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

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U.S. Department of the Interior

U.S. Geological Survey

A Cooperative Study With FEMA.

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

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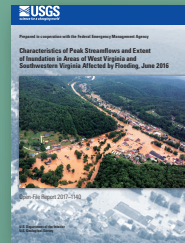U.S. Geological Survey
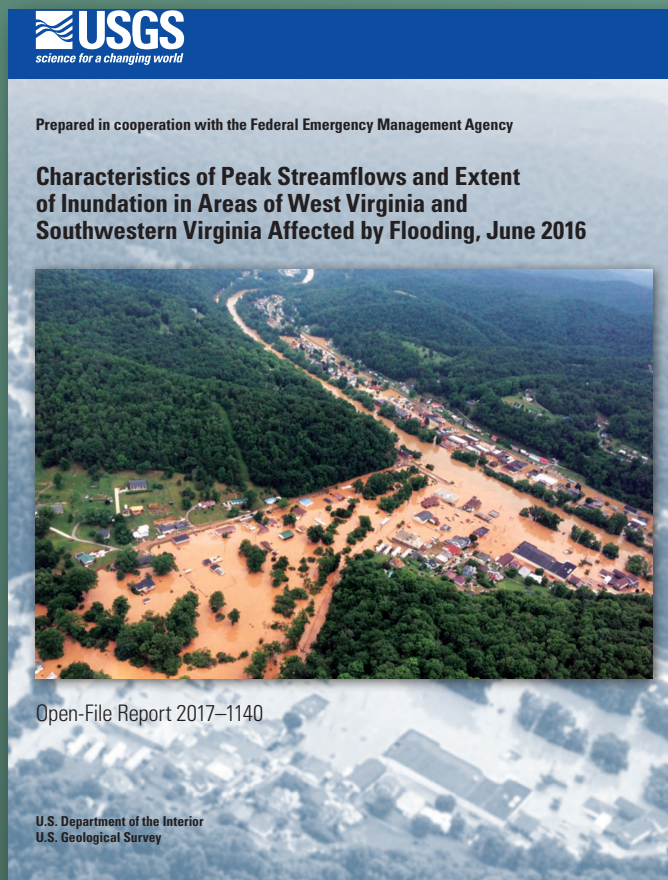
Outline

- **Introduction**
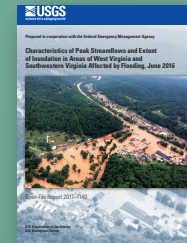
- **Examples**

- **Two Summary Tables**

- **Questions**
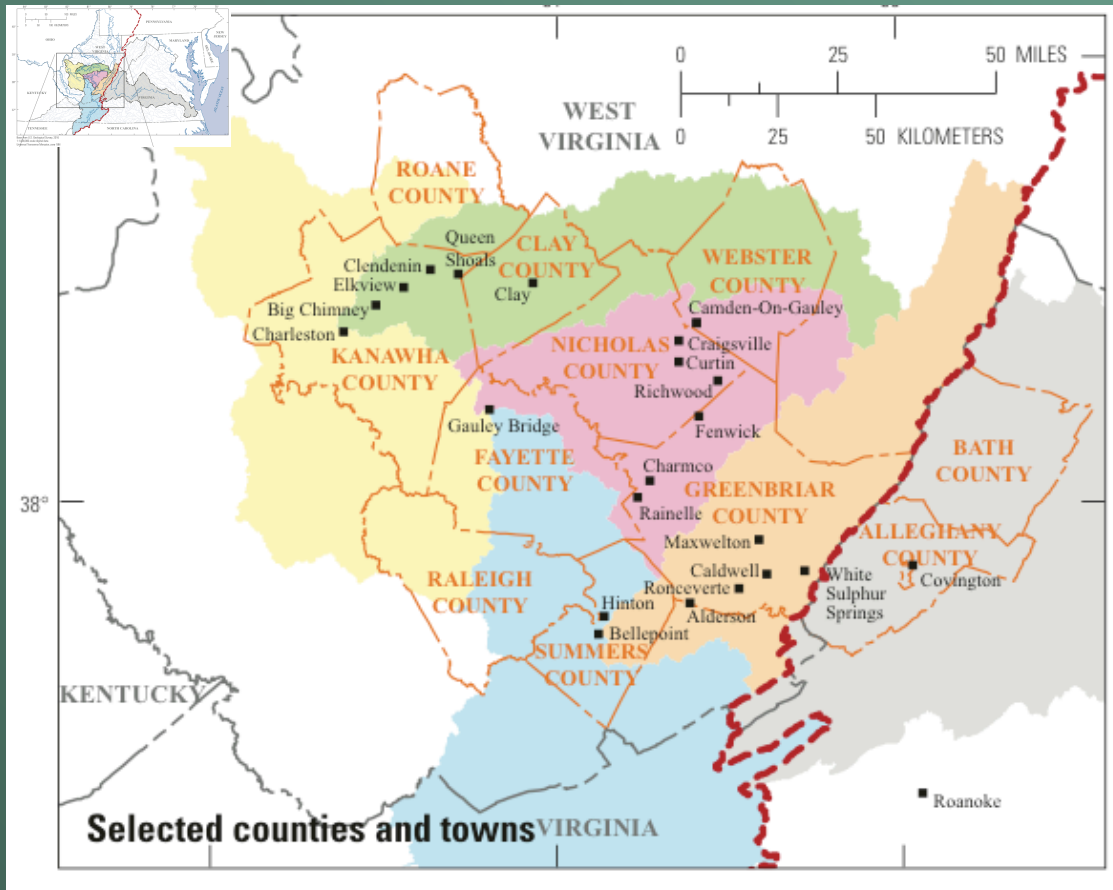
Introduction
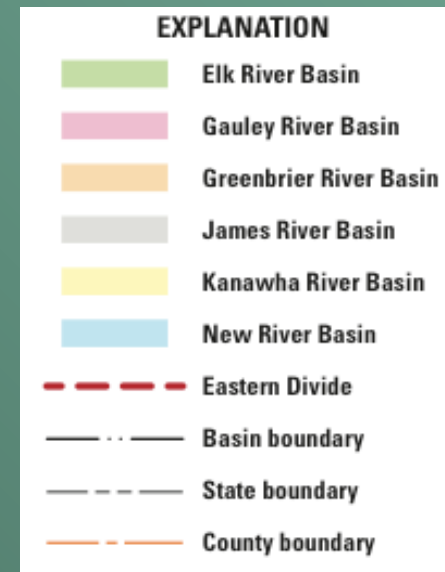
Introduction: Purpose of the report.

- 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.

- These include:

    - Describing atmospheric conditions.

    - Analyzing select peak-flow magnitudes and statistical probabilities.

    - Identifying, surveying, and analyzing high-water mark locations and elevations to produce flood-inundation maps in six heavily flooded areas.
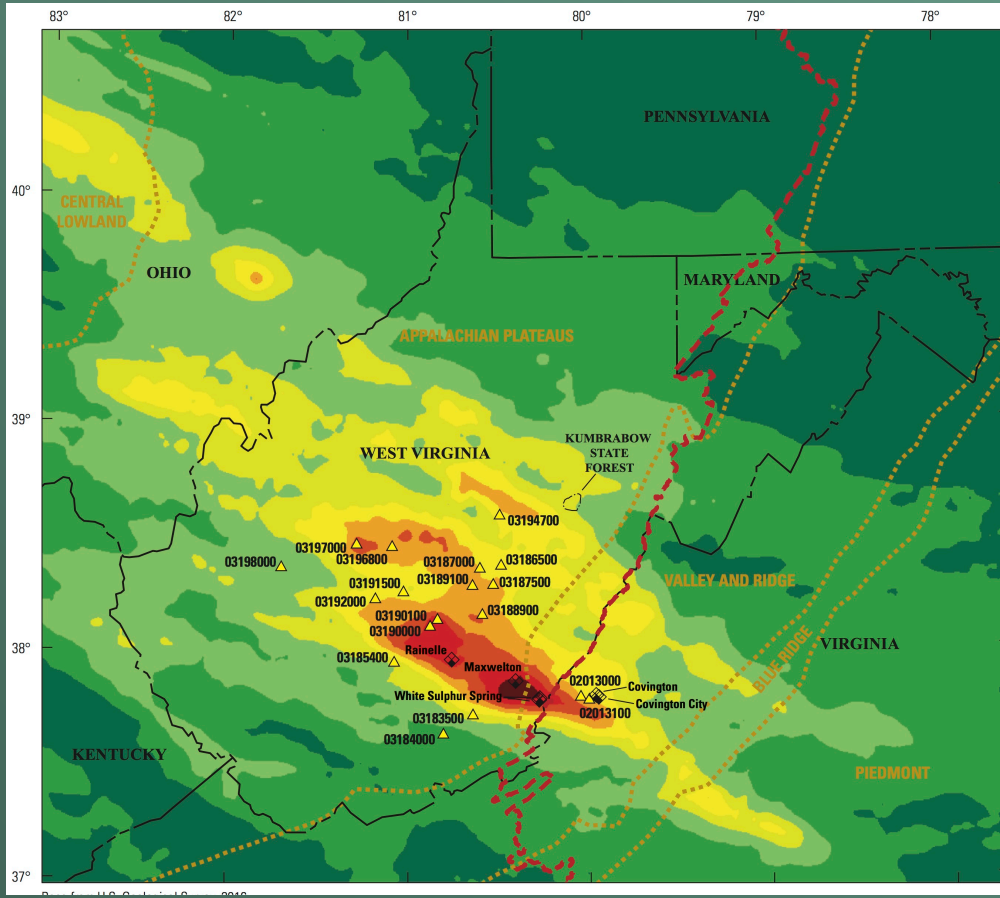
Introduction: Description of the study area.

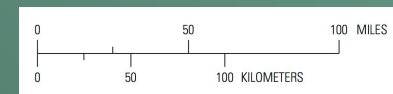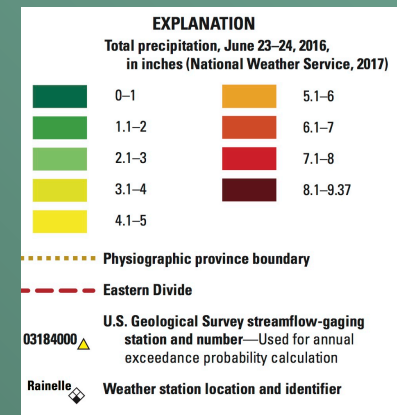The study area encompasses central and southeastern West Virginia and parts of southwestern Virginia. Flooded areas are found primarily within the Appalachian Plateaus and the Valley and Ridge Physiographic Provinces.

EXPLANATION

- Elk River Basin
- Gauley River Basin
- Greenbrier River Basin
- James River Basin
- Kanawha River Basin
- New River Basin
- Eastern Divide
- Basin boundary
- State boundary
- County boundary

Introduction: 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 in late spring were wet with May rainfall about 125–150 percent of normal across much of the area.
- Rainfall totals in excess of 7.0 in. were recorded in Maxwelton (9.37 in.), Rainelle, (7.53 in.), and White Sulphur Springs, (9.17 in

EXPLANATION

Total precipitation, June 23–24, 2016, in inches (National Weather Service, 2017)

▮ 0–1		▮ 5.1–6	
▮ 1.1–2		▮ 6.1–7	
▮ 2.1–3		▮ 7.1–8	
▮ 3.1–4		▮ 8.1–9.37	
▮ 4.1–5			

······· Physiographic province boundary

▬ ▬ ▬ Eastern Divide

△ 03184000 U.S. Geological Survey streamflow-gaging station and number—Used for annual exceedance probability calculation

◆ Rainelle Weather station location and identifier

0	50	100 MILES
0	50	100 KILOMETERS

Introduction: Reported rainfall totals.

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

Introduction: Examples of flood damage.

A. ELK RIVER AT CLAY, WEST VIRGINIA
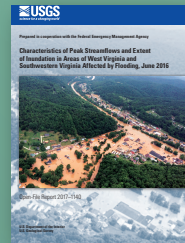
B. GAULEY RIVER NEAR CRAIGSVILLE, WEST VIRGINIA

Figure 3. Flood damage *A*, on the Elk River at Clay, West Virginia and *B*, on the Gauley River near Craigsville, West Virginia.
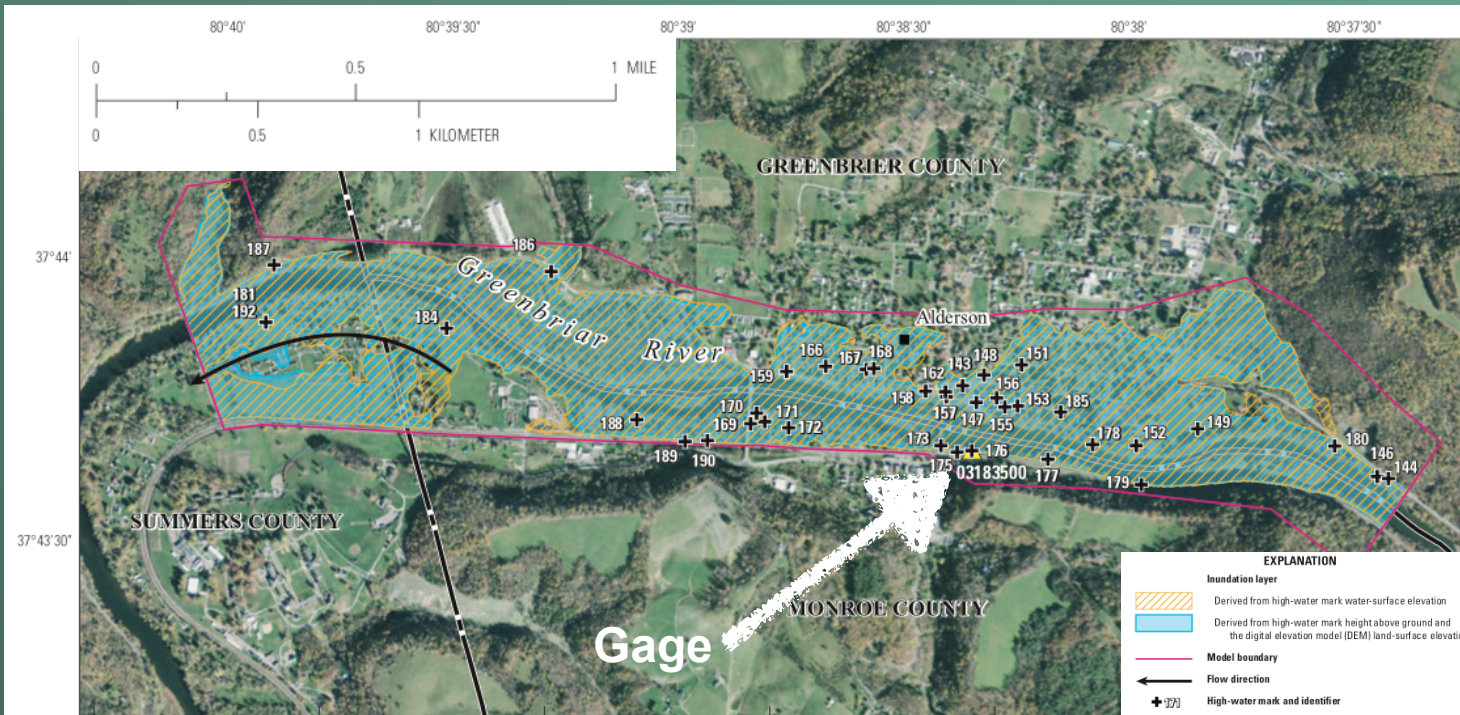
Introduction: Examples of flood damage.

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.)
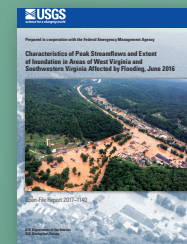
Examples

Example 1 page 1: Flood-inundation maps: Greenbrier River Basin: Greenbrier River at Alderson.

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

- The 2.6-mi reach of the Greenbrier River mapped for this study flows through the community of Alderson in Greenbrier County. 50 HWMs were documented along this reach, and 32 were surveyed and used to develop the inundation map.

- 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 stream flow-gaging station at Alderson, West Virginia (03183500).

From Table 3

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)
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

From Table 4

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)										
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

From Table 5

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)										
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

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

- The 2.6-mi reach of the Greenbrier River mapped for this study flows through the community of Alderson in Greenbrier County. 50 HWMs were documented along this reach, and 32 were surveyed and used to develop the inundation map.

- 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 stream flow-gaging station at Alderson, West Virginia (03183500).

So, we now know that:

For the June 2016 flooding shown on the map (above): Gage Height: 22.00 ft. Peak Flow: 80,700 ft^3/s Peak POR Rank: 3 Equiv. RI: 86-years.

For 2016 the 0.01 AEP (100-year RI) flow for this gage: 81,990 ft^3/s using the EMA method, 81,900 ft^3/s using the 17B method.

The percent change since 1990 in the 0.01 AEP (100-year RI) flow for this gage is: 4% using EMA method, 4% using the 17B method.
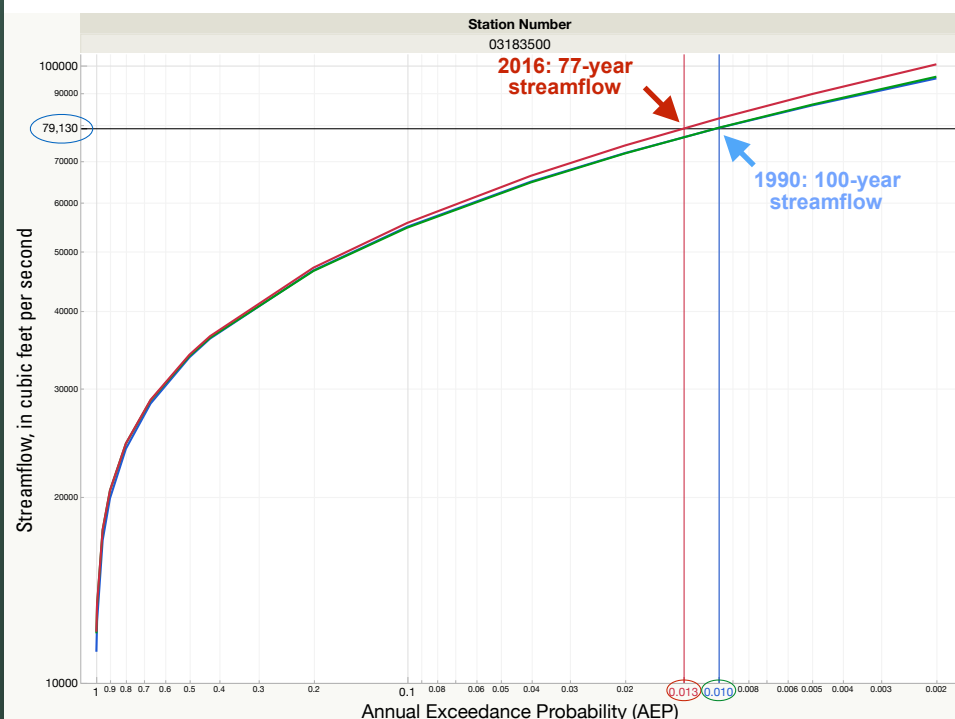
Example 1 page 4: Flood-inundation maps: Greenbrier River Basin: Greenbrier River at Alderson.

If you want more…
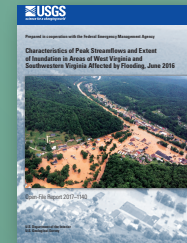
Graphs in **Appendix 1** compare POR annual exceedance probabilities (AEP) at selected sites in West Virginia Through **1990**, **2015**, and **2016** using the **EMA** method.

03183500 Greenbrier River at Alderson, West Virginia

EXPLANATION
Expected Moments
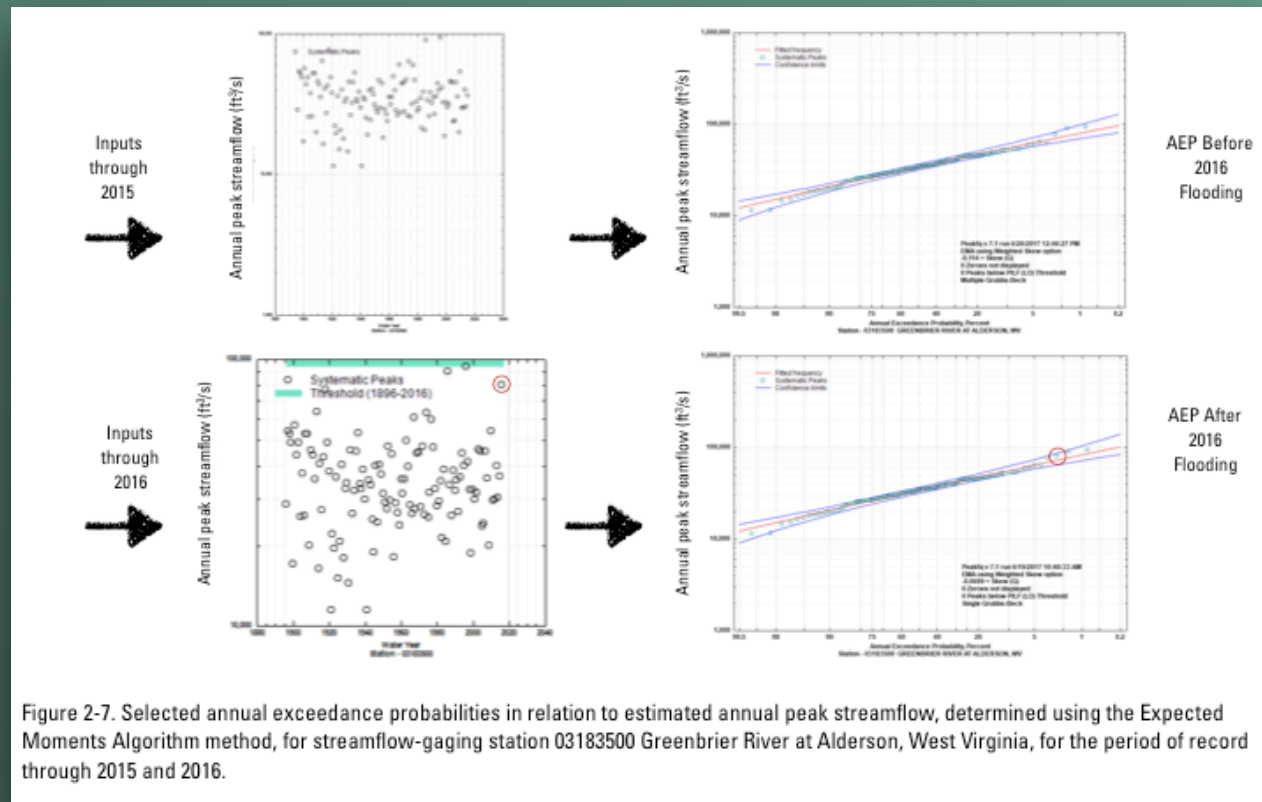Algorithm (EMA) Method

2016
2015
1990

A 100-year streamflow (AEP 0.010) of 79,130 ft³/s in 1990 (blue curve), is equivalent to an 100-year streamflow (AEP 0.010) in 2015 (green curve), and to a 77-year streamflow (AEP 0.013) in 2016 (red curve).

Example 1 page 5: Flood-inundation maps: Greenbrier River Basin: Greenbrier River at Alderson.

And if you want *even more…*

Graphs in **Appendix 2** show the data and curves describing annual exceedance probabilities (AEP) for **2015** and **2016** determined using the **EMA** method…

Figure 2-7. Selected annual exceedance probabilities in relation to estimated annual peak streamflow, determined using the Expected Moments Algorithm method, for streamflow-gaging station 03183500 Greenbrier River at Alderson, West Virginia, for the period of record through 2015 and 2016.
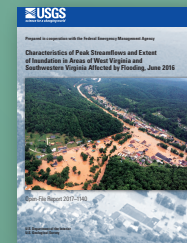
But wait, there's more

And…

Graphs in **Appendix 2** show the data and curves describing annual exceedance probabilities (AEP) for **2015** and **2016** determined using the **17B** method.
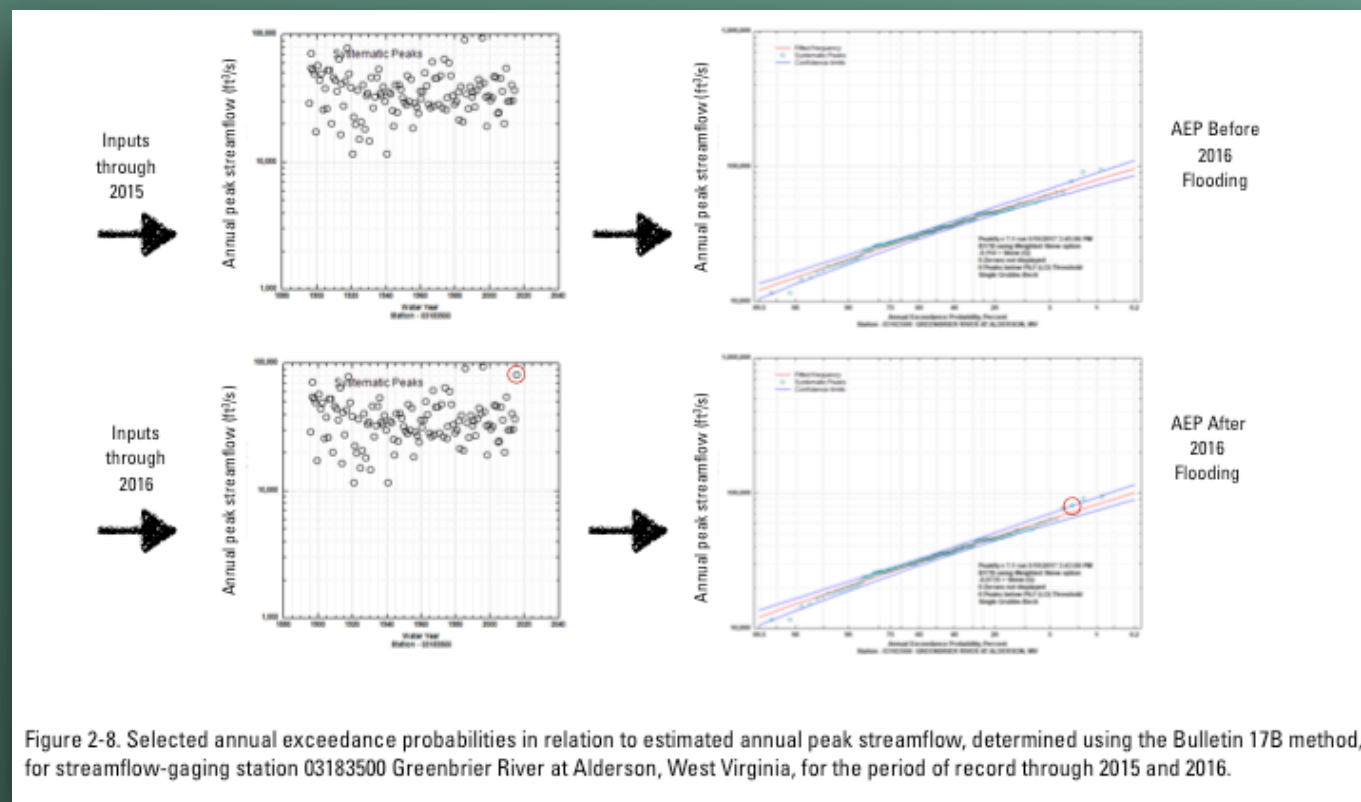

Figure 2-8. Selected annual exceedance probabilities in relation to estimated annual peak streamflow, determined using the Bulletin 17B method, for streamflow-gaging station 03183500 Greenbrier River at Alderson, West Virginia, for the period of record through 2015 and 2016.
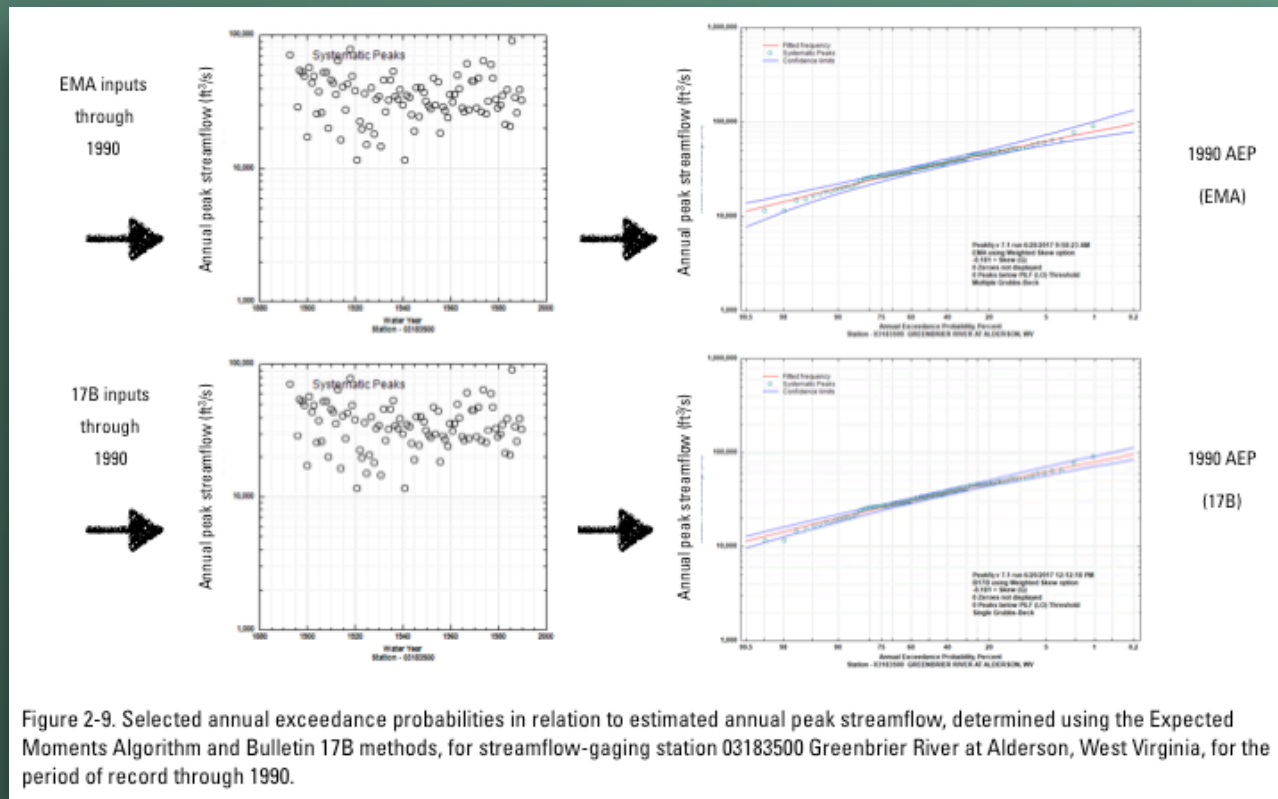
Hang on, there's even more!

Example 1 page 7: Flood-inundation maps: Greenbrier River Basin: Greenbrier River at Alderson.

And…

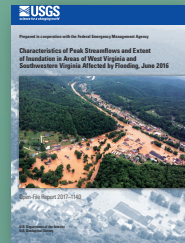**Graphs in Appendix 2 show the data and curves describing annual exceedance probabilities (AEP) for 1990 determined using the EMA method and the 17B method.**

Figure 2-9. Selected annual exceedance probabilities in relation to estimated annual peak streamflow, determined using the Expected Moments Algorithm and Bulletin 17B methods, for streamflow-gaging station 03183500 Greenbrier River at Alderson, West Virginia, for the period of record through 1990.

That's it !

*(Psst…
We won't even mention
Appendix 3 !)*
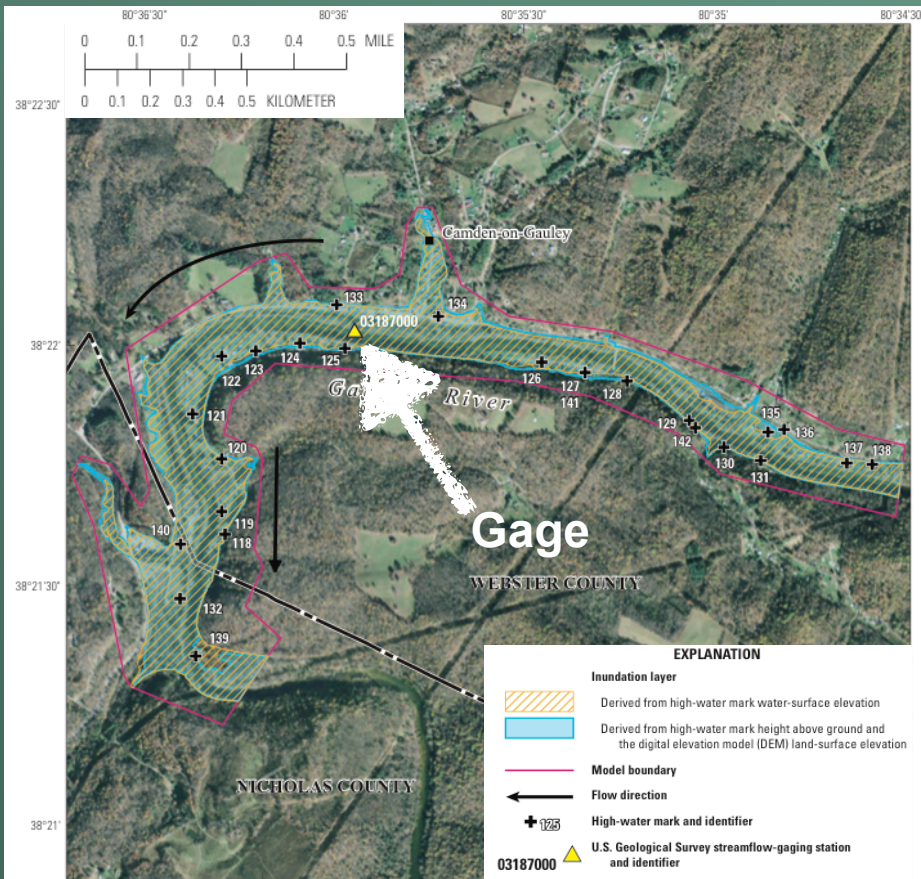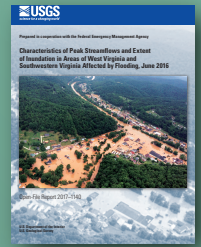
Example 2

Example 2 page 1: Flood-inundation maps: Gauley River in Camden-on-Gauley.

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

- A 2.7-mi reach of the Gauley River mapped for this study flows through the community of Camden-on-Gauley in Webster County.

- Precipitation ranged from about 4.4 to 5.6 in. within the Gauley River Basin over the duration of the event.

Example 2 page 2: Flood-inundation maps: Gauley River in Camden-on-Gauley.

From Table 3

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)
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

From Table 4

USGS station number	USGS station name	Analysis method	Return period (yrs) 2 / 0.500	2.5 / 0.400	5 / 0.200	10 / 0.100	20 / 0.050	25 / 0.040	40 / 0.025	50 / 0.020	100 / 0.010	200 / 0.005	500 / 0.002
			Peak Flow Exceedance Value (ft³/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

From Table 5

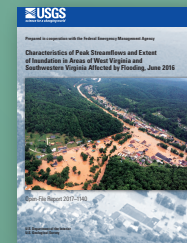| USGS station number	USGS station name	Analysis method	Return period (yrs) 2 / 0.500	2.5 / 0.400	5 / 0.200	10 / 0.100	20 / 0.050	25 / 0.040	40 / 0.025	50 / 0.020	100 / 0.010	200 / 0.005	500 / 0.002
			Change in peak flow exceedance values since 1990 (percent)										
03187000	Gauley River at Camden-on-Gauley, 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

Example 2 page 3: Flood-inundation maps: Gauley River in Camden-on-Gauley.
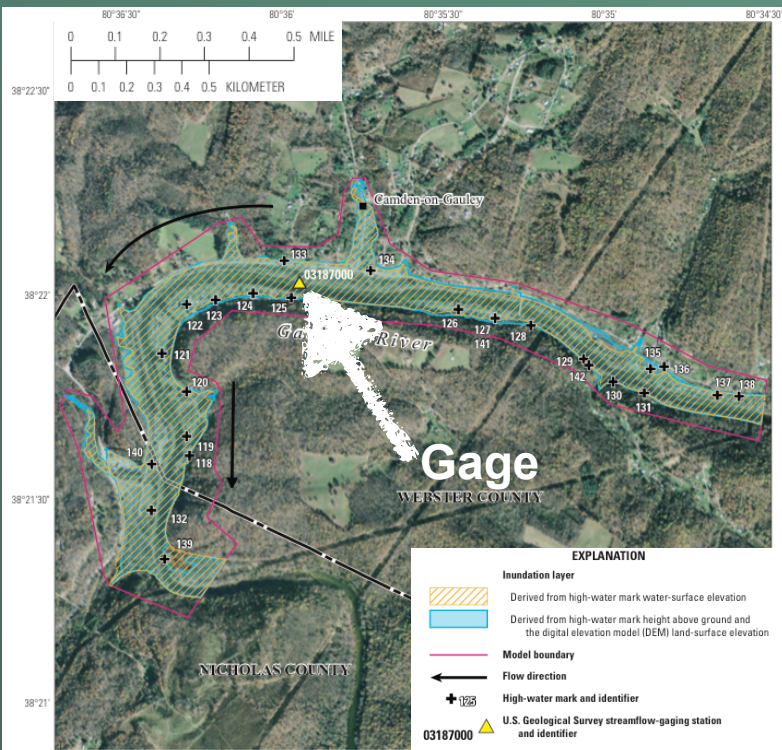

Figure 7. Inundated area along the Gauley River in Camden-on-Gauley, West Virginia, June 23–24, 2016.

- A 2.7-mi reach of the Gauley River mapped for this study flows through the community of Camden-on-Gauley in Webster County.

- Precipitation ranged from about 4.4 to 5.6 in. within the Gauley River Basin over the duration of the event.

So, we now know that:

For the June 2016 flooding shown on the map (above): Gage Height: 29.75ft. Peak Flow: 37,600 ft³/s Peak POR Rank: 2 Equiv. RI: 75-years.

For 2016 the 0.01 AEP (100-year RI) flow for this gage: 39,730 ft³/s using the EMA method, 38,610 ft³/s using the 17B method.

The percent change since 1990 in the 0.01 AEP (100-year RI) flow for this gage is:7% using EMA method, 9% using the 17B method.
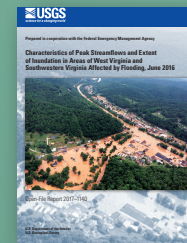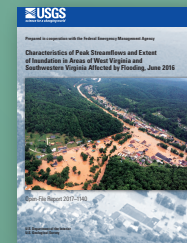
Two Summary Tables

Summary Table 1: Gage height versus BFE.

USGS station number[1]	USGS station name	USGS Gage Flood WSE NAVD 88 (ft)	BFE from FIRM NAVD 88 (ft)	Difference (WSE minus BFE) (ft)
02013000	DUNLAP CREEK NEAR COVINGTON, VA	1,311.0	1,311.0	0.0
02013100	JACKSON RIVER BL DUNLAP CREEK AT COVINGTON, VA	1,228.4	1,228.7	-0.3
03183500	GREENBRIER RIVER AT ALDERSON, WV	1,551.0	1,552.2	-1.2
03187000	GAULEY RIVER AT CAMDEN-ON-GAULEY, WV	2,033.1	2,027.3	5.8
03194700	ELK RIVER BELOW WEBSTER SPRINGS, WV	1,037.3	1,036.1	1.2
03196800	ELK RIVER AT CLAY, WV	707.6	701.0	6.6
03197000	ELK RIVER AT QUEEN SHOALS, WV	636.8	633.5	3.3

Summary Table 2: Comparison of FIS 0.01 AEP streamflow estimates and USGS 2016 equivalent estimates.

USGS station number[1]	USGS station name	June 2016 peak date (yyyy-mm-dd)	USGS gage height (ft)	USGS peak flow June 2016 (ft³/s)	Annual exceedance probability estimating method	USGS June 2016 equivalent recurrence interval	USGS June 2016 0.01 AEP flow estimate	FIS 0.01 AEP (100-year) flow estimate	USGS AEP equivalent for FIS 0.01 AEP flow estimate	USGS recurrence interval equivalent for FIS 100-year flow estimate
02013000	DUNLAP CREEK NEAR COVINGTON, VA	2016-06-23	16.66	23,600	EMA Fitted Annual Frequency Curve	94	23,910	19,100	0.023	44
					17B Fitted Annual Frequency Curve	95	23,820	19,100	0.023	44
02013100	JACKSON RIVER BL DUNLAP CREEK AT COVINGTON, VA	2016-06-23	22.41	27,100[F]	EMA Fitted Annual Frequency Curve	Not available[2]	Not available[2]	31,000	Flow regulated	Flow regulated
					17B Fitted Annual Frequency Curve	Not available[2]	Not available[2]	31,000	Flow regulated	Flow regulated
03183500	GREENBRIER RIVER AT ALDERSON, WV	2016-06-24	22.00	80,700	EMA Fitted Annual Frequency Curve	86	81,990	79,500	0.013	77
					17B Fitted Annual Frequency Curve	87	81,900	79,500	0.013	77
03187000	GAULEY RIVER AT CAMDEN-ON-GAULEY, WV	2016-06-23	29.75	37,600	EMA Fitted Annual Frequency Curve	75	39,730	32,000	0.025	40
					17B Fitted Annual Frequency Curve	86	38,610	32,000	0.023	44
03194700	ELK RIVER BELOW WEBSTER SPRINGS, WV	2016-06-23	17.82	34,600	EMA Fitted Annual Frequency Curve	72	36,690	34,900	0.013	75
					17B Fitted Annual Frequency Curve	69	37,030	34,900	0.014	72
03196800	ELK RIVER AT CLAY, WV	2016-06-23	30.30	63,100[F]	EMA Fitted Annual Frequency Curve	Not available[2]	Not available[2]	54,000	Flow regulated	Flow regulated
					17B Fitted Annual Frequency Curve	Not available[2]	Not available[2]	54,000	Flow regulated	Flow regulated
03197000	ELK RIVER AT QUEEN SHOALS, WV	2016-06-24	33.31	82,700[F]	EMA Fitted Annual Frequency Curve	Not available[2]	Not available[2]	64,500	Flow regulated	Flow regulated
					17B Fitted Annual Frequency Curve	Not available[2]	Not available[2]	64,500	Flow regulated	Flow regulated

Questions?

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