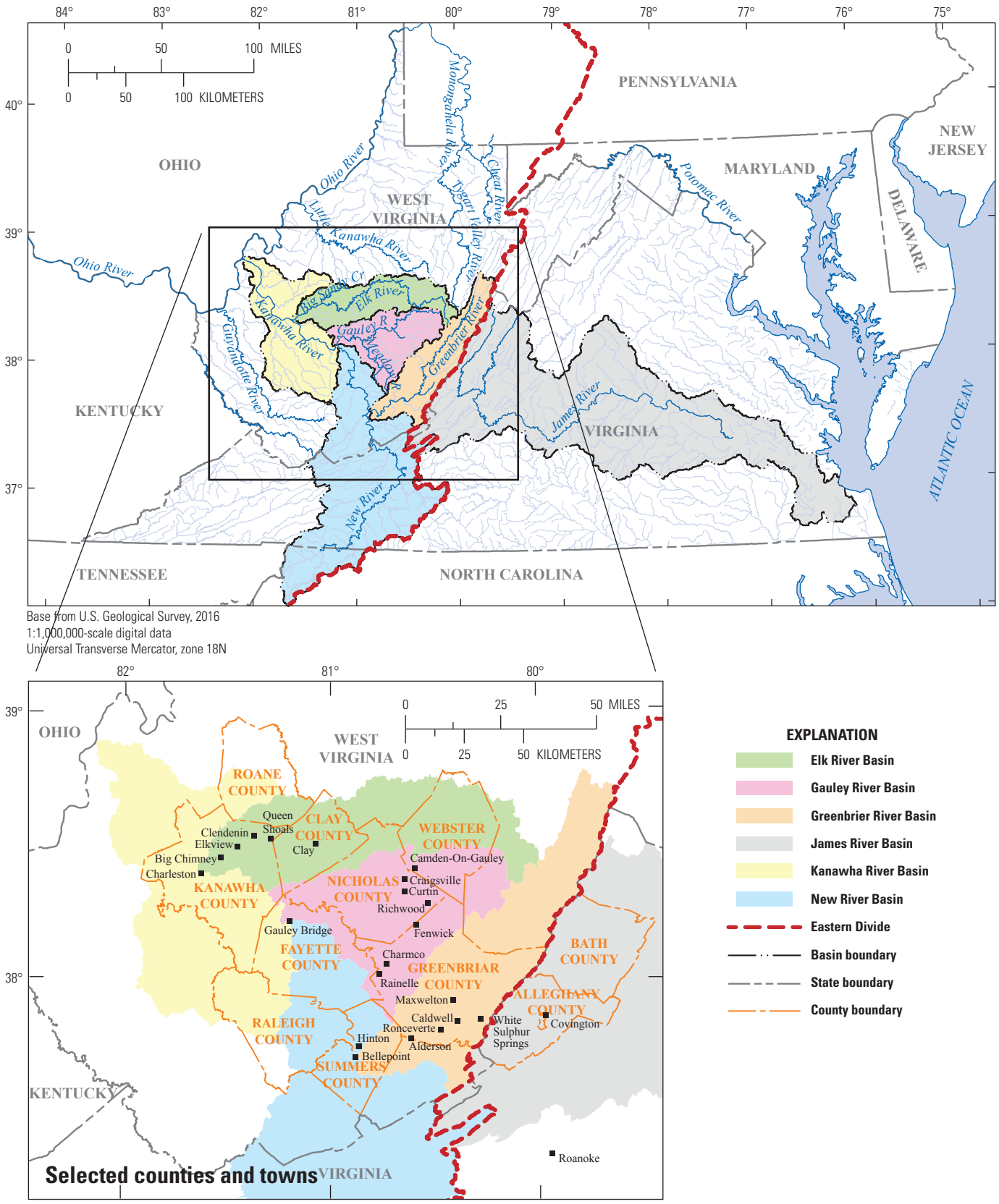


Figure 2. Location of streams, cities, and basins within the study area in West Virginia and southwestern Virginia.

3–4 foot (ft) snowpack, flooding the upper Potomac, Cheat, Elk, and the Greenbrier Rivers. The Tug Fork and Guyandotte Rivers flooded in May 1984. The Kanawha and Monongahela Rivers flooded in March 1967. In March 1963, flooding occurred on the Big Sandy, Guyandotte, Little Kanawha, Cheat, and Greenbrier Rivers. In June 1949, flooding was documented on the South Branch of the Potomac River. In March 1936 flooding occurred on the Potomac and Cheat Rivers. The Greenbrier and Gauley Rivers flooded in March 1918, the Tygart Valley River flooded in July 1912, the North Branch of the Potomac River flooded in May and June 1889, and the Monongahela River flooded in July 1888. The New River flooded in September 1878, the South Branch of the Potomac River flooded in 1877, and the Cheat River flooded in July 1844 (Wiley and Atkins, 2010).

Typically, flooding in West Virginia can occur rapidly as a result of steep gradients and narrow channel valleys, often resulting in significant soil erosion and property damage (fig. 2). Uprooted trees and large volumes of debris swept downstream can block stream channels, creating "backwater" effects as fast moving high-gradient tributary streams pour water into the lower parts of river valleys. The resulting storage and slower movement of floodwaters yields increased flood heights and extents (figs. 3 and 4).

The U.S. Geological Survey (USGS) collects streamflow data at more than 8,000 streamflow-gaging stations nationwide in cooperation with local, state, and Federal agencies. This includes more than 380 streamflow-gaging stations currently operating in West Virginia and Virginia. Collection of streamflow data documents the extent and effects of flooding. Streamflow data collected before and during flooding are vital because they can provide advanced flood warning, forecasts of the extent and potential effects of flooding, and information useful in optimizing allocation of emergency management resources to the most severely affected areas. In intervals between floods, long-term streamflow data are used to anticipate, prepare for, and mitigate the effects of future flooding through effective design and repair of roads, bridges, reservoirs, pipelines, houses, and other infrastructure. In the immediate aftermath of the June 2016 flood, USGS and the Federal Emergency Management Agency (FEMA) initiated a cooperative study to evaluate the flood's magnitude, extent, and probability of occurrence.

Purpose and Scope

The purpose of this report is to document high-water-mark data, flood-peak magnitudes, and flood-inundation products generated by the USGS in support of the FEMA response and recovery operations following the June 2016 flood in West Virginia and southwestern Virginia. The technical scope of the report includes (1) a description of the atmospheric conditions and the temporal and spatial patterns of rainfall that triggered the flooding and a narrative of the flood and its effects, (2) an analysis of peak-flow magnitudes and the statistical probabilities at selected locations, and (3) the identification and surveying of high-water marks (HWM) and the geographic information system (GIS) analysis of HWM locations and elevations used to produce flood-inundation maps (areal extent and depth of flooding) for six heavily flooded areas in West Virginia. Data from the study are in tables and appendixes to this report and a separate data release.

Description of Study Area

The study area encompasses central and southeastern West Virginia and parts of southwestern Virginia. Flooded areas are found primarily within the Appalachian Plateaus and the Valley and Ridge Physiographic Provinces (fig. 1; Fenneman, 1938). In general, the area consists of rolling hills in the northern and central parts of the study area with sharper relief found in southern and eastern parts. Land-surface elevations within the flooded areas range from about 600 to over 4,300 ft referenced to the North American Vertical Datum of 1988 (NAVD 88). The West Virginia 30-year normal rainfall from 1981 to 2010 varied from 39.8 in. near Alderson in the south of the study area to 61.7 in. near Kumbrabow State Forest in the north (NOAA Climatological Data Tools: 1981–2010 Normals, https://www.ncdc.noaa.gov/cdo-web/datatools/normals).

The Kanawha River Basin is mountainous, contained within an area known as the Appalachian Highlands, and associated with three physiographic provinces: Appalachian Plateaus, Valley and Ridge, and Blue Ridge (Messinger and Hughes, 2000). The sites affected by flooding in the Kanawha River Basin are in the Appalachian Plateaus Physiographic Province, an area in which differential erosion of Paleozoic sedimentary rocks created dissected plateaus capped by resistant rock layers (Fenneman, 1938). Valleys in this region are often narrow with river gradients generally ranging from moderate (0.02 ft/ft) to steep (0.09 ft/ft). The western part of the James River Basin begins in the Alleghany Mountains at the Virginia–West Virginia State boundary and the confluence of the Cowpasture and Jackson Rivers. The entire basin, approximately 10,000 square miles, spans five physiographic provinces; they are—from west to east through the center of Virginia—Appalachian Plateaus, Valley and Ridge, Blue Ridge, Piedmont, and the Coastal Plain. Sites affected by flooding in the James River Basin are in the Appalachian Plateaus Physiographic Province; the James River Basin has topography similar to that in the Kanawha River Basin (Fenneman, 1938).

A. ELK RIVER AT CLAY, WEST VIRGINIA



B. GAULEY RIVER NEAR CRAIGSVILLE, WEST VIRGINIA



Figure 3. Flood damage *A*, on the Elk River at Clay, West Virginia (photo by Russ Lotspeich, U.S. Geological Survey) and *B*, on the Gauley River near Craigsville, West Virginia (photo by Katherine Grindle, U.S. Geological Survey).



Figure 4. Aerial view of the extent of flooding on the Elk River at Clendenin, West Virginia (Photo by Dan Thom, WOWK CBS 13 News.)

Weather Conditions Before and During the Flood

On June 23, 2016, several rounds of convective rainfall brought torrential rain to much of West Virginia and southwestern Virginia. Antecedent conditions across much of West Virginia and western Virginia in late spring were wet with May rainfall, about 125–150 percent of normal across much of the area. June rainfall in the 3 weeks preceding the flooding was above normal (100–125 percent) over southeastern West Virginia and western Virginia. On June 22, 2016, the first Flash Flood Watch, indicating a 50–80 percent possibility of flash flooding, was issued by the NWS Weather Forecast Office in Charleston, West Virginia, for parts of southeastern Ohio and much of central and southeastern West Virginia. A warm front over Ohio and Pennsylvania was expected to become the focus for storms as a strong upper level disturbance crossed the region. Heavy rain began falling during the early morning of June 23, and additional flash flood warnings were issued for the area as rainfall continued throughout the day. The combination of a deep tropical moisture convergence and a strengthening low level jet stream from the central plains was believed likely to support rainfall rates exceeding 2 inches per hour for several hours, with flash flooding possible. Throughout the morning, NWS forecasts indicated diminishing rainfall in some areas, but the forecasts changed as convection renewed and persisted throughout the afternoon.

Moderate flooding was widespread throughout south-central West Virginia. Extreme flooding was evident within three rainfall bands in this area where supercells developed and remained for extended periods in the Elk, Gauley, and Greenbrier River Basins in West Virginia, and the James River Basin in Virginia. Floodflows from the Greenbrier River also resulted in flooding on the New River in, and downstream from, Hinton, West Virginia.

For some of the hardest hit areas of Roane, Kanawha, Clay, Fayette, Nicholas, and Greenbrier Counties in West Virginia, the NWS estimated rainfall return periods exceeding 1,000 years. Rainfall totals in excess of 7.0 in. were recorded in many areas of West Virginia, including Maxwelton (9.37 in.), Rainelle, (7.53 in.), and White Sulphur Springs, (9.17 in.; table 1). The path of large total rainfall extended from Charleston, West Virginia, to Roanoke, Virginia. The hardest hit areas in Virginia were Alleghany and Bath Counties. The town of Covington, Virginia, in Alleghany County received 5.03 in. of rainfall over the 24-hour period.

Methods

Methods for identifying, documenting, and referencing flood HWMs (table 2) and methods used to create flood-inundation maps from HWMs are discussed in this section, as are methods for estimating flood magnitude and frequency using annual peak streamflows at 18 streamflow-gaging stations operated by the USGS. All streamflow data used in this report were obtained from the USGS National Water Information System (U.S. Geological Survey, 2017).

Collection of High-Water-Mark Data

HWMs provide valuable data for understanding flood events (Koenig and others, 2016). The best HWMs are formed from small seeds or floating debris carried by floodwaters that adhere to smooth surfaces or lodge in tree bark to form a distinct line. Stain lines on buildings, fences, and other structures also provide excellent marks. The HWMs are best identified immediately following the peak stage because time and weather may alter evidence of the peak water line. The HWMs collected for this flood are available through the USGS Short-Term Network (STN) Data Portal (STN; U.S. Geological Survey, 2016; http://stn.wim.usgs.gov/STNDataPortal/#), an online interface created to facilitate dissemination of field data.

Table 1. Rainfall totals reported from meteorological stations during June 23–24, 2016, floods in West Virginia.

[in., inches; EST, eastern standard time; WV, West Virginia; Va., Virginia; E, east; NNW, north, northwest; CWOP, Citizen Weather Observer Program; CO-OP Observer, National Weather Service Cooperative Observer Program observer; GOES, Geostationary Operational Environmental Satellite; U.S. Army COE, U.S. Army Corps of Engineers; CoCoRAHS, Community Collaborative Rain, Hail, and Snow Network]

Location	Rainfall amount (in.)	Time (EST)	Date	Meteorological station operator
Maxwelton, WV	9.37	7:59 a.m.	06/24/2017	CWOP
White Sulphur Spring, WV	9.17	7 a.m.	06/24/2017	CO-OP Observer
White Sulphur Spring, WV	8.63	7:45 a.m.	06/24/2017	GOES
Rainelle, WV	7.53	7:45 a.m.	06/24/2017	U.S. Army COE
4 E Covington, Va.	5.59	7 a.m.	06/24/2017	CoCoRAHS
3 NNW Covington City, Va.	5.2	7:58 a.m.	06/24/2017	CWOP

Table 2. Site description and number of high-water marks in West Virginia used to generate flood-inundation maps for the June 2016 flood.

Community	Waterbody or waterbodies	County or counties	Reach length (miles)	Number of high-water marks used to generate flood-inundation map for each community
Clay, Clendenin, Elkview, Big Chimney	Elk River	Kanawha, Clay	45	37
Camden-on-Gauley	Gauley River	Nicholas, Webster	2.7	25
Richwood, Fenwick	Cherry River	Nicholas	4.3	43
Alderson	Howard Creek	Greenbrier	2.6	32
Ronceverte	Greenbrier River	Greenbrier	4.8	48
White Sulphur Springs, Caldwell	Greenbrier River	Greenbrier	7.7	51
Rainelle, Charmco	Sewell Creek, Meadow River	Greenbrier	[1]8.2	49
Hinton	New River	Summers, Raleigh	4	24

[1]Reach length shown is sum of modeled segment of Sewell Creek (4.5 miles) and modeled segment of Meadow River (3.7 miles).

USGS field crews identified 422 HWMs in West Virginia with water depth above land surface measured in feet. Of these, 351 HWMs were surveyed to identify elevation above land surface. Identification and marking of HWMs began on July 2 and continued through July 9, 2016. Written descriptions, sketches, photographs, and Global Positioning System (GPS) horizontal measurements obtained with a hand-held GPS unit were made so the marks could easily be found later and surveyed to the standard vertical datum, NAVD 88.

During the mapping process, the HWMs used to create flood-inundation maps (Watson and Cauller, 2017) were checked for location and elevation accuracy using field note diagrams and descriptions, aerial photography, and detailed street and parcel maps. An HWM was not used if the location could not be determined accurately or the elevation was substantially different from other HWMs in the area.

Flood-Inundation Mapping

Flood documentation maps were created using a geographic information system (GIS) to show the extent of inundation along affected river reaches in West Virginia. Flood-inundation maps are intended to be estimates of the areal extent and depth of flooding that correspond to the HWMs identified and surveyed by USGS hydrographers following the flood. The community, county, waterbody, reach length, and number of HWMs used to generate the flood-inundation maps are listed in table 2. The first step in the generation of the flood-inundation maps was the creation of a flood-elevation raster surface. Flood extent and depth surfaces were created independently for each community using the HWM elevations and a GIS interpolation technique. The GIS interpolation method used to create the flood-inundation maps follows methods described for the "Topo-to-Raster" tool in Musser and others (2016). A geographic limit of the generated surface was based on the distribution of HWMs and an understanding of the natural hydrologic flow in the area of each community.

The flood-elevation surface that was created by using GIS interpolation was combined with the State Addressing and Mapping Board (SAMB) 5-meter cell size (16.4-ft cell size) digital elevation model (DEM) (http://www.wvgis.wvu.edu/resources/dataProductDevelopment/SAMB_elev_conv_procedures_draft.pdf). The SAMB DEM was derived from stereo photogrammetric points from aerial photography done in 2003 and supports vertical map accuracy contour standards of 10 ft. Inundated areas were depicted where flood-elevation surfaces were higher than DEM land surfaces. The depth of flooding was determined as the difference between the flood-surface elevation and the DEM land surface. Because of the large number of bridges involved in the flood-inundation mapping, the inundation surfaces were not clipped to show bridges that were not inundated.

Uncertainties in the mapped extent and depth of flooding exist within the maps because of the mapping methods used and the number and spatial distribution of HWMs. Hydraulic models were not used to determine the extent or depth of flood inundation. All flood-elevation surfaces were created using interpolation between HWM elevations rather than hydraulic models. Changes in land-surface features in flood plains, timing of the flooding that may occur because of inflow from some small tributaries rather than large main stem tributaries, and the intermingling flows from adjacent streams are not accounted for without hydraulic models. In locations where HWMs are spaced relatively far apart, there is a greater possibility of decreased accuracy of spatial interpretation of the extent and depth of flood inundation. Within a given mapped area, some extrapolation was performed beyond the most upstream and downstream HWMs. In many cases, the boundary was extended to a structure, such as a road or bridge crossing.

For this study, two sets of inundation layers were generated for each reach. Differences in elevation between the surveyed HWMs and the land surface from the DEM data produced uncertainty in the inundation extent of the generated layers. Often elevation differences of +/- 20 ft were observed between the surveyed elevation of a HWM and the DEM land-surface elevation. As a result of these elevation differences, a second method of interpolating the water-surface layer was used. The recorded height above land surface of the surveyed HWM was added to the DEM land-surface elevation at that point. This created a new water-surface elevation value to be used with the Topo-to-Raster interpolation method. The product of this method is called the DEM-derived inundation layer. DEM-derived and HWM-derived inundation layers were created for each reach, are displayed in the figures, and are provided in a USGS ScienceBase data release (Watson and Cauller, 2017 https://doi.org/10.5066/F76T0K4K).

The flood-inundation maps should not be used for navigation or regulatory, permitting, or other legal purposes. The USGS provides these maps "as is" for a quick reference, emergency planning tool but assumes no legal liability or responsibility resulting from the use of this information. These maps are only depicting the June 2016 event and may not be representative of other flooding conditions.

Peak-Flow Data Evaluation

Flood magnitude and frequency were determined from annual peak streamflows measured at 18 USGS streamflow-gaging stations. Streamflow-gaging stations were selected for inclusion in the study if at least one of the following criteria was met: (1) the magnitude of instantaneous peak discharge recorded at the station and associated with the June 2016 flooding, as measured, was one of the five largest peak streamflow magnitudes recorded at the site over the period of record; and (2) the measured water level at the streamflow-gaging station associated with the June 2016 flooding exceeded the NWS major flood stage for the site. Prior to analysis of flood frequency, peak-flow measurements from each streamflow-gaging station, collected during each site's period of record were plotted in station-specific scatter plots, and each scatter plot was visually checked for evidence of trends. Summary statistics were generated for each of these datasets along with additional statistics useful for identifying trends in data and monotonic, non-monotonic, linear, and non-linear correlations, including (1) Kendall's Tau, (2) an index of Kendall's trend probability, and (3) Spearman's rho (Helsel and Hirsch, 2002). Other statistical analyses performed prior to calculating peak-flow discharges include (4) calculating and plotting a linear regression of each dataset with time, (5) plotting residuals to help identify any significant correlation with time and any negative or positive autocorrelation, and (6) performing runs tests to identify any significantly non-linear change over time.

The results of these statistical tests were summarized for each candidate dataset and used to determine the degree of significant autocorrelation within the data on each candidate site. If no significant trend was evident at a 0.05 confidence level ($p = 0.05$), all data at the site were analyzed as part of the study pool. If a significant trend was evident in the dataset for a candidate site, the trend in the data was further evaluated to determine whether (1) the trend could be directly attributed to a causal factor or (2) the trend produced values that exceed those normally expected from a random sample. If the trend could not be directly attributed to a causal factor or trend values ranged within the bounds of expected statistical variation, then the trend was considered non-problematic, and no efforts were made to compensate for it by adjusting the station dataset. If the trend could be attributed to a causal factor or trend values were determined to range outside the bounds of expected statistical variation, then several methods to evaluate the dataset and remove the trend were considered. These methods included (1) testing the dataset against an annual precipitation time series to identify any correlation with annual precipitation; (2) sampling from the dataset, then re-evaluating the autocorrelation of the sample; (3) grouping the data into alternate time periods and computing a summary statistic for the period, such as a time-weighted mean or median; and (4) removing the site and dataset from the pool of sites to be analyzed. If trends persisted in the revised dataset, then the candidate site and dataset would be removed from consideration as a possible study site.

One of the 18 datasets in the study could not be effectively analyzed because too few data points were available from which to make meaningful comparisons. Six of the 18 datasets in the study could not be analyzed as a result of excessively regulated flow. No statistical trends were identified in the remaining 11 datasets. Nine of the datasets in the study contained intervals of missing data when streamgages were not operating. No censoring of data was required because of any peak-flow measurements below the streamgage base.

Flood-Frequency Analysis

Log-Pearson Type III adjusted flood-frequency analyses of data from each of the streamflow-gaging stations were used to determine peak flows at each site. The Log-Pearson Type III analyses were performed using the program PeakFQ (Veilleux and others, 2014; Flynn and others, 2006) and following methods outlined in the revised Bulletin 17B and draft Bulletin 17C of the Hydrology Subcommittee of the Interagency Advisory Committee on Water Data (Interagency Advisory Committee on Water Data, 1982). These two methods of analysis involve calculating expected moments of data and fitting a Pearson Type III frequency distribution to the logarithms of annual peak flows and are recommended for use by all Federal agencies for determining flood frequency. Major steps performed as part of this process are summarized below.

1. Systematic-Record Analysis. An analysis of the systematic record of data collected at each selected streamflow-gaging station was performed to compute the mean, standard deviation, and coefficient of skewness (mean X, S, and G, respectively) of the common logarithms of the annual peak flows.

2. Outlier Tests. Peaks that departed substantially from the trend of the remaining peaks were tested as possible outliers. Adjustments of the initial frequency curve involved detecting and accounting for high and low outliers. An iterative sequence of tests and adjustments was made to each initial frequency curve to compensate for any outlier values. The order of this sequence of adjustments was dependent on the station skew coefficient, G, as computed in the systematic-record analysis.

3. Historical-Record Adjustment. Recalculation of the statistics of the above-base peaks was performed after detection of outliers or historical information such as historical peaks, as specified in Appendix 6 of Bulletin 17B (Interagency Advisory Committee on Water Data, 1982). This historical adjustment filled in the ungaged part of the historical period in each record with an appropriate number of replications of the below-historical threshold streamflow part of the systematic record.

4. Conditional-Probability Adjustment. After the peak-streamflow frequency curve parameters were determined, the historically weighted frequency curve was tabulated. If no low outliers, zero flows, or below-gage base peaks were present, Pearson Type III standardized ordinates for the desired skew coefficient and probability were determined, and the logarithmic frequency curve ordinates were computed. When peaks below the flood base were present, a conditional frequency curve was determined describing only those peaks above the base. Then, a conditional probability adjustment was made to account for the fraction of the population below the flood base.

5. Computation of Weighted Skew Coefficient. The station skew coefficient reflects the average of the cubed deviations from the sample mean and is highly sensitive to the observations in both the upper and lower tails of the sample. The station skew coefficient was combined with the generalized skew, which is a skew coefficient representative of neighboring stations, in a weighted average coefficient that is more accurate than either of its constituents.

6. Expected-Probability Adjustment. The expected probability frequency curve and a set of upper and lower confidence limits were computed. These computations aid the interpretation of the principal, historically weighted frequency curve calculated in the conditional-probability adjustment.

Fitting the Log-Pearson Type III frequency distribution to the logarithms of the annual peak flows required the calculation of the mean, standard deviation, and skew coefficient of the logarithms of the annual peak-flow series. The mean, standard deviation, and skew coefficient describe the midpoint, slope, and curvature, respectively, of the peak-flow frequency curve. Identifying expected moments of peak-flow data required iterative processes known collectively as the Expected Moments Algorithm (EMA).

Annual exceedance probabilities (AEPs), the reciprocals of which are recurrence intervals, may be expressed as fractions (or percentages) that indicate the likelihood that a particular peak flow may occur. An annual exceedance probability of 1 indicates a 1/1 (or 100-percent) chance of a particular flow, whereas an annual exceedance probability of 0.10 indicates a 1/10 (or 10-percent) chance of a particular peak flow. Using this terminology, a particular flood-frequency AEP may be termed a P-percent chance flow where P is the probability. Estimates of the annual peak-flow probabilities were computed with program PeakFQ by inserting the three statistics of the frequency distribution into the following equation:

$$X = X_{bar} + KS \quad (1)$$

where

X is the logarithm of the magnitude of the P-percent chance discharge, in cubic feet per second;

X_{bar} is the mean of the logarithms of the annual peak streamflows;

K is the integration factor based on the skew of the logarithms and the given P-percent chance as tabulated in Bulletin 17B; and

S is the standard deviation of the logarithms and a measure of the variation of the peaks about the mean.

Completion of this analytical process resulted in peak-flow frequency estimates. These estimates are based on weighting of the streamflow-gaging station skew and the generalized skew as identified in Plate I of Bulletin 17B (Interagency Advisory Committee on Water Data, 1982).

Flood Probabilities of Peak Streamflows

An AEP is determined from the measured annual peak streamflow data for a streamflow-gaging station collected over the station's period of record. An annual peak streamflow is the maximum instantaneous streamflow measured at a streamflow-gaging station during the water year (October 1 of a given year through September 30 of the following year). Because more data spanning longer periods of time are available, streamflow-gaging stations with longer annual peak streamflow records are the most reliable for the estimation of AEP. An AEP of 0.01 means there is a 1-percent chance that

a measured peak streamflow may occur at a specific location in a given water year. Since recurrence interval is the reciprocal of AEP and may be determined by dividing AEP into 1, a probable recurrence interval of 100 years is equivalent to an AEP of 0.01 (that is, 1 divided by 0.01 = 100 years).

During the flood of June 2016, USGS hydrographers made streamflow measurements using direct (Rantz and others, 1982a; Turnipseed and Sauer, 2010) and indirect methods (Benson and Dalrymple, 1967; Rantz and others, 1982b) at continuous-record streamflow-gaging stations. Streamflow measurements were made to verify accuracies of stage–streamflow rating curves or to extend the stage–streamflow rating curve for a given streamflow-gaging station (Rantz and others, 1982a). The stage-streamflow rating curve for a given streamflow-gaging station is used to calculate instantaneous streamflow values for a given streamflow-gaging station, which in turn are used to populate USGS annual peak streamflow files.

For 11 of 18 streamflow-gaging stations, AEPs specific to each peak streamflow during the June 2016 flood, and streamflows associated with each AEP, were estimated using the EMA (Cohn and others, 1997, 2001) and methods described in Bulletin 17B (Interagency Advisory Committee on Water Data, 1982). Computations were made using the USGS program PeakFQ. Site information, exceedance probabilities, and summary statistics specific to the June 2016 flooding at 18 streamflow-gaging stations associated with the flooding in West Virginia are presented in table 3, and a more detailed summary of this information is found in appendix 3, table 3-1. Outputs from the USGS program PeakFQ provided estimates of 25 specific AEPs, ranging from 0.9950 to 0.0020, for each computation method. EMA and 17B AEP computations specific to each of 11 June 2016 flood peaks are listed in table 3 with their equivalent recurrence intervals. Computations for 7 of 18 streamflow-gaging stations were not possible because either too few systematic peaks were available for meaningful estimation as a result of streamflow regulation or too few systematic peaks were available for meaningful estimation as a result of a period of record that was too short (table 3).

Comparisons of AEP results were made using EMA and 17B estimation methods across three time intervals. Results of these 6 analyses for 15 of the 18 streamflow-gaging stations are listed in table 4, and an expanded summary of this information is found in appendix 3, table 3-2. Peak flow exceedance values are listed for each AEP in each of six categories of analysis.

1. Peak flows for the period of record through 2016 using the EMA method.
2. Peak flows for the period of record through 2016 using the Bulletin 17B method.
3. Peak flows for the period of record through 2015 using the EMA method.
4. Peak flows for the period of record through 2015 using the Bulletin 17B method.
5. Peak flows for the period of record through 1990 using the EMA method.
6. Peak flows for the period of record through 1990 using the Bulletin 17B method.

Comparisons of AEPs immediately before and immediately after June 2016 flooding may be made using the analyses in categories 1 through 4. Comparisons of AEPs immediately before and after June 2016 flooding with earlier AEP estimates available to FEMA may be made using the analyses in categories 1 through 6. Analyses 5 and 6 provide proxies for AEP estimates used in many FEMA studies conducted during 1971–90, for example Federal Emergency Management Agency (Federal Emergency Management Agency, 1990 and 1989). Each interval in categories 5 and 6 (period of record through 1990) encompasses all years associated with the AEP estimates identified as having been previously available to FEMA (table 4).

Changes in estimated peak-flow annual exceedance values from 1990 through 2016 are listed in table 5, and an expanded summary of this information is found in appendix 3, table 3-3. Percent increases and decreases in peak flows associated with AEPs in each of six categories of analysis are presented for 10 of 18 streamflow-gaging stations.

Percent changes in peak flows in lower frequency AEP categories (0.2000 through 0.0200) at eight selected streamflow-gaging stations from 1990 through 2016 are shown in figure 5. Increases since 1990 in peak-flow discharges associated with lower frequency (higher flow) AEP categories indicate larger peak-flow discharges are more common in 2016 at the selected streamflow-gaging stations than they were in 1990. Graphs illustrating 2016, 2015, and 1990 0.01 (100-year) AEPs at selected streamflow-gaging stations are presented in appendix 1.

Table 3. Site description, exceedance probabilities, equivalent recurrence intervals, and summary statistics for 18 streamflow-gaging stations associated with June 2016 flooding in West Virginia and southwestern Virginia.

[USGS, U.S. Geological Survey; NWIS, National Water Information System; yyyy-mm-dd, year-month-day; mi^2, square miles; ft, feet; ft^3/s, cubic feet per second; POR, period of record; EMA, Expected Moments Algorithm (Cohn and others, 2001); 17B, Bulletin 17B (Interagency Advisory Committee on Water Data, 1982); NA, not available; --, not determined; R, flow is regulated; This is a summary, see appendix 3, table 3-1 for additional detail]

USGS station number[1]	USGS station name	NWIS drainage area (mi^2)	Gage latitude (decimal degrees)	Gage longitude (decimals degrees)	June 2016 peak date (yyyy-mm-dd)	USGS gage height (ft)	USGS peak flow (ft^3/s)	Peak POR rank	Annual exceedance probability estimating method	Annual exceedance probability	Equivalent recurrence interval	Upper 95-percent confidence limit (equivalent recurrence interval)	Lower 95-percent confidence limit (equivalent recurrence interval)
02013000	Dunlap Creek near Covington, Virginia	162.00	37.803	-80.047	2016-06-23	16.66	23,600	2	EMA Hirsch-Stedinger Plotting Position	0.022	45	--	--
									17B Hirsch-Stedinger Plotting Position	0.023	44	--	--
									EMA Fitted Annual Frequency Curve	0.011	94	16	362
									17B Fitted Annual Frequency Curve	0.010	95	16	362
02013100	Jackson River Bl Dunlap Creek at Covington, Virginia	612.00	37.789	-80.001	2016-06-23	22.41	27,100R	4	EMA Hirsch-Stedinger Plotting Position	NA[2]	NA[2]	NA[2]	NA[2]
									17B Hirsch-Stedinger Plotting Position	NA[2]	NA[2]	NA[2]	NA[2]
									EMA Fitted Annual Frequency Curve	NA[2]	NA[2]	NA[2]	NA[2]
									17B Fitted Annual Frequency Curve	NA[2]	NA[2]	NA[2]	NA[2]
03183500	Greenbrier River at Alderson, West Virginia	1,364.00	37.724	-80.642	2016-06-24	22.00	80,700	3	EMA Hirsch-Stedinger Plotting Position	0.025	41	--	--
									17B Hirsch-Stedinger Plotting Position	0.025	41	--	--
									EMA Fitted Annual Frequency Curve	0.012	86	17	194
									17B Fitted Annual Frequency Curve	0.011	87	17	194
03184000	Greenbrier River at Hilldale, West Virginia	1,619.00	37.64	-80.805	2016-06-24	25.45	82,500	3	EMA Hirsch-Stedinger Plotting Position	0.037	27	--	--
									17B Hirsch-Stedinger Plotting Position	0.037	27	--	--
									EMA Fitted Annual Frequency Curve	0.016	64	12	130
									17B Fitted Annual Frequency Curve	0.016	64	12	130
03185400	New River at Thurmond, West Virginia	6,687.00	37.955	-81.077	2016-06-24	19.55	90,500R	5	EMA Hirsch-Stedinger Plotting Position	NA[2]	NA[2]	NA[2]	NA[2]
									17B Hirsch-Stedinger Plotting Position	NA[2]	NA[2]	NA[2]	NA[2]
									EMA Fitted Annual Frequency Curve	NA[2]	NA[2]	NA[2]	NA[2]
									17B Fitted Annual Frequency Curve	NA[2]	NA[2]	NA[2]	NA[2]
03186500	Williams River at Dyer, West Virginia	128.00	38.379	-80.484	2016-06-23	22.75	32,300	1	EMA Hirsch-Stedinger Plotting Position	0.011	88	--	--
									17B Hirsch-Stedinger Plotting Position	0.011	88	--	--
									EMA Fitted Annual Frequency Curve	0.005	202	24	3,437
									17B Fitted Annual Frequency Curve	0.005	202	24	3,437
03187000	Gauley River at Camden-on-Gauley, West Virginia	236.00	38.366	-80.601	2016-06-23	29.75	37,600	2	EMA Hirsch-Stedinger Plotting Position	0.018	57	--	--
									17B Hirsch-Stedinger Plotting Position	0.025	40	--	--
									EMA Fitted Annual Frequency Curve	0.013	75	15	325
									17B Fitted Annual Frequency Curve	0.012	86	14	320

Table 3. Site description, exceedance probabilities, equivalent recurrence intervals, and summary statistics for 18 streamflow-gaging stations associated with June 2016 flooding in West Virginia and southwestern Virginia.—Continued

[USGS, U.S. Geological Survey; NWIS, National Water Information System; yyyy-mm-dd, year-month-day; mi², square miles; ft, feet; ft³/s, cubic feet per second; POR, period of record; EMA, Expected Moments Algorithm (Cohn and others, 2001); 17B, Bulletin 17B (Interagency Advisory Committee on Water Data, 1982); NA, not available; --, not determined; R, flow is regulated; This is a summary, see appendix 3, table 3-1 for additional detail]

USGS station number[1]	USGS station name	NWIS drainage area (mi²)	Gage latitude (decimal degrees)	Gage longitude (decimals degrees)	June 2016 peak date (yyyy-mm-dd)	USGS gage height (ft)	USGS peak flow (ft³/s)	Peak POR rank	Annual exceedance probability estimating method	Annual exceedance probability	Equivalent recurrence interval	Upper 95-percent confidence limit (equivalent recurrence interval)	Lower 95-percent confidence limit (equivalent recurrence interval)
03187500	Cranberry River near Richwood, West Virginia	80.40	38.295	-80.527	2016-06-23	11.80	10,700	5	EMA Hirsch-Stedinger Plotting Position	0.079	13	--	--
									17B Hirsch-Stedinger Plotting Position	0.068	15	--	--
									EMA Fitted Annual Frequency Curve	0.050	20	6	36
									17B Fitted Annual Frequency Curve	0.046	22	7	52
03188900	Laurel Creek near Fenwick, West Virginia	32.70	38.164	-80.588	2016-06-23	18.23	15,000	1	EMA Hirsch-Stedinger Plotting Position	NA[3]	NA[3]	NA[3]	NA[3]
									17B Hirsch-Stedinger Plotting Position	NA[3]	NA[3]	NA[3]	NA[3]
									EMA Fitted Annual Frequency Curve	NA[3]	NA[3]	NA[3]	NA[3]
									17B Fitted Annual Frequency Curve	NA[3]	NA[3]	NA[3]	NA[3]
03189100	Gauley River near Craigsville, West Virginia	529.00	38.291	-80.641	2016-06-23	29.04	80,000	1	EMA Hirsch-Stedinger Plotting Position	0.010	100	--	--
									17B Hirsch-Stedinger Plotting Position	0.020	51	--	--
									EMA Fitted Annual Frequency Curve	0.009	109	15	2,054
									17B Fitted Annual Frequency Curve	0.011	91	15	2,054
03190000	Meadow River at Nallen, West Virginia	287.00	38.113	-80.876	2016-06-23	24.78	39,300	1	EMA Hirsch-Stedinger Plotting Position	0.018	56	--	--
									17B Hirsch-Stedinger Plotting Position	0.018	56	--	--
									EMA Fitted Annual Frequency Curve	0.002	500	15	2,173
									17B Fitted Annual Frequency Curve	0.002	500	15	2,173
03190100	Anglins Creek near Nallen, West Virginia	23.50	38.141	-80.837	2016-06-23	19.64	10,200	1	EMA Hirsch-Stedinger Plotting Position	0.052	19	--	--
									17B Hirsch-Stedinger Plotting Position	0.053	19	--	--
									EMA Fitted Annual Frequency Curve	0.024	42	5	711
									17B Fitted Annual Frequency Curve	0.023	43	5	711
03191500	Peters Creek near Lockwood, West Virginia	40.20	38.263	-81.023	2016-06-23	17.02	7,570	3	EMA Hirsch-Stedinger Plotting Position	0.064	16	--	--
									17B Hirsch-Stedinger Plotting Position	0.044	23	--	--
									EMA Fitted Annual Frequency Curve	0.048	21	7	73
									17B Fitted Annual Frequency Curve	0.034	29	8	184
03192000	Gauley River Above Belva, West Virginia	1,317.00	38.233	-81.181	2016-06-23	27.18	80,900R	4	EMA Hirsch-Stedinger Plotting Position	NA[2]	NA[2]	NA[2]	NA[2]
									17B Hirsch-Stedinger Plotting Position	NA[2]	NA[2]	NA[2]	NA[2]
									EMA Fitted Annual Frequency Curve	NA[2]	NA[2]	NA[2]	NA[2]
									17B Fitted Annual Frequency Curve	NA[2]	NA[2]	NA[2]	NA[2]

Table 3. Site description, exceedance probabilities, equivalent recurrence intervals, and summary statistics for 18 streamflow-gaging stations associated with June 2016 flooding in West Virginia and southwestern Virginia.—Continued

[USGS, U.S. Geological Survey; NWIS, National Water Information System; yyyy-mm-dd, year-month-day; mi^2, square miles; ft, feet; ft^3/s, cubic feet per second; POR, period of record; EMA, Expected Moments Algorithm (Cohn and others, 2001); 17B, Bulletin 17B (Interagency Advisory Committee on Water Data, 1982); NA, not available; --, not determined; R, flow is regulated; This is a summary, see appendix 3, table 3-1 for additional detail]

USGS station number[1]	USGS station name	NWIS drainage area (mi^2)	Gage latitude (decimal degrees)	Gage longitude (decimals degrees)	June 2016 peak date (yyyy-mm-dd)	USGS gage height (ft)	USGS peak flow (ft^3/s)	Peak POR rank	Annual exceedance probability estimating method	Annual exceedance probability	Equivalent recurrence interval	Upper 95-percent confidence limit (equivalent recurrence interval)	Lower 95-percent confidence limit (equivalent recurrence interval)
03194700	Elk River Below Webster Springs, West Virginia	266.00	38.597	-80.491	2016-06-23	17.82	34,600	2	EMA Hirsch-Stedinger Plotting Position	0.023	43	--	--
									17B Hirsch-Stedinger Plotting Position	0.023	43	--	--
									EMA Fitted Annual Frequency Curve	0.014	72	16	349
									17B Fitted Annual Frequency Curve	0.015	69	16	349
03196800	Elk River at Clay, West Virginia	992.00	38.461	-81.088	2016-06-23	30.30	63,100R	1	EMA Hirsch-Stedinger Plotting Position	NA[2]	NA[2]	NA[2]	NA[2]
									17B Hirsch-Stedinger Plotting Position	NA[2]	NA[2]	NA[2]	NA[2]
									EMA Fitted Annual Frequency Curve	NA[2]	NA[2]	NA[2]	NA[2]
									17B Fitted Annual Frequency Curve	NA[2]	NA[2]	NA[2]	NA[2]
03197000	Elk River at Queen Shoals, West Virginia	1,145.00	38.471	-81.284	2016-06-24	33.31	82,700R	1	EMA Hirsch-Stedinger Plotting Position	NA[2]	NA[2]	NA[2]	NA[2]
									17B Hirsch-Stedinger Plotting Position	NA[2]	NA[2]	NA[2]	NA[2]
									EMA Fitted Annual Frequency Curve	NA[2]	NA[2]	NA[2]	NA[2]
									17B Fitted Annual Frequency Curve	NA[2]	NA[2]	NA[2]	NA[2]
03198000	Kanawha River at Charleston, West Virginia	10,448.00	38.371	-81.702	2016-06-24	NA	163,000R	4	EMA Hirsch-Stedinger Plotting Position	NA[2]	NA[2]	NA[2]	NA[2]
									17B Hirsch-Stedinger Plotting Position	NA[2]	NA[2]	NA[2]	NA[2]
									EMA Fitted Annual Frequency Curve	NA[2]	NA[2]	NA[2]	NA[2]
									17B Fitted Annual Frequency Curve	NA[2]	NA[2]	NA[2]	NA[2]

[1]This is a list of the 18 sites that meet the following criteria: 1, instantaneous peak flow at site for event was the POR, or 2, instantaneous peak flow at site for event was in the top 5 of all peak flows, or 3, instantaneous peak flow at site for event was greater than the National Weather Service Major Flood Stage.

[2]Too few systematic peaks for meaningful estimation. Flow is regulated.

[3]Too few systematic peaks for meaningful estimation. Period of record is too short.

Table 4. Summary of results from six analyses estimating peakflow annual exceedance probabilities at 18 streamflow-gaging stations associated with June 2016 flooding in West Virginia and southwestern Virginia.

[USGS, U.S. Geological Survey; ft³/s, cubic feet per second; yrs, years; EMA, Expected Moments Algorithm method; 17B, Bulletin 17B method; --, not determined; This is a summary, see appendix 3, table 3-2 for additional detail]

USGS station number	USGS station name	Analysis method	Return period (yrs)										
			2	2.5	5	10	20	25	40	50	100	200	500
			Exceedance probability										
			0.500	0.400	0.200	0.100	0.050	0.040	0.025	0.020	0.010	0.005	0.002
			Peak Flow Exceedance Value (ft³/s)										
02013000	Dunlap Creek near Covington, Virginia	EMA through 2016	5,275	6,146	8,861	11,770	14,970	16,080	18,540	19,780	23,910	28,530	35,470
02013000	Dunlap Creek near Covington, Virginia	17B through 2016	5,279	6,151	8,864	11,760	14,950	16,050	18,500	19,720	23,820	28,390	35,240
02013000	Dunlap Creek near Covington, Virginia	EMA through 2015	5,227	6,060	8,605	11,260	14,110	15,080	17,210	18,270	21,770	25,610	31,250
02013000	Dunlap Creek near Covington, Virginia	17B through 2015	5,231	6,065	8,607	11,250	14,090	15,050	17,170	18,230	21,690	25,490	31,050
02013000	Dunlap Creek near Covington, Virginia	EMA through 1990	5,054	5,849	8,275	10,800	13,510	14,430	16,470	17,470	20,800	24,450	29,810
02013000	Dunlap Creek near Covington, Virginia	17B through 1990	5,072	5,869	8,285	10,780	13,430	14,330	16,300	17,280	20,480	23,960	29,040
02013100	Jackson River below Dunlap Creek at Covington, Virginia	EMA through 2016	--	--	--	--	--	--	--	--	--	--	--
02013100	Jackson River below Dunlap Creek at Covington, Virginia	17B through 2016	--	--	--	--	--	--	--	--	--	--	--
02013100	Jackson River below Dunlap Creek at Covington, Virginia	EMA through 2015	--	--	--	--	--	--	--	--	--	--	--
02013100	Jackson River below Dunlap Creek at Covington, Virginia	17B through 2015	--	--	--	--	--	--	--	--	--	--	--
02013100	Jackson River below Dunlap Creek at Covington, Virginia	EMA through 1990	--	--	--	--	--	--	--	--	--	--	--
02013100	Jackson River below Dunlap Creek at Covington, Virginia	17B through 1990	--	--	--	--	--	--	--	--	--	--	--
03183500	Greenbrier River at Alderson, West Virginia	EMA through 2016	34,000	37,500	47,010	55,540	63,670	66,240	71,600	74,140	81,990	89,840	100,300
03183500	Greenbrier River at Alderson, West Virginia	17B through 2016	34,000	37,510	47,010	55,540	63,640	66,200	71,550	74,080	81,900	89,730	100,100
03183500	Greenbrier River at Alderson, West Virginia	EMA through 2015	33,840	37,260	46,440	54,570	62,220	64,620	69,610	71,960	79,180	86,340	95,780
03183500	Greenbrier River at Alderson, West Virginia	17B through 2015	33,840	37,260	46,440	54,570	62,220	64,620	69,610	71,960	79,180	86,340	95,780
03183500	Greenbrier River at Alderson, West Virginia	EMA through 1990	33,670	37,180	46,540	54,750	62,410	64,800	69,740	72,050	79,130	86,090	95,180
03183500	Greenbrier River at Alderson, West Virginia	17B through 1990	33,670	37,180	46,530	54,750	62,410	64,800	69,740	72,050	79,130	86,090	95,180
03184000	Greenbrier River at Hilldale, West Virginia	EMA through 2016	37,000	40,390	49,800	58,570	67,210	70,010	75,940	78,780	87,780	97,080	109,900
03184000	Greenbrier River at Hilldale, West Virginia	17B through 2016	37,000	40,390	49,800	58,570	67,200	69,990	75,920	78,760	87,750	97,030	109,800
03184000	Greenbrier River at Hilldale, West Virginia	EMA through 2015	36,750	40,020	48,980	57,190	65,160	67,720	73,120	75,690	83,780	92,050	103,300
03184000	Greenbrier River at Hilldale, West Virginia	17B through 2015	36,750	40,020	48,980	57,190	65,160	67,720	73,120	75,690	83,780	92,050	103,300
03184000	Greenbrier River at Hilldale, West Virginia	EMA through 1990	36,200	39,470	48,400	56,540	64,400	66,900	72,180	74,700	82,560	90,550	101,400
03184000	Greenbrier River at Hilldale, West Virginia	17B through 1990	36,200	39,470	48,400	56,540	64,400	66,900	72,180	74,700	82,560	90,550	101,400
03185400	New River at Thurmond, West Virginia	EMA through 2016	--	--	--	--	--	--	--	--	--	--	--
03185400	New River at Thurmond, West Virginia	17B through 2016	--	--	--	--	--	--	--	--	--	--	--
03185400	New River at Thurmond, West Virginia	EMA through 2015	--	--	--	--	--	--	--	--	--	--	--
03185400	New River at Thurmond, West Virginia	17B through 2015	--	--	--	--	--	--	--	--	--	--	--
03185400	New River at Thurmond, West Virginia	EMA through 1990	--	--	--	--	--	--	--	--	--	--	--
03185400	New River at Thurmond, West Virginia	17B through 1990	--	--	--	--	--	--	--	--	--	--	--
03186500	Williams River at Dyer, West Virginia	EMA through 2016	8,103	9,075	12,020	15,100	18,420	19,560	22,090	23,350	27,540	32,210	39,210
03186500	Williams River at Dyer, West Virginia	17B through 2016	8,104	9,076	12,020	15,090	18,420	19,560	22,080	23,330	27,520	32,180	39,160
03186500	Williams River at Dyer, West Virginia	EMA through 2015	8,070	8,986	11,680	14,370	17,190	18,130	20,190	21,200	24,500	28,070	33,250
03186500	Williams River at Dyer, West Virginia	17B through 2015	8,070	8,986	11,680	14,370	17,190	18,130	20,190	21,200	24,500	28,070	33,250
03186500	Williams River at Dyer, West Virginia	EMA through 1990	7,534	8,394	10,970	13,620	16,440	17,400	19,510	20,560	24,030	27,850	33,510
03186500	Williams River at Dyer, West Virginia	17B through 1990	7,534	8,394	10,970	13,620	16,440	17,400	19,510	20,560	24,030	27,850	33,510

Table 4. Summary of results from six analyses estimating peakflow annual exceedance probabilities at 18 streamflow-gaging stations associated with June 2016 flooding in West Virginia and southwestern Virginia.—Continued

[USGS, U.S. Geological Survey; ft^3/s, cubic feet per second; yrs, years; EMA, Expected Moments Algorithm method; 17B, Bulletin 17B method; --, not determined; This is a summary, see appendix 3, table 3-2 for additional detail]

USGS station number	USGS station name	Analysis method	Return period (yrs)										
			2	2.5	5	10	20	25	40	50	100	200	500
			Exceedance probability										
			0.500	0.400	0.200	0.100	0.050	0.040	0.025	0.020	0.010	0.005	0.002
			Peak Flow Exceedance Value (ft^3/s)										
03187000	Gauley River at Camden-on-Gauley, West Virginia	EMA through 2016	11,420	12,880	17,280	21,810	26,670	28,320	31,950	33,760	39,730	46,300	56,030
03187000	Gauley River at Camden-on-Gauley, West Virginia	17B through 2016	11,300	12,720	16,990	21,380	26,060	27,650	31,150	32,880	38,610	44,900	54,200
03187000	Gauley River at Camden-on-Gauley, West Virginia	EMA through 2015	11,310	12,700	16,850	21,030	25,440	26,920	30,160	31,760	37,000	42,690	50,980
03187000	Gauley River at Camden-on-Gauley, West Virginia	17B through 2015	11,200	12,550	16,540	20,540	24,720	26,130	29,180	30,690	35,600	40,900	48,600
03187000	Gauley River at Camden-on-Gauley, West Virginia	EMA through 1990	11,180	12,560	16,700	20,900	25,360	26,870	30,160	31,790	37,150	43,000	51,580
03187000	Gauley River at Camden-on-Gauley, West Virginia	17B through 1990	11,050	12,390	16,350	20,330	24,530	25,940	29,020	30,540	35,520	40,920	48,780
03187500	Cranberry River near Richwood, West Virginia	EMA through 2016	4,989	5,570	7,265	8,945	10,690	11,270	12,530	13,140	15,150	17,290	20,380
03187500	Cranberry River near Richwood, West Virginia	17B through 2016	4,938	5,505	7,157	8,792	10,490	11,050	12,270	12,870	14,820	16,910	19,910
03187500	Cranberry River near Richwood, West Virginia	EMA through 2015	4,939	5,512	7,193	8,870	10,620	11,200	12,480	13,100	15,140	17,340	20,520
03187500	Cranberry River near Richwood, West Virginia	17B through 2015	4,872	5,420	7,012	8,584	10,210	10,750	11,920	12,500	14,360	16,350	19,210
03187500	Cranberry River near Richwood, West Virginia	EMA through 1990	4,601	5,158	6,846	8,598	10,490	11,140	12,570	13,280	15,650	18,280	22,220
03187500	Cranberry River near Richwood, West Virginia	17B through 1990	4,481	4,990	6,509	8,059	9,708	10,270	11,490	12,100	14,110	16,300	19,550
03188900	Laurel Creek near Fenwick, West Virginia	EMA through 2016	--	--	--	--	--	--	--	--	--	--	--
03188900	Laurel Creek near Fenwick, West Virginia	17B through 2016	--	--	--	--	--	--	--	--	--	--	--
03188900	Laurel Creek near Fenwick, West Virginia	EMA through 2015	--	--	--	--	--	--	--	--	--	--	--
03188900	Laurel Creek near Fenwick, West Virginia	17B through 2015	--	--	--	--	--	--	--	--	--	--	--
03188900	Laurel Creek near Fenwick, West Virginia	EMA through 1990	--	--	--	--	--	--	--	--	--	--	--
03188900	Laurel Creek near Fenwick, West Virginia	17B through 1990	--	--	--	--	--	--	--	--	--	--	--
03189100	Gauley River near Craigsville, West Virginia	EMA through 2016	26,180	29,270	38,190	46,920	55,840	58,790	65,160	68,260	78,260	88,870	103,900
03189100	Gauley River near Craigsville, West Virginia	17B through 2016	26,070	29,200	38,350	47,440	56,880	60,030	66,860	70,210	81,090	92,770	109,600
03189100	Gauley River near Craigsville, West Virginia	EMA through 2015	25,990	28,920	37,230	45,120	53,000	55,560	61,040	63,680	72,080	80,820	92,960
03189100	Gauley River near Craigsville, West Virginia	17B through 2015	25,750	28,640	36,850	44,670	52,510	55,060	60,520	63,160	71,560	80,310	92,520
03189100	Gauley River near Craigsville, West Virginia	EMA through 1990	25,160	28,190	36,850	45,140	53,470	56,190	62,000	64,810	73,770	83,110	96,120
03189100	Gauley River near Craigsville, West Virginia	17B through 1990	24,840	27,830	36,300	44,390	52,470	55,110	60,730	63,450	72,070	81,040	93,490
03190000	Meadow River at Nallen, West Virginia	EMA through 2016	5,876	6,535	8,626	10,930	13,560	14,490	16,590	17,660	21,350	25,630	32,380
03190000	Meadow River at Nallen, West Virginia	17B through 2016	5,876	6,535	8,626	10,930	13,560	14,490	16,590	17,660	21,350	25,630	32,380
03190000	Meadow River at Nallen, West Virginia	EMA through 2015	6,000	6,538	7,999	9,321	10,590	11,000	11,850	12,250	13,510	14,780	16,500
03190000	Meadow River at Nallen, West Virginia	17B through 2015	6,000	6,538	7,999	9,321	10,590	11,000	11,850	12,250	13,510	14,780	16,500
03190000	Meadow River at Nallen, West Virginia	EMA through 1990	5,977	6,523	8,014	9,374	10,690	11,110	12,000	12,420	13,740	15,080	16,900
03190000	Meadow River at Nallen, West Virginia	17B through 1990	5,981	6,527	8,016	9,371	10,680	11,100	11,980	12,390	13,700	15,030	16,830
03190100	Anglins Creek near Nallen, West Virginia	EMA through 2016	1,711	2,084	3,410	5,090	7,238	8,050	9,982	11,020	14,780	19,540	27,770
03190100	Anglins Creek near Nallen, West Virginia	17B through 2016	1,718	2,092	3,417	5,083	7,201	7,998	9,888	10,900	14,550	19,150	27,030
03190100	Anglins Creek near Nallen, West Virginia	EMA through 2015	1,583	1,874	2,839	3,956	5,275	5,750	6,841	7,405	9,369	11,690	15,430
03190100	Anglins Creek near Nallen, West Virginia	17B through 2015	1,583	1,874	2,839	3,956	5,275	5,750	6,841	7,405	9,369	11,690	15,430
03190100	Anglins Creek near Nallen, West Virginia	EMA through 1990	--	--	--	--	--	--	--	--	--	--	--
03190100	Anglins Creek near Nallen, West Virginia	17B through 1990	--	--	--	--	--	--	--	--	--	--	--

Table 4. Summary of results from six analyses estimating peakflow annual exceedance probabilities at 18 streamflow-gaging stations associated with June 2016 flooding in West Virginia and southwestern Virginia.—Continued

[USGS, U.S. Geological Survey; ft³/s, cubic feet per second; yrs, years; EMA, Expected Moments Algorithm method; 17B, Bulletin 17B method; --, not determined; This is a summary, see appendix 3, table 3-2 for additional detail]

USGS station number	USGS station name	Analysis method	Return period (yrs)										
			2	2.5	5	10	20	25	40	50	100	200	500
			Exceedance probability										
			0.500	0.400	0.200	0.100	0.050	0.040	0.025	0.020	0.010	0.005	0.002
			Peak Flow Exceedance Value (ft³/s)										
03191500	Peters Creek near Lockwood, West Virginia	EMA through 2016	2,504	2,933	4,297	5,791	7,474	8,062	9,384	10,050	12,320	14,890	18,840
03191500	Peters Creek near Lockwood, West Virginia	17B through 2016	2,451	2,846	4,056	5,326	6,703	7,174	8,213	8,731	10,450	12,340	15,130
03191500	Peters Creek near Lockwood, West Virginia	EMA through 2015	2,443	2,851	4,142	5,548	7,126	7,677	8,911	9,535	11,640	14,040	17,700
03191500	Peters Creek near Lockwood, West Virginia	17B through 2015	2,396	2,768	3,896	5,065	6,316	6,740	7,673	8,135	9,656	11,320	13,750
03191500	Peters Creek near Lockwood, West Virginia	EMA through 1990	2,443	2,801	3,871	4,954	6,093	6,476	7,309	7,719	9,057	10,500	12,580
03191500	Peters Creek near Lockwood, West Virginia	17B through 1990	2,443	2,801	3,871	4,954	6,093	6,476	7,309	7,719	9,057	10,500	12,580
03192000	Gauley River above Belva, West Virginia	EMA through 2016	--	--	--	--	--	--	--	--	--	--	--
03192000	Gauley River above Belva, West Virginia	17B through 2016	--	--	--	--	--	--	--	--	--	--	--
03192000	Gauley River above Belva, West Virginia	EMA through 2015	--	--	--	--	--	--	--	--	--	--	--
03192000	Gauley River above Belva, West Virginia	17B through 2015	--	--	--	--	--	--	--	--	--	--	--
03192000	Gauley River above Belva, West Virginia	EMA through 1990	--	--	--	--	--	--	--	--	--	--	--
03192000	Gauley River above Belva, West Virginia	17B through 1990	--	--	--	--	--	--	--	--	--	--	--
03194700	Elk River below Webster Springs, West Virginia	EMA through 2016	12,030	13,370	17,340	21,340	25,570	26,990	30,100	31,640	36,690	42,180	50,230
03194700	Elk River below Webster Springs, West Virginia	17B through 2016	12,000	13,340	17,320	21,360	25,650	27,100	30,270	31,850	37,030	42,690	51,030
03194700	Elk River below Webster Springs, West Virginia	EMA through 2015	11,920	13,200	16,960	20,700	24,590	25,890	28,730	30,120	34,660	39,550	46,640
03194700	Elk River below Webster Springs, West Virginia	17B through 2015	11,900	13,180	16,950	20,710	24,650	25,970	28,840	30,260	34,890	39,900	47,180
03194700	Elk River below Webster Springs, West Virginia	EMA through 1990	11,040	12,210	15,730	19,330	23,180	24,480	27,360	28,780	33,500	38,680	46,370
03194700	Elk River below Webster Springs, West Virginia	17B through 1990	10,940	12,110	15,660	19,380	23,440	24,840	27,930	29,490	34,680	40,500	49,300
03196800	Elk River at Clay, West Virginia	EMA through 2016	--	--	--	--	--	--	--	--	--	--	--
03196800	Elk River at Clay, West Virginia	17B through 2016	--	--	--	--	--	--	--	--	--	--	--
03196800	Elk River at Clay, West Virginia	EMA through 2015	--	--	--	--	--	--	--	--	--	--	--
03196800	Elk River at Clay, West Virginia	17B through 2015	--	--	--	--	--	--	--	--	--	--	--
03196800	Elk River at Clay, West Virginia	EMA through 1990	--	--	--	--	--	--	--	--	--	--	--
03196800	Elk River at Clay, West Virginia	17B through 1990	--	--	--	--	--	--	--	--	--	--	--
03197000	Elk River at Queen Shoals, West Virginia	EMA through 2016	--	--	--	--	--	--	--	--	--	--	--
03197000	Elk River at Queen Shoals, West Virginia	17B through 2016	--	--	--	--	--	--	--	--	--	--	--
03197000	Elk River at Queen Shoals, West Virginia	EMA through 2015	--	--	--	--	--	--	--	--	--	--	--
03197000	Elk River at Queen Shoals, West Virginia	17B through 2015	--	--	--	--	--	--	--	--	--	--	--
03197000	Elk River at Queen Shoals, West Virginia	EMA through 1990	--	--	--	--	--	--	--	--	--	--	--
03197000	Elk River at Queen Shoals, West Virginia	17B through 1990	--	--	--	--	--	--	--	--	--	--	--
03198000	Kanawha River at Charleston, West Virginia	EMA through 2016	--	--	--	--	--	--	--	--	--	--	--
03198000	Kanawha River at Charleston, West Virginia	17B through 2016	--	--	--	--	--	--	--	--	--	--	--
03198000	Kanawha River at Charleston, West Virginia	EMA through 2015	--	--	--	--	--	--	--	--	--	--	--
03198000	Kanawha River at Charleston, West Virginia	17B through 2015	--	--	--	--	--	--	--	--	--	--	--
03198000	Kanawha River at Charleston, West Virginia	EMA through 1990	--	--	--	--	--	--	--	--	--	--	--
03198000	Kanawha River at Charleston, West Virginia	17B through 1990	--	--	--	--	--	--	--	--	--	--	--

Table 5. Summary of percent changes since 1990 in estimated peak-flow annual exceedance probabilities from six analyses using two methods for 18 streamflow-gaging stations associated with June 2016 flooding in West Virginia and southwestern Virginia for the period of record through 1990, 2015, and 2016.

[USGS, U.S. Geological Survey; yrs, years; EMA, Expected Moments Algorithm method; 17B, Bulletin 17B method; --, not determined; This is a summary, see appendix 3, table 3-3 for additional detail]

USGS station number	USGS station name	Analysis method	Return period (yrs)										
			2	2.5	5	10	20	25	40	50	100	200	500
			Exceedance probability										
			0.500	0.400	0.200	0.100	0.050	0.040	0.025	0.020	0.010	0.005	0.002
			Change in peak flow exceedance values since 1990 (percent)										
02013000	Dunlap Creek near Covington, Virginia	EMA through 2016	4	5	7	9	11	11	13	13	15	17	19
02013000	Dunlap Creek near Covington, Virginia	17B through 2016	4	5	7	9	11	12	13	14	16	18	21
02013000	Dunlap Creek near Covington, Virginia	EMA through 2015	3	4	4	4	4	5	4	5	5	5	5
02013000	Dunlap Creek near Covington, Virginia	17B through 2015	3	3	4	4	5	5	5	5	6	6	7
02013000	Dunlap Creek near Covington, Virginia	EMA through 1990	0	0	0	0	0	0	0	0	0	0	0
02013000	Dunlap Creek near Covington, Virginia	17B through 1990	0	0	0	0	0	0	0	0	0	0	0
02013100	Jackson River below Dunlap Creek at Covington, Virginia	EMA through 2016	--	--	--	--	--	--	--	--	--	--	--
02013100	Jackson River below Dunlap Creek at Covington, Virginia	17B through 2016	--	--	--	--	--	--	--	--	--	--	--
02013100	Jackson River below Dunlap Creek at Covington, Virginia	EMA through 2015	--	--	--	--	--	--	--	--	--	--	--
02013100	Jackson River below Dunlap Creek at Covington, Virginia	17B through 2015	--	--	--	--	--	--	--	--	--	--	--
02013100	Jackson River below Dunlap Creek at Covington, Virginia	EMA through 1990	--	--	--	--	--	--	--	--	--	--	--
02013100	Jackson River below Dunlap Creek at Covington, Virginia	17B through 1990	--	--	--	--	--	--	--	--	--	--	--
03183500	Greenbrier River at Alderson, West Virginia	EMA through 2016	1	1	1	1	2	2	3	3	4	4	5
03183500	Greenbrier River at Alderson, West Virginia	17B through 2016	1	1	1	1	2	2	3	3	4	4	5
03183500	Greenbrier River at Alderson, West Virginia	EMA through 2015	1	0	-0	-0	-0	-0	-0	-0	0	0	1
03183500	Greenbrier River at Alderson, West Virginia	17B through 2015	1	0	-0	-0	-0	-0	-0	-0	0	0	1
03183500	Greenbrier River at Alderson, West Virginia	EMA through 1990	0	0	0	0	0	0	0	0	0	0	0
03183500	Greenbrier River at Alderson, West Virginia	17B through 1990	0	0	0	0	0	0	0	0	0	0	0
03184000	Greenbrier River at Hilldale, West Virginia	EMA through 2016	2	2	3	4	4	5	5	5	6	7	8
03184000	Greenbrier River at Hilldale, West Virginia	17B through 2016	2	2	3	4	4	5	5	5	6	7	8
03184000	Greenbrier River at Hilldale, West Virginia	EMA through 2015	2	1	1	1	1	1	1	1	1	2	2
03184000	Greenbrier River at Hilldale, West Virginia	17B through 2015	2	1	1	1	1	1	1	1	1	2	2
03184000	Greenbrier River at Hilldale, West Virginia	EMA through 1990	0	0	0	0	0	0	0	0	0	0	0
03184000	Greenbrier River at Hilldale, West Virginia	17B through 1990	0	0	0	0	0	0	0	0	0	0	0
03185400	New River at Thurmond, West Virginia	EMA through 2016	--	--	--	--	--	--	--	--	--	--	--
03185400	New River at Thurmond, West Virginia	17B through 2016	--	--	--	--	--	--	--	--	--	--	--
03185400	New River at Thurmond, West Virginia	EMA through 2015	--	--	--	--	--	--	--	--	--	--	--
03185400	New River at Thurmond, West Virginia	17B through 2015	--	--	--	--	--	--	--	--	--	--	--
03185400	New River at Thurmond, West Virginia	EMA through 1990	--	--	--	--	--	--	--	--	--	--	--
03185400	New River at Thurmond, West Virginia	17B through 1990	--	--	--	--	--	--	--	--	--	--	--

Table 5. Summary of percent changes since 1990 in estimated peak-flow annual exceedance probabilities from six analyses using two methods for 18 streamflow-gaging stations associated with June 2016 flooding in West Virginia and southwestern Virginia for the period of record through 1990, 2015, and 2016.—Continued

[USGS, U.S. Geological Survey; yrs, years; EMA, Expected Moments Algorithm method; 17B, Bulletin 17B method; --, not determined; This is a summary, see appendix 3, table 3-3 for additional detail]

USGS station number	USGS station name	Analysis method	Return period (yrs)										
			2	2.5	5	10	20	25	40	50	100	200	500
			Exceedance probability										
			0.500	0.400	0.200	0.100	0.050	0.040	0.025	0.020	0.010	0.005	0.002
			Change in peak flow exceedance values since 1990 (percent)										
03186500	Williams River at Dyer, West Virginia	EMA through 2016	8	8	10	11	12	12	13	14	15	16	17
03186500	Williams River at Dyer, West Virginia	17B through 2016	8	8	10	11	12	12	13	13	15	16	17
03186500	Williams River at Dyer, West Virginia	EMA through 2015	7	7	6	6	5	4	3	3	2	1	-1
03186500	Williams River at Dyer, West Virginia	17B through 2015	7	7	6	6	5	4	3	3	2	1	-1
03186500	Williams River at Dyer, West Virginia	EMA through 1990	0	0	0	0	0	0	0	0	0	0	0
03186500	Williams River at Dyer, West Virginia	17B through 1990	0	0	0	0	0	0	0	0	0	0	0
03187000	Gauley River at Camden-on-Gauley, West Virginia	EMA through 2016	2	3	3	4	5	5	6	6	7	8	9
03187000	Gauley River at Camden-on-Gauley, West Virginia	17B through 2016	2	3	4	5	6	7	7	8	9	10	11
03187000	Gauley River at Camden-on-Gauley, West Virginia	EMA through 2015	1	1	1	1	0	0	0	-0	-0	-1	-1
03187000	Gauley River at Camden-on-Gauley, West Virginia	17B through 2015	1	1	1	1	1	1	1	0	0	-0	-0
03187000	Gauley River at Camden-on-Gauley, West Virginia	EMA through 1990	0	0	0	0	0	0	0	0	0	0	0
03187000	Gauley River at Camden-on-Gauley, West Virginia	17B through 1990	0	0	0	0	0	0	0	0	0	0	0
03187500	Cranberry River near Richwood, West Virginia	EMA through 2016	8	8	6	4	2	1	-0	-1	-3	-5	-8
03187500	Cranberry River near Richwood, West Virginia	17B through 2016	10	10	10	9	8	8	7	6	5	4	2
03187500	Cranberry River near Richwood, West Virginia	EMA through 2015	7	7	5	3	1	1	-1	-1	-3	-5	-8
03187500	Cranberry River near Richwood, West Virginia	17B through 2015	9	9	8	7	5	5	4	3	2	0	-2
03187500	Cranberry River near Richwood, West Virginia	EMA through 1990	0	0	0	0	0	0	0	0	0	0	0
03187500	Cranberry River near Richwood, West Virginia	17B through 1990	0	0	0	0	0	0	0	0	0	0	0
03188900	Laurel Creek near Fenwick, West Virginia	EMA through 2016	--	--	--	--	--	--	--	--	--	--	--
03188900	Laurel Creek near Fenwick, West Virginia	17B through 2016	--	--	--	--	--	--	--	--	--	--	--
03188900	Laurel Creek near Fenwick, West Virginia	EMA through 2015	--	--	--	--	--	--	--	--	--	--	--
03188900	Laurel Creek near Fenwick, West Virginia	17B through 2015	--	--	--	--	--	--	--	--	--	--	--
03188900	Laurel Creek near Fenwick, West Virginia	EMA through 1990	--	--	--	--	--	--	--	--	--	--	--
03188900	Laurel Creek near Fenwick, West Virginia	17B through 1990	--	--	--	--	--	--	--	--	--	--	--
03189100	Gauley River near Craigsville, West Virginia	EMA through 2016	4	4	4	4	4	5	5	5	6	7	8
03189100	Gauley River near Craigsville, West Virginia	17B through 2016	5	5	6	7	8	9	10	11	13	14	17
03189100	Gauley River near Craigsville, West Virginia	EMA through 2015	3	3	1	-0	-1	-1	-2	-2	-2	-3	-3
03189100	Gauley River near Craigsville, West Virginia	17B through 2015	4	3	2	1	0	-0	-0	-0	-1	-1	-1
03189100	Gauley River near Craigsville, West Virginia	EMA through 1990	0	0	0	0	0	0	0	0	0	0	0
03189100	Gauley River near Craigsville, West Virginia	17B through 1990	0	0	0	0	0	0	0	0	0	0	0

Table 5. Summary of percent changes since 1990 in estimated peak-flow annual exceedance probabilities from six analyses using two methods for 18 streamflow-gaging stations associated with June 2016 flooding in West Virginia and southwestern Virginia for the period of record through 1990, 2015, and 2016.—Continued

[USGS, U.S. Geological Survey; yrs, years; EMA, Expected Moments Algorithm method; 17B, Bulletin 17B method; --, not determined; This is a summary, see appendix 3, table 3-3 for additional detail]

USGS station number	USGS station name	Analysis method	Return period (yrs)										
			2	2.5	5	10	20	25	40	50	100	200	500
			Exceedance probability										
			0.500	0.400	0.200	0.100	0.050	0.040	0.025	0.020	0.010	0.005	0.002
			Change in peak flow exceedance values since 1990 (percent)										
03190000	Meadow River at Nallen, West Virginia	EMA through 2016	-2	0	8	17	27	30	38	42	55	70	92
03190000	Meadow River at Nallen, West Virginia	17B through 2016	-2	0	8	17	27	31	38	43	56	71	92
03190000	Meadow River at Nallen, West Virginia	EMA through 2015	0	0	-0	-1	-1	-1	-1	-1	-2	-2	-2
03190000	Meadow River at Nallen, West Virginia	17B through 2015	0	0	-0	-1	-1	-1	-1	-1	-1	-2	-2
03190000	Meadow River at Nallen, West Virginia	EMA through 1990	0	0	0	0	0	0	0	0	0	0	0
03190000	Meadow River at Nallen, West Virginia	17B through 1990	0	0	0	0	0	0	0	0	0	0	0
03190100	Anglins Creek near Nallen, West Virginia	EMA through 2016	--	--	--	--	--	--	--	--	--	--	--
03190100	Anglins Creek near Nallen, West Virginia	17B through 2016	--	--	--	--	--	--	--	--	--	--	--
03190100	Anglins Creek near Nallen, West Virginia	EMA through 2015	--	--	--	--	--	--	--	--	--	--	--
03190100	Anglins Creek near Nallen, West Virginia	17B through 2015	--	--	--	--	--	--	--	--	--	--	--
03190100	Anglins Creek near Nallen, West Virginia	EMA through 1990	--	--	--	--	--	--	--	--	--	--	--
03190100	Anglins Creek near Nallen, West Virginia	17B through 1990	--	--	--	--	--	--	--	--	--	--	--
03191500	Peters Creek near Lockwood, West Virginia	EMA through 2016	2	5	11	17	23	24	28	30	36	42	50
03191500	Peters Creek near Lockwood, West Virginia	17B through 2016	0	2	5	8	10	11	12	13	15	18	20
03191500	Peters Creek near Lockwood, West Virginia	EMA through 2015	0	2	7	12	17	19	22	24	29	34	41
03191500	Peters Creek near Lockwood, West Virginia	17B through 2015	-2	-1	1	2	4	4	5	5	7	8	9
03191500	Peters Creek near Lockwood, West Virginia	EMA through 1990	0	0	0	0	0	0	0	0	0	0	0
03191500	Peters Creek near Lockwood, West Virginia	17B through 1990	0	0	0	0	0	0	0	0	0	0	0
03192000	Gauley River above Belva, West Virginia	EMA through 2016	--	--	--	--	--	--	--	--	--	--	--
03192000	Gauley River above Belva, West Virginia	17B through 2016	--	--	--	--	--	--	--	--	--	--	--
03192000	Gauley River above Belva, West Virginia	EMA through 2015	--	--	--	--	--	--	--	--	--	--	--
03192000	Gauley River above Belva, West Virginia	17B through 2015	--	--	--	--	--	--	--	--	--	--	--
03192000	Gauley River above Belva, West Virginia	EMA through 1990	--	--	--	--	--	--	--	--	--	--	--
03192000	Gauley River above Belva, West Virginia	17B through 1990	--	--	--	--	--	--	--	--	--	--	--
03194700	Elk River below Webster Springs, West Virginia	EMA through 2016	9	10	10	10	10	10	10	10	10	9	8
03194700	Elk River below Webster Springs, West Virginia	17B through 2016	10	10	11	10	9	9	8	8	7	5	4
03194700	Elk River below Webster Springs, West Virginia	EMA through 2015	8	8	8	7	6	6	5	5	3	2	1
03194700	Elk River below Webster Springs, West Virginia	17B through 2015	9	9	8	7	5	5	3	3	1	-1	-4
03194700	Elk River below Webster Springs, West Virginia	EMA through 1990	0	0	0	0	0	0	0	0	0	0	0
03194700	Elk River below Webster Springs, West Virginia	17B through 1990	0	0	0	0	0	0	0	0	0	0	0

Table 5. Summary of percent changes since 1990 in estimated peak-flow annual exceedance probabilities from six analyses using two methods for 18 streamflow-gaging stations associated with June 2016 flooding in West Virginia and southwestern Virginia for the period of record through 1990, 2015, and 2016.—Continued

[USGS, U.S. Geological Survey; yrs, years; EMA, Expected Moments Algorithm method; 17B, Bulletin 17B method; --, not determined; This is a summary, see appendix 3, table 3-3 for additional detail]

USGS station number	USGS station name	Analysis method	Return period (yrs)										
			2	2.5	5	10	20	25	40	50	100	200	500
			Exceedance probability										
			0.500	0.400	0.200	0.100	0.050	0.040	0.025	0.020	0.010	0.005	0.002
			Change in peak flow exceedance values since 1990 (percent)										
03196800	Elk River at Clay, West Virginia	EMA through 2016	--	--	--	--	--	--	--	--	--	--	--
03196800	Elk River at Clay, West Virginia	17B through 2016	--	--	--	--	--	--	--	--	--	--	--
03196800	Elk River at Clay, West Virginia	EMA through 2015	--	--	--	--	--	--	--	--	--	--	--
03196800	Elk River at Clay, West Virginia	17B through 2015	--	--	--	--	--	--	--	--	--	--	--
03196800	Elk River at Clay, West Virginia	EMA through 1990	--	--	--	--	--	--	--	--	--	--	--
03196800	Elk River at Clay, West Virginia	17B through 1990	--	--	--	--	--	--	--	--	--	--	--
03197000	Elk River at Queen Shoals, West Virginia	EMA through 2016	--	--	--	--	--	--	--	--	--	--	--
03197000	Elk River at Queen Shoals, West Virginia	17B through 2016	--	--	--	--	--	--	--	--	--	--	--
03197000	Elk River at Queen Shoals, West Virginia	EMA through 2015	--	--	--	--	--	--	--	--	--	--	--
03197000	Elk River at Queen Shoals, West Virginia	17B through 2015	--	--	--	--	--	--	--	--	--	--	--
03197000	Elk River at Queen Shoals, West Virginia	EMA through 1990	--	--	--	--	--	--	--	--	--	--	--
03197000	Elk River at Queen Shoals, West Virginia	17B through 1990	--	--	--	--	--	--	--	--	--	--	--
03198000	Kanawha River at Charleston, West Virginia	EMA through 2016	--	--	--	--	--	--	--	--	--	--	--
03198000	Kanawha River at Charleston, West Virginia	17B through 2016	--	--	--	--	--	--	--	--	--	--	--
03198000	Kanawha River at Charleston, West Virginia	EMA through 2015	--	--	--	--	--	--	--	--	--	--	--
03198000	Kanawha River at Charleston, West Virginia	17B through 2015	--	--	--	--	--	--	--	--	--	--	--
03198000	Kanawha River at Charleston, West Virginia	EMA through 1990	--	--	--	--	--	--	--	--	--	--	--
03198000	Kanawha River at Charleston, West Virginia	17B through 1990	--	--	--	--	--	--	--	--	--	--	--

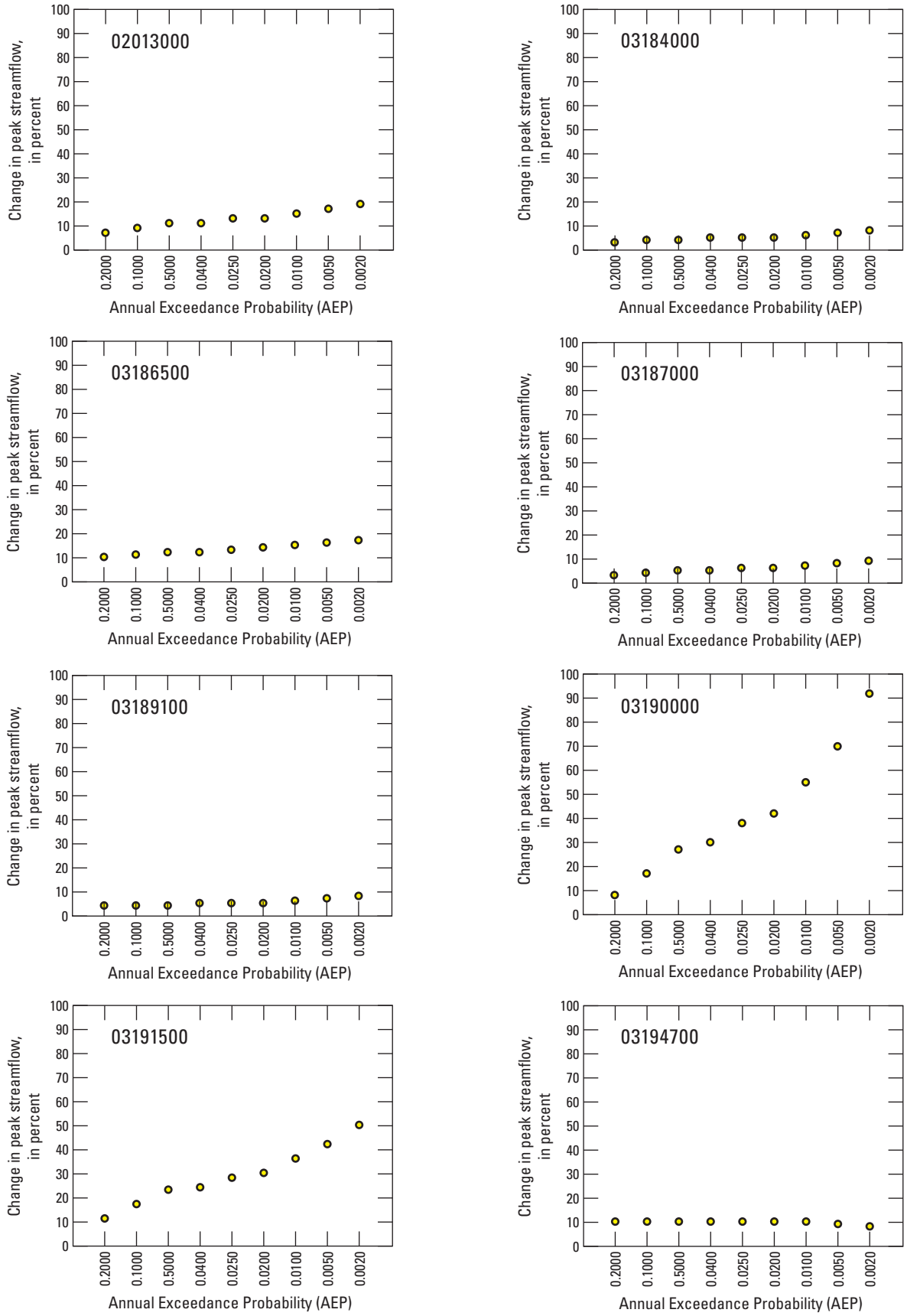


Figure 5. Percent change in peak flows at selected annual exceedance probabilities using the Expected Moments Algorithm method for eight streamflow-gaging stations in West Virginia for 1990–2016.

Estimated Magnitudes and Flood Probabilities for Peak Streamflows

During the June 2016 flooding new streamflow peaks of record occurred at 7 of the 18 USGS streamflow-gaging stations associated with the flooding (table 3). Peak streamflows at the remaining 11 streamflow-gaging stations ranked among the five largest peak flows over the period of record. AEP estimates, prepared for three time intervals using two estimation methods, are listed in table 4. Percent changes in AEP estimates since 1990 are given in table 5. Graphs summarizing the details of all peak-flow AEP estimates are presented in appendix 2.

AEP estimates for Hirsch-Stedinger plotting positions of peak flows specific to the June 2016 flooding ranged from 0.0791 to 0.0100 using EMA estimation and 0.0678 to 0.0114 using 17B estimation (Hirsch and Stedinger 1987). AEP estimates from fitted annual frequency curves of peak flows specific to the June 2016 flooding ranged from 0.0498 to 0.0020 using the EMA method and 0.0462 to 0.0020 using 17B method. AEP estimates were not available for 7 of the 18 streamflow-gaging stations because too few systematic peaks were available for meaningful estimation as a result of either regulated streamflow or a short period of record (table 3). The period of record for the 18 streamflow-gaging stations analyzed ranged from 3 to 155 years.

Peak-flow magnitudes and probabilities were determined at ungaged reaches using the USGS Slope-Area Method for computing peak discharge (Dalrymple and Benson, 1967). Many of the same HWMs that were used to develop inundation maps were used to compute the water-surface slope through the reaches. Surveys of cross-sectional geometry along the reaches were conducted in April 2017. A total of 26 cross-sections were surveyed along more than 15 river miles (mi). Two of the reaches, Howard Creek at White Sulphur Springs, West Virginia, and Cherry River at Richwood, West Virginia, had confounding features that made them unsuitable for channel geometry, reach length, and HWM measurements of sufficient accuracy for use in the slope-area discharge estimation method. The peak-flood magnitudes for each of these reaches were determined using a single cross-section along the reach, commonly referred to as the "slope-conveyance" method. These results have greater uncertainty than those determined using the slope-area method (table 6).

Table 6. Description of ungaged stream reaches in West Virginia with peak flood magnitudes for the June 2016 flood.

[ft^3/s, cubic feet per second; mi^2, square miles; $ft^3/s/mi^2$, cubic feet per second per square mile;WV, West Virginia; e, estimated peak flood magnitude using slope-conveyance method]

Reach name	Peak flood magnitude (ft^3/s)	Drainage area (mi^2)	Unit discharge ($ft^3/s/mi^2$)
Elk River at Queen Shoals, WV	83,000e	1,145	72.5
Cherry River at Richwood, WV	28,900e	88.1	328
Greenbrier River at Ronceverte, WV	83,600	1,124	74.4
Meadow River at Charmco, WV	16,200	164	98.8
New River at Hinton, WV	85,100	6,256	13.6

Flood-Inundation Maps

Maps documenting the extent of flood inundation were created for eight reaches within communities in West Virginia. Each map presents the areal extent of the floodwaters. Two sets of inundation layers are presented for each reach. One was created using the elevations surveyed and recorded at the HWMs, and the other was derived from the elevations recorded in the digital elevation model dataset and the measured height above ground. The inundation layers are overlaid on each map, and the extent of flooding identified by each inundation layer may be visually compared. Professional judgment is encouraged when comparing the inundation estimates described by each inundation layer overlay. The HWMs used to create the inundation maps and associated information may be accessed at the USGS STN website (U.S. Geological Survey, 2016) and are provided in Watson and Cauller (2017). Digital datasets of the inundation areas, mapping boundaries, and water-depth rasters are available online for download from Watson and Cauller (2017). The locations of specific flood-inundation maps are described in the following sections.

Elk River Basin

The headwater of the Elk River is in central West Virginia; the river flows generally southwest for approximately 172 mi to its confluence with the Kanawha River in Charleston, West Virginia. The 45-mi reach of the Elk River mapped for this study flows through communities in Clay and Kanawha Counties, including the towns of Clay, Clendenin, Elkview, and Big Chimney (fig. 6). The upstream extent of the inundation map is in the town of Clay, and the downstream extent is in the town of Big Chimney. A total of 66 HWMs were documented along this reach, and 37 were surveyed and used to develop the inundation map. The depths of water at the HWMs ranged from 0.5 ft to 16 ft above ground, and the water-surface elevations at the HWMs ranged from 604.3 ft to 640.5 ft NAVD 88.

The USGS operates two streamflow-gaging stations on the Elk River that were used in the creation of the inundation map. These are

1. Elk River at Queen Shoals, West Virginia (USGS 03197000), where a peak stage of 33.31 ft gage datum and a water-surface elevation of 636.81 ft NAVD 88, with a corresponding flow of 82,700 cubic feet per second, were recorded on June 24, 2016, and

2. Elk River at Clay, West Virginia (USGS 03196800), where a peak stage of 30.30 ft gage datum and a water-surface elevation of 707.6 ft NAVD 88, with a corresponding flow of 63,100 cubic feet per second were recorded on June 23, 2016.

Precipitation ranged from about 2.3 in. to 6.8 in. in the Elk River Basin over the duration of the flood. The aerial extent of flood inundation for the lower Elk River, which extends from Clay to Big Chimney, is shown in figure 6.

Gauley River Basin

The Gauley River flows southwest through Nicholas and Webster Counties in central West Virginia. A 2.7-mi reach of the Gauley River mapped for this study flows through the community of Camden-on-Gauley in Webster County. A total of 25 HWMs were documented and surveyed along the Gauley River near Camden-on-Gauley, and 23 of the HWMs were used in the creation of the inundation maps. The measured depths of water at the HWM ranged from 0.0 ft to 9.1 ft above land surface and the water-surface elevations ranged from 2,026.9 ft to 2,036.4 ft NAVD 88.

The USGS operates a streamflow-gaging station (03187000) on the Gauley River in Camden-on-Gauley that was used in the creation of the inundation map. The Gauley River streamflow-gaging station used in the creation of the inundation map is Gauley River at Camden-on-Gauley (03187000). A peak stage of 29.75 ft gage datum and a water-surface elevation of 2,033.07 ft NAVD 88, with a corresponding flow of 37,600 cubic feet per second, were recorded on June 23, 2016. Precipitation ranged from about 4.4 to 5.6 in. within the Gauley River Basin over the duration of the event. The location of streamflow-gaging station USGS 03187000 and the aerial extent of flood inundation are shown in figure 7.

Cherry River Basin

The Cherry River flows in a generally northwesterly direction through central West Virginia into the Gauley River near Curtin, West Virginia. A 4.3-mi reach of the Cherry River mapped for this study flows through the communities of Richwood and Fenwick in Nicholas County. A total of 53 HWMs were documented along this reach, and 43 were surveyed and used to develop the inundation map. The depths of water at the HWMs ranged from 0.0 ft to 5.5 ft, and the elevations ranged from 2,088.7 ft to 2,218.7 ft NAVD 88. Precipitation ranged from about 4.4 in. to 5.6 in. within the Gauley River Basin over the duration of the flood. The aerial extent of flood inundation for this reach of the Cherry River is from Richwood to Fenwick and is shown in figure 8.

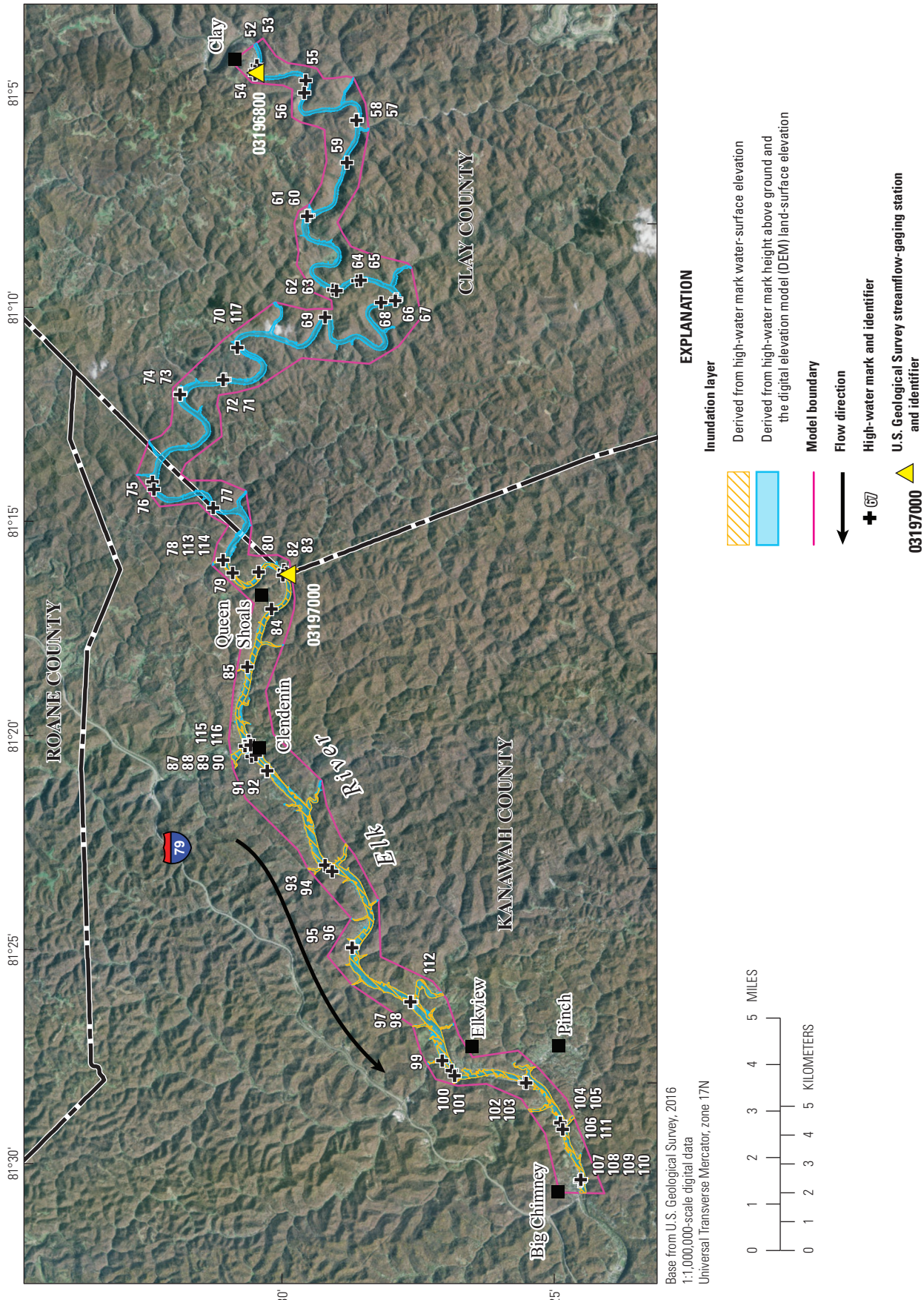


Figure 6. Inundated area along the Elk River in Kanawha and Clay Counties, West Virginia, June 23–24, 2016.

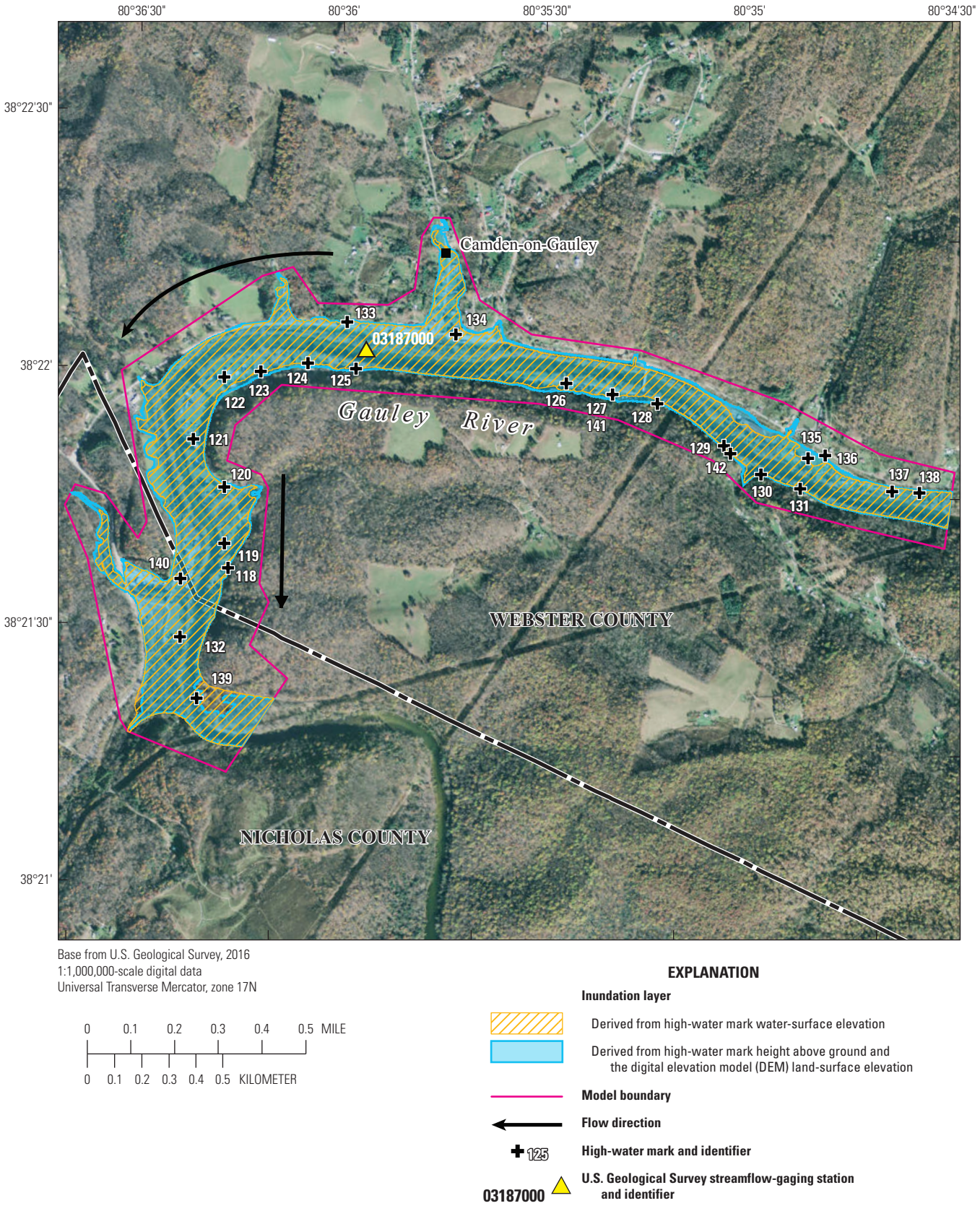


Figure 7. Inundated area along the Gauley River in Camden-on-Gauley, West Virginia, June 23–24, 2016.

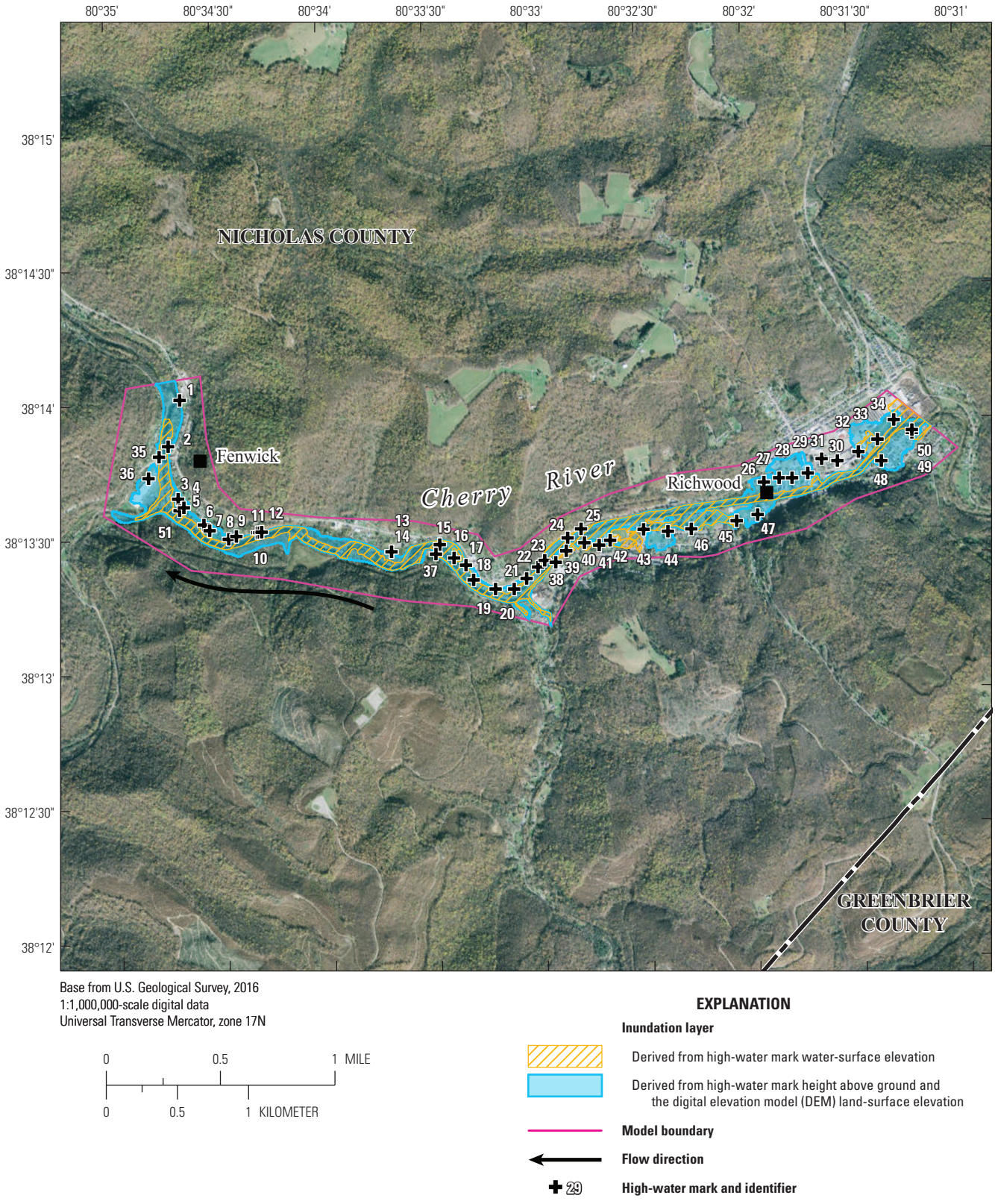


Figure 8. Inundated area along the Cherry River from Richwood to Fenwick, West Virginia, June 23–24, 2016.

Greenbrier River Basin

The Greenbrier River flows in a generally southwesterly direction through West Virginia for 173 mi, into the New River near Bellepoint, West Virginia. The USGS operates one streamflow-gaging station in the Greenbrier River Basin—Greenbrier River at Alderson, West Virginia (03183500). At this streamflow-gaging station, a peak stage of 22.00 ft gage datum and a water-surface elevation of 1,551 ft NAVD 88, with a corresponding flow of 80,700 cubic feet per second, were recorded on June 24, 2016. Precipitation ranged from about 1.3 in. to 9.05 in. within the Greenbrier River Basin over the duration of the event.

Maps documenting flood extent were created for four contributing river subbasins within the Greenbrier River Basin. The maps were created to document the flood extent on two reaches along the Greenbrier River (figs. 9 and 10), one reach on Howard Creek (fig. 11), and one reach each on Meadow River and Sewell Creek (fig. 12).

Greenbrier River at Alderson

The 2.6-mi reach of the Greenbrier River mapped for this study flows through the community of Alderson in Greenbrier County. A total of 50 HWMs were documented along this reach, and 32 were surveyed and used to develop the inundation map. The depths of water at the HWMs ranged from 0.0 ft to 8.0 ft, and the water-surface elevations ranged from 1,544.3 ft to 1,555.8 ft NAVD 88. The aerial extent of flood inundation for this reach of the Greenbrier River extends 0.9 mi upstream and 1.7 mi downstream from the USGS Greenbrier River streamflow-gaging station at Alderson, West Virginia (03183500), and is shown in figure 9.

Greenbrier River at Ronceverte

The 4.8-mi reach of the Greenbrier River mapped for this study flows through the community of Ronceverte in Greenbrier County. A total of 52 HWMs were documented along this reach; 48 were surveyed and used to develop the inundation map. The depths of water at the HWMs ranged from 0.0 ft to 8.55 ft, and the water-surface elevations ranged from 1,650.4 ft to 1,673.5 ft NAVD 88. The aerial extent of flood inundation for the Greenbrier River, which extends 1.5 mi upstream and 2 mi downstream from Ronceverte, is shown in figure 10.

Howard Creek

Howard Creek flows in a generally southwesterly direction into the Greenbrier River near Caldwell, West Virginia. The 7.7-mi reach of Howard Creek mapped for this study flows through the communities of White Sulphur Springs, the Greenbrier Resort, and Caldwell in Greenbrier County. A total of 51 HWMs identified and surveyed along Howard Creek were used to develop the inundation map. The depths of water at the HWMs ranged from 0.0 ft to 8.0 ft, and the water-surface elevations ranged from 1,690.8 ft to 1,866.4 ft NAVD 88. Precipitation ranged from about 3.5 in. to 8.3 in. within the Howard Creek Basin over the duration of the event. The aerial extent of flood inundation for Howard Creek, which extends from White Sulphur Creek to Caldwell, is shown in figure 11.

Meadow River and Sewell Creek

The Meadow River flows northwest through southern West Virginia. Sewell Creek, a tributary to the Meadow River, flows generally north with a confluence in Rainelle, West Virginia. Parts of each stream were mapped—a 3.7-mi reach of the Meadow River and a 4.5-mi reach of Sewell Creek. These reaches flow through the communities of Charmco on Meadow River and Rainelle on Sewell Creek in Greenbrier County. A total of 77 HWMs were documented along these reaches, and 49 were surveyed and used to develop the inundation map. Water depths at the HWMs ranged from 0.0 ft to 9.3 ft, and water-surface elevations ranged from 2,395.8 ft to 2,409.3 ft NAVD 88. Precipitation ranged from about 4.6 in. to 7.3 in. within the Meadow River and Sewell Creek Basins over the duration of the event. The aerial extent of flood inundation for Meadow River and Sewell Creek is shown in figure 12.

New River Basin

The New River flows generally north for about 360 mi through North Carolina, Virginia, and West Virginia. The New River joins the Gauley River at Gauley Bridge, West Virginia, to form the Kanawha River. Much of the river flowing through West Virginia is designated New River Gorge National River. The segment of the New River in this study flows 4.0 mi through Summers and Raleigh Counties in southern West Virginia. A total of 45 HWMs were documented and surveyed along the New River, and 24 of the HWMs were used in the creation of an inundation depth map for the city of Hinton and surrounding areas. The measured depths of water at the HWMs ranged from 0 ft to 5.35 ft above ground, and the elevations ranged from 1,346.1 ft to 1,385.2 ft NAVD 88. The streamflow-gaging station used in the creation of the inundation maps is New River at Hinton (USGS 03184500), a currently inactive streamflow-gaging station where HWMs were recovered and slope-area calculations identified a peak stage of 9.69 ft gage datum and a water-surface elevation of 1,364.5 ft NAVD 88 on June 24, 2016. The aerial extent of flood inundation along the New River near Hinton, West Virginia, is shown in figure 13.

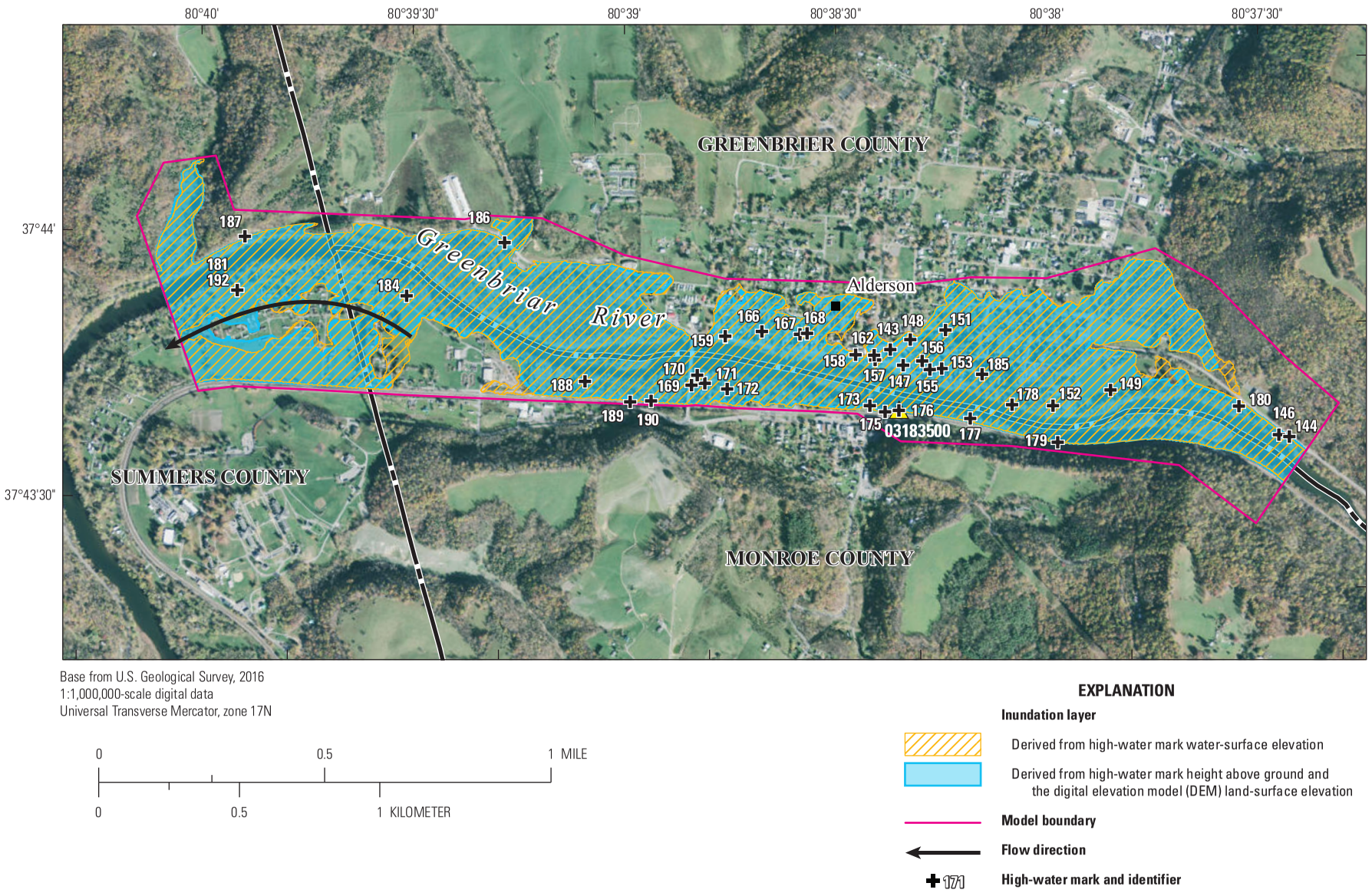


Figure 9. Inundated area along the Greenbrier River in Alderson, West Virginia, June 23–24, 2016.

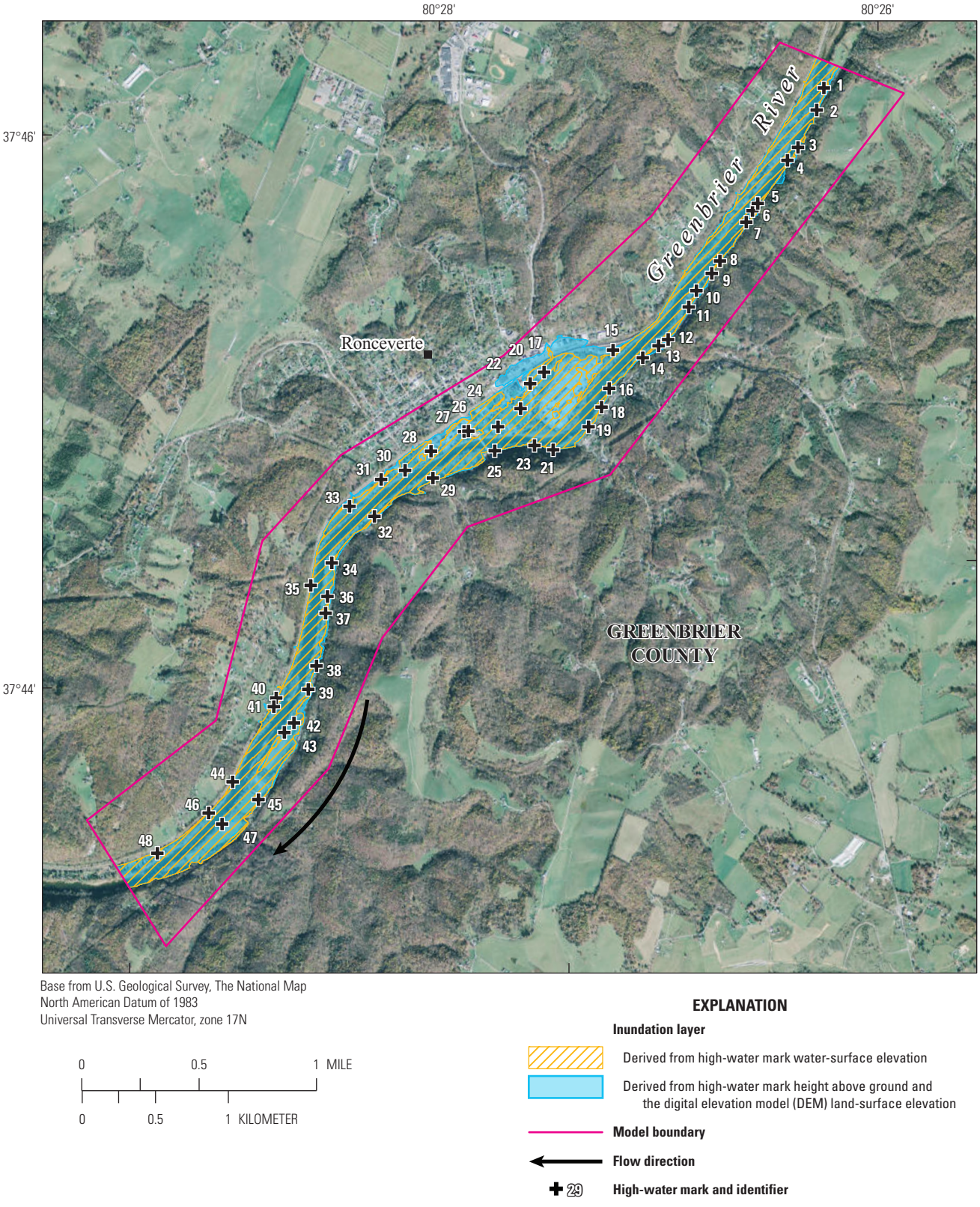


Figure 10. Inundated area along the Greenbrier River in Ronceverte, West Virginia, June 23–24, 2016.

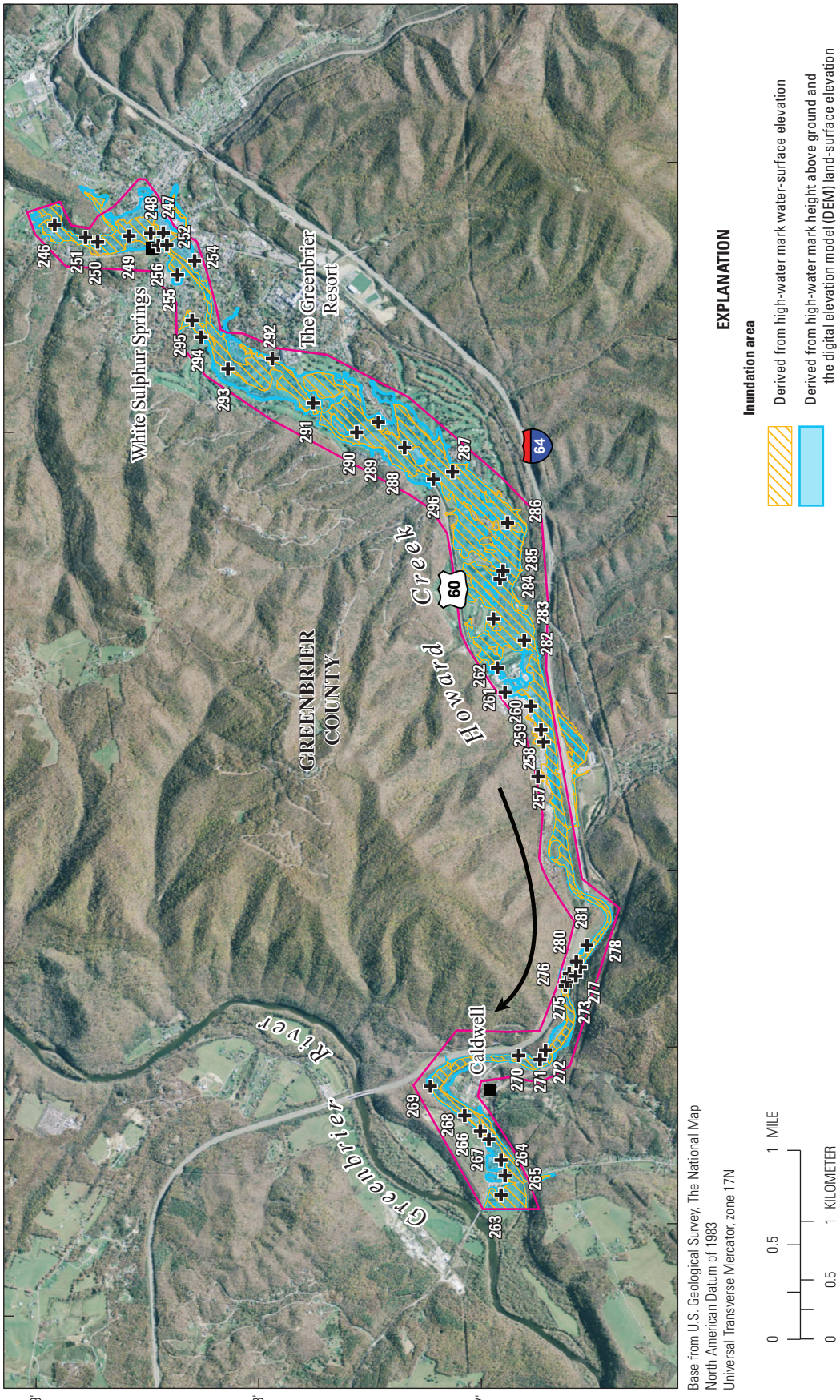


Figure 11. Inundated area along Howard Creek, from White Sulphur Springs to Caldwell, West Virginia, June 23–24, 2016.

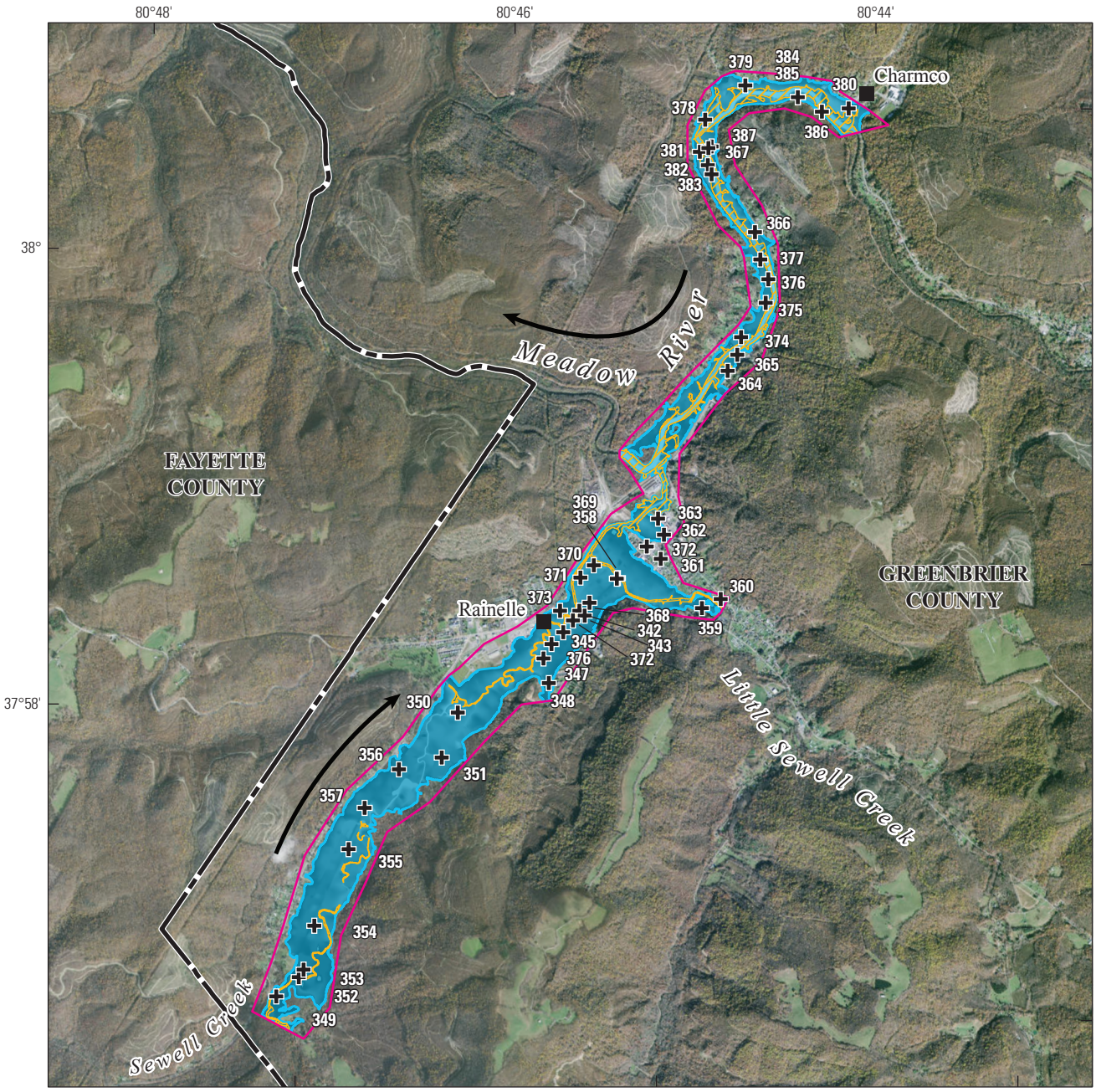


Figure 12. Inundated area along the Sewell Creek and Meadow River in Rainelle, West Virginia, June 23–24, 2016.

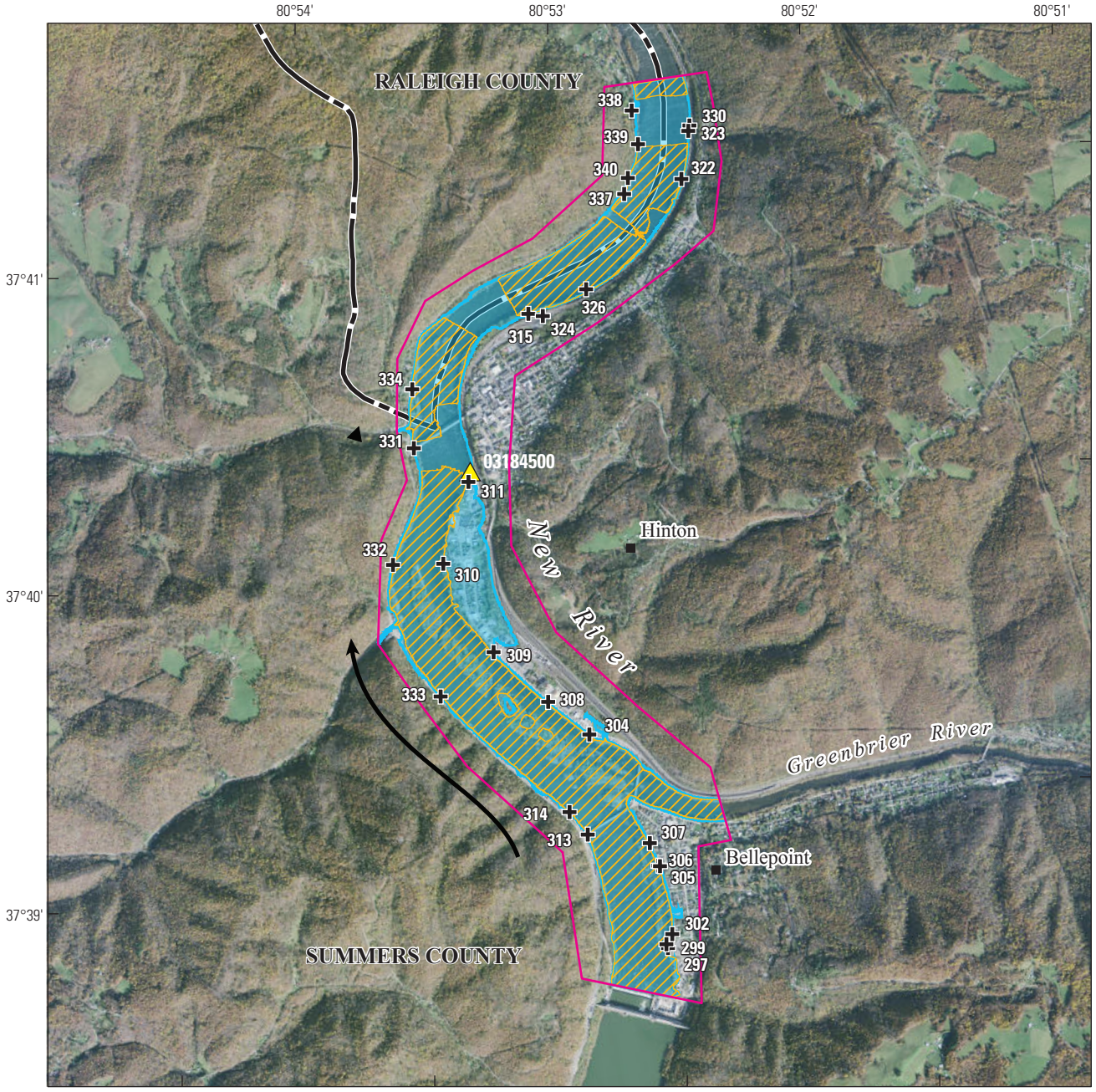


Figure 13. Inundated area along the New River in Hinton, West Virginia, June 23–24, 2016.

Flood Damages

During June 2016, flooding on numerous streams and rivers in West Virginia resulted in at least 23 fatalities and damage to thousands of homes and businesses (NOAA, 2016b). More than 1,500 roads and bridges were damaged or destroyed, significantly affecting the infrastructure. Monetary losses from flooding and wind damage to homes, businesses, and infrastructure were estimated to be $1 billion (NOAA, 2016a). This storm is regarded as one of the worst natural disasters in West Virginia history and the deadliest flash flood event in the United States since the Tennessee floods of 2010 (http://pages.geo.wvu.edu/~skite/DeadliestFloodsInWestVirginiaHistoryDRAFT.pdf, accessed May 2017).

Summary

Thunderstorms brought torrential rain to central West Virginia and southwestern Virginia on June 23 and 24, 2016. Eight to 10 inches of rain fell during a 12-hour period, producing widespread and destructive flash flooding. Record peak streamflows occurred at seven U.S. Geological Survey (USGS) streamflow-gaging stations. Peak flow on the Elk River was the highest recorded since 1888. All of the 18 streamflow-gaging stations included in this study had peak streamflows that rank in the top five for the period of record.

At least 23 fatalities were reported, and the costs of damages from flooding and high winds were estimated at $1 billion. Immediately after the flood, the USGS and the Federal Emergency Management Agency (FEMA) initiated a cooperative study to evaluate the flood's magnitude, extent, and probability of occurrence. USGS hydrographers identified and documented 422 high-water marks, some of which were used to create 8 flood-inundation maps that document the extent and depth of flooding. Two sets of inundation layers are presented for each map reach. One was created using the elevations surveyed and recorded at the high-water marks, and the other was derived from the water-surface elevations recorded from the available digital elevation model dataset and the measured height above the land surface. The inundation layers are overlaid on each map, and the extent of flooding identified by each inundation layer may be visually compared. Many of the high-water marks used to develop inundation maps were used to compute water-surface slope through the reaches.

Peak gage-height data, peak streamflow data, and estimated annual exceedance probabilities are provided for 18 streamflow-gaging stations operated by the USGS in West Virginia and southwestern Virginia. New streamflow peaks of record occurred at 7 of the 18 USGS streamflow-gaging stations associated with the flooding, and 11 streamflow-gaging stations had peak streamflows that ranked in the five largest peak flows over the period of record. Annual exceedance probability estimates from fitted annual frequency curves of peak flows specific to the June 2016 flooding ranged from 0.0498 to 0.0020 using Expected Moments Algorithm method and 0.0462 to 0.0020 using 17B method.

References Cited

Benson, M.A., and Dalrymple, Tate, 1967, General field and office procedures for indirect measurements: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. Al, 30 p. [Also available at http://pubs.er.usgs.gov/publication/twri03A1.]

Dalrymple, Tate, and Benson, M.A., 1967, Measurement of peak discharge by the slope-area method: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A2, 12 p. [Also available at https://pubs.usgs.gov/twri/twri3-a2/.]

Cohn, T.A., Lane, W.L., and Baier, W.G., 1997, An algorithm for computing moments-based flood quantile estimates when historical flood information is available: Water Resources Research, v. 33, no. 9, p. 2089–2096.

Cohn, T.A., Lane, W.L., and Stedinger, J.R., 2001, Confidence intervals for Expected Moments Algorithm flood quantile estimates: Water Resources Research, v. 37, no. 6, p. 1695–1706.

Federal Emergency Management Agency (FEMA), 1990, Flood insurance study, city of Petersburg, West Virginia, Grant County: FEMA Flood Insurance Study Number 1.209:540039.

Federal Emergency Management Agency (FEMA), 1989, Flood insurance study, Grant County, West Virginia, unincorporated areas: FEMA Flood Insurance Study Number 1.209:540038.

Fenneman, N.M., 1938, Physiography of Eastern United States: New York, McGraw-Hill, 714 p.

Flynn, K.M., Kirby, W.H., and Hummel, P.R., 2006, User's manual for program PeakFQ annual flood-frequency analysis using Bulletin 17B guidelines: U.S. Geological Survey Techniques and Methods, book 4, chap. B4, 42 p.

Helsel, D.R., and Hirsch, R.M., 2002, Statistical methods in water resources: U.S. Geological Survey Techniques of Water-Resources Investigations Report, book 4, chap. A3, 510 p.

Interagency Advisory Committee on Water Data, 1982, Guidelines for determining flood flow frequency: Water Resources Council Bulletin 17B, 28 p.

Hirsch, R.M., and Stedinger, J.R., 1987, Plotting positions for historical floods and their precision: Water Resources Research, v. 23, no. 4, p.715–727. [Also available at http://dx.doi.org/10.1029/wr023i004p00715.]

Koenig, T.A., Bruce, J.L., O'Connor, J.E., McGee, B.D., Holmes, R.R., Jr., Hollins, Ryan, Forbes, B.T., Kohn, M.S., Schellekens, M.F., Martin, Z.W., and Peppler, M.C., 2016, Identifying and preserving high-water mark data: U.S. Geological Survey Techniques and Methods, book 3, chap. A24, 47 p. [Also available at http://dx.doi.org/10.3133/tm3A24.]

Messinger, Terrance, and Hughes, C.A., 2000, Environmental setting and its relations to water quality in the Kanawha River Basin: U.S. Geological Survey Water-Resources Investigations Report 00–4020, 65 p.

Musser, J.W., Watson, K.M., Painter, J.A., and Gotvald, A.J., 2016, Flood-inundation maps of selected areas affected by the flood of October 2015 in central and coastal South Carolina: U.S. Geological Survey Open-File Report 2016–1019, 81 p. [Also available at http://dx.doi.org/10.3133/ofr20161019.]

National Oceanic and Atmospheric Administration (NOAA), 2016a, National Centers for Environmental Information, Billion-dollar weather and climate disasters: Table of events, accessed June 1, 2017, at https://www.ncdc.noaa.gov/billions/events.

National Oceanic and Atmospheric Administration (NOAA), 2016b, National Weather Service, August 2016 record flooding, accessed December 8, 2016, at http://www.weather.gov/lix/August2016flood.

Paulson, R.W., Chase, E.B., Roberts, R.S., and Moody, D.W., comps., 1991, National water summary, 1988–89 Hydrologic events and floods and droughts: U.S. Geological Survey Water-Supply Paper 2375, 591 p.

Rantz, S.E., and others, 1982a, Measurement and computation of streamflow: U.S. Geological Survey Water-Supply Paper 2175, v. 1, 284 p. [Also available at http://pubs.usgs.gov/wsp/wsp2175/pdf/WSP2175_vol1a.pdf.]

Rantz, S.E., and others, 1982b, Measurement and computation of streamflow: U.S. Geological Survey Water-Supply Paper 2175, v. 2, 631 p. [Also available at http://pubs.usgs.gov/wsp/wsp2175/pdf/WSP2175_vol2a.pdf.]

Runner, G.S., 1980, Runoff studies on small drainage areas (Technique for estimating magnitude and frequency of floods in West Virginia), West Virginia Department of Highways Research Project 16: U.S. Geological Survey Open-File Report 80-1218, 44 p.

Turnipseed, D.P., and Sauer, V.B., 2010, Discharge measurements at gaging stations: U.S. Geological Survey Techniques and Methods book 3, chap. A8, 87 p. [Also available at http://pubs.usgs.gov/tm/tm3-a8/.]

U.S. Geological Survey, 2016, Short-Term Network Data Portal, accessed May 15, 2017, at http://water.usgs.gov/floods/FEV.

U.S. Geological Survey, 2017, National Water Information System—Web interface, accessed September 28, 2016, at http://dx.doi.org/10.5066/F7P55KJN.

Veilleux, A.G., Cohn, T.A., Flynn, K.M., Mason, R.R., Jr., and Hummel, P.R., 2014, Estimating magnitude and frequency of floods using the PeakFQ 7.0 program: U.S. Geological Survey Fact Sheet 2013–3108, 2 p. [Also available at http://pubs.usgs.gov/fs/2013/3108/.]

Watson, K.M., and Cauller, S.J., 2017, Flood Inundation, flood depth, and high-water marks for selected areas in West Virginia from the June 2016 Flood: U.S. Geological Survey data release, accessed September 2017 at https://doi.org/10.5066/F76T0K4K.

Wiley, J.B., and Atkins, J.T., Jr., 2010, Estimation of flood-frequency discharges for rural, unregulated streams in West Virginia: U.S. Geological Survey Scientific Investigations Report 2010–5033, 78 p.

Appendix 1. Graphs showing Selected Annual Exceedance Probabilities in Relation to Streamflow Using the Expected Moments Algorithm Method for Selected Streamflow-Gaging Stations in West Virginia for the Period of Record through 1990, 2015, and 2016

A PDF of appendix 1 is available for download at https://doi.org/10.3133/ofr20171140.

Appendix 2. Graphs showing Annual Exceedance Probabilities in Relation to Annual Peak Streamflow, Determined Using the Expected Moments Algorithm and Bulletin 17B Methods, for Selected Streamflow-Gaging Stations for the Period of Record through 1990, 2015, and 2016 and Annual Peak Streamflow, by Water Year[1] 1900–2016.

A PDF of appendix 2 is available for download at https://doi.org/10.3133/ofr20171140.

Appendix 3. Three Tables Listing Expanded Summaries of Site Descriptions, Exceedance Probabilities, Equivalent Recurrence Intervals, Statistics, and Percent Change Since 1990 in Estimated Peak-Flow Annual Exceedance Probabilities for 18 Streamflow-Gaging Stations Associated with June 2016 Flooding in West Virginia and Southwestern Virginia Using Data for the Period of Record through 1990, 2015, and 2016.

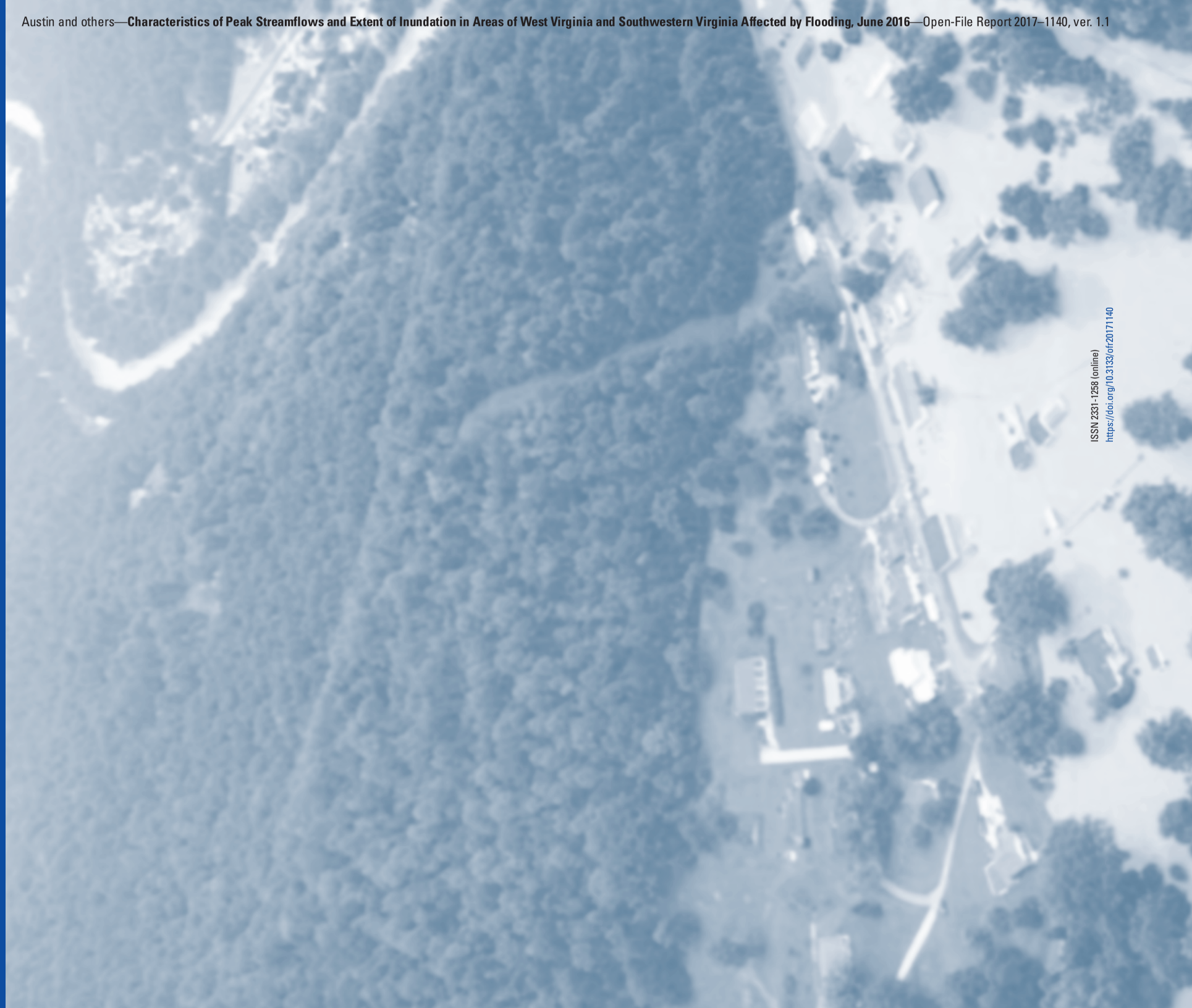
Appendix 3 tables are available for download as Microsoft Excel spreadsheets (*.xls) at https://doi.org/10.3133/ofr20171140.

[1]A water year is the 12-month period beginning October 1 and ending September 30. It is designated by the year in which it ends.

For additional information, contact::
Director, Virginia and West Virginia Water Science Center
U.S. Geological Survey
1730 East Parham Road
Richmond, VA 23228

or visit our website at:
http://va.water.usgs.gov/

Prepared by USGS West Trenton Publishing Service Center



ISSN 2331-1258 (online)
https://doi.org/10.3133/ofr20171140