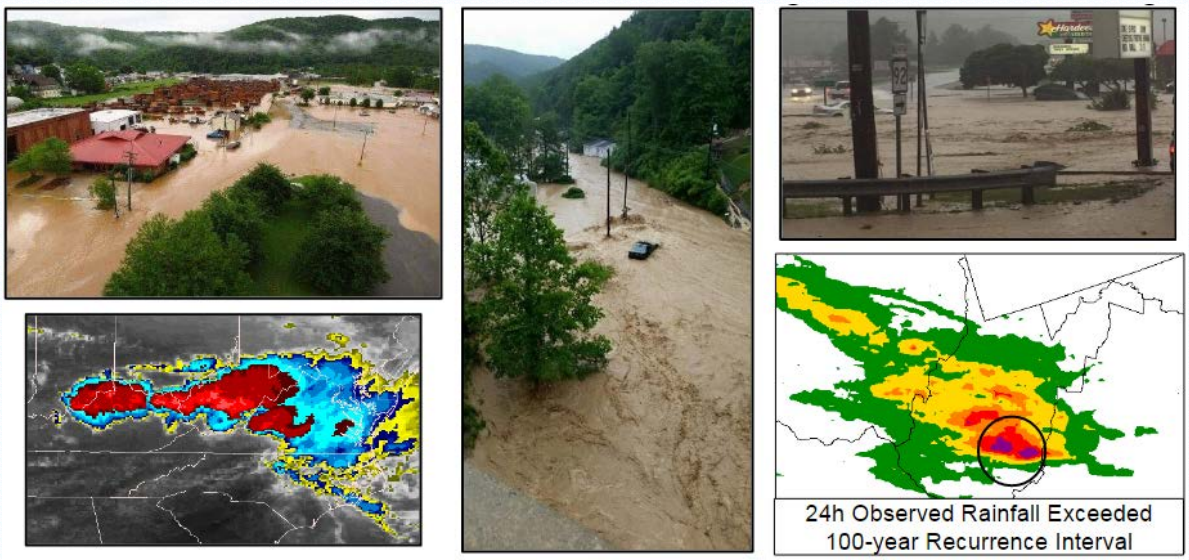
U. S. Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service – Eastern Region Headquarters
Regional Operations Center
630 Johnson Avenue
Bohemia, NY 11716

NWS Summary Report
West Virginia Flash Flooding
June 23, 2016

EVENT SUMMARY

a. Meteorological Overview

During Thursday, June 23, 2016, several rounds of intense convection spread northwest to southeast across the central Appalachians associated with a progressive shortwave trough and frontal system. Lift with the trough and front acted upon an anomalously moist and unstable air mass. Terrain and convective cold pool influences likely enhanced rainfall intensity and resulted in catastrophic flash flooding, historic river flooding, and 23 fatalities in West Virginia.



Five days in advance, June 19, the Weather Prediction Center (WPC) extended forecast discussion and the Weather Forecast Office (WFO) Blacksburg, VA (RNK) hazard weather outlook first mentioned the possibility of a heavy rain event.

EXTENDED FORECAST DISCUSSION
NWS WEATHER PREDICTION CENTER
COLLEGE PARK MD
241 AM EDT SUN JUN 19 2016

12Z WED JUN 22 2016 - 12Z SUN JUN 26 2016

FARTHER EWD IMPORTANT DETAILS ARE YET TO BE RESOLVED BUT THERE IS GRADUALLY INCREASING SIGNAL TOWARD THE EXISTENCE OF APLAINS TO WRN ATLC SYSTEM **WEDNESDAY ONWARD WHICH WILL BE ACCOMPANIED BY ORGANIZED CONVECTIVE RAINFALL. SOME OF THIS ACTIVITY MAY BE LOCALLY HVY AND/OR STRONG.**

Four days in advance, June 20, experimental reforecast and extreme event guidance, derived from near real time GFS numerical weather prediction began to indicate the possibility of an extreme precipitation event (> 95th percentile rank) and WFO Charleston, WV (RLX) hazard weather outlook highlighted an excessive rainfall threat (Fig. 1)

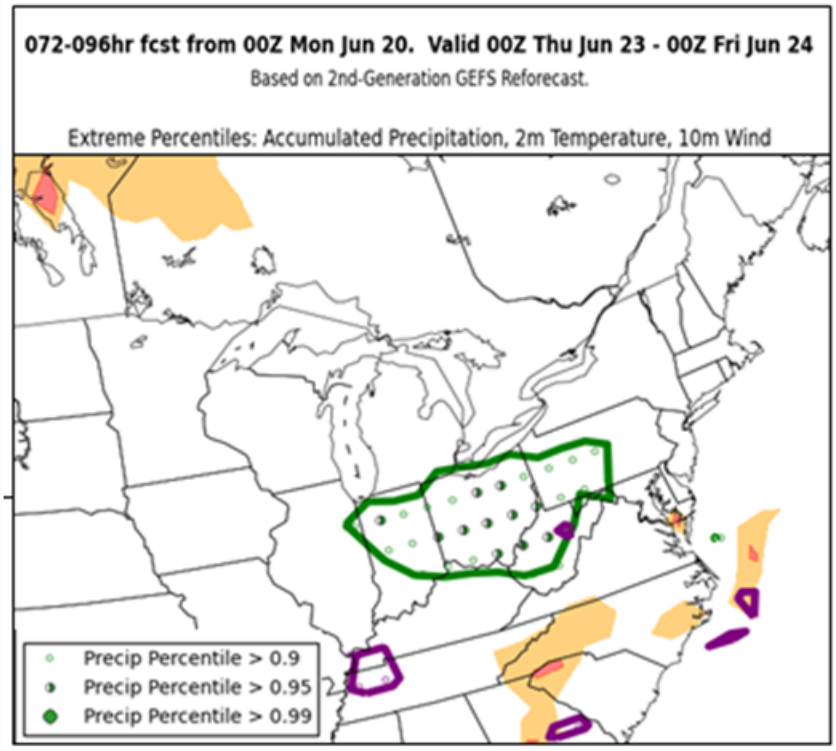


Figure 1. 00UTC Mon Jun 20 GEFS Reforecast and Extreme Event Guidance 072-096hr forecast valid 00UTC Thu Jun 23 – 00UTC Fri Jun 24

HAZARDOUS WEATHER OUTLOOK
NATIONAL WEATHER SERVICE CHARLESTON, WV

CARTER-BOYD-LAWRENCE KY-DICKENSON-BUCHANAN-WAYNE-CABELL-LINCOLN-
PUTNAM-KANAWHA-MINGO-LOGAN-BOONE-CLAY-BRAXTON-MCDOWELL-WYOMING-
RALEIGH-FAYETTE-NICHOLAS-WEBSTER-POCAHONTAS-RANDOLPH-
444 AM EDT MON JUN 20 2016

.DAY ONE...TODAY AND TONIGHT.
HAZARDOUS WEATHER IS NOT EXPECTED AT THIS TIME.

.DAYS TWO THROUGH SEVEN...TUESDAY THROUGH SUNDAY.
THERE IS A SLIGHT RISK FOR SEVERE THUNDERSTORMS TUESDAY AFTERNOON AND EVENING...AND AGAIN WEDNESDAY NIGHT THROUGH THURSDAY...DURING WHICH TIME AN EXCESSIVE RAINFALL THREAT MAY ALSO DEVELOP.

WPC 24 hour QPF totals are valid for the 00-00 UTC period from Wednesday evening (EDT), June 22 through Thursday evening (EDT), June 23 during which most of the extreme rainfall and flash flooding was observed (Fig. 2). Maximum amounts of 2-3+ inches, and the forecast location of the heaviest precipitation, improved as lead time to the event decreased. The 24 hour forecast issued late Wednesday, June 22 and valid for the upcoming Day 1 time frame, placed the maximum QPF of 3.89 of inches in about the exact location to where the maximum rainfall was observed. WPC forecasts also correctly trended south with time, indicating the maximum rainfall would occur south of where numerical weather prediction forecasts were suggesting.

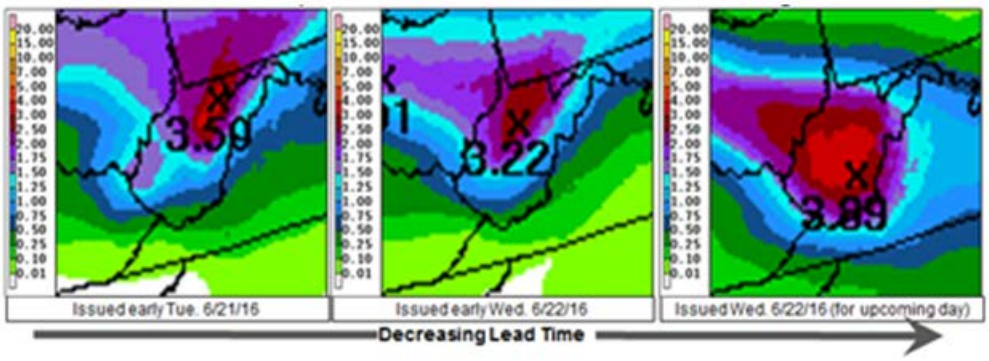


Figure 2. WPC 24-Hour Precipitation Forecasts Valid 00-00UTC Wed Jun 22 – Thu Jun 23

The first watches hit the streets early Wednesday morning, June 22. RLX issued a flash flood watch at 4:26 am for the northern half of its county warning area (~30 hour lead time). The watch included four of the counties in the hardest hit areas (Jackson, Roane, Webster and Pocahontas). The watch was expanded at 2:57 pm to include four more counties in the hardest hit area (Clay, Fayette, Kanawha and Nicholas). RNK issued a flash flood watch for its four southeast WV counties (Greenbrier, Summers, Mercer and Monroe) and two VA counties (Alleghany & Bath) at 5:09 pm (~18 hour lead time). This included the areas that would eventually be most impacted by flooding the following day. RLX would expand the flash flood watch again at 9:23 pm to include Lincoln County so that all the counties that would later receive a Federal Declaration due to flooding were now covered.

In WPC's mesoscale precipitation discussion late Wednesday night 0345 UTC, June 23, the possibility of heavy rainfall and flash flooding was highlighted as a concern across northern West Virginia as a maturing MCS continued to progress southeast (Fig. 3). The combination of a plume of deep moisture convergence and a strengthening low level jet from the Central Plains to West Virginia was likely to support rainfall rates exceeding 2 inches per hour (Fig. 4). WPC's discussion specifically highlighted the increasing threat for isolated areas of flash flood guidance exceedance, especially in West Virginia later in the period where values were lower.

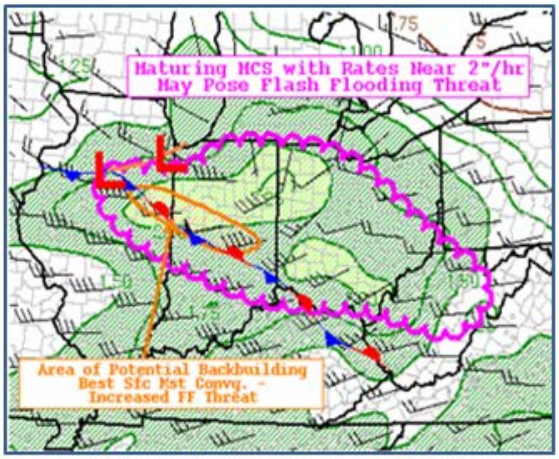


Figure 3. WPC Mesoscale Discussion MPD #0397 issued 11:43PM EDT Wed Jun 22

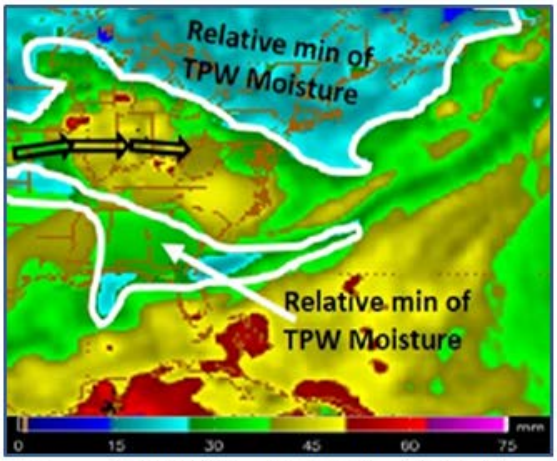


Figure 4. NESDIS Blended Total Precipitable Water (TPW) Moisture Imagery 0300UTC Thu Jun 23

Water vapor/infrared satellite loop showed the long fetch *"atmospheric river"* of moisture convergence with embedded short wave forcing heading for West Virginia. The mid-level wind flow was parallel to the deep moisture plume and provided good moisture transport from the tropical eastern Pacific to the Central Plains to West Virginia. A strengthening upper level jet to over 110 KTS was expected to track across New York and

New England allowing for additional upward vertical velocity divergence in the right entrance region as it progressed across Ohio toward West Virginia later in the period (Fig. 5 and Fig. 6)

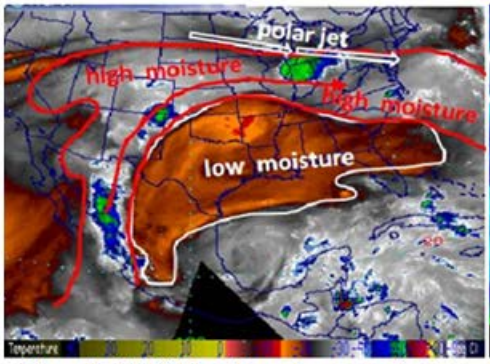


Figure 5. GOES Water Vapor Imagery and Analysis 0315UTC Thu Jun 23

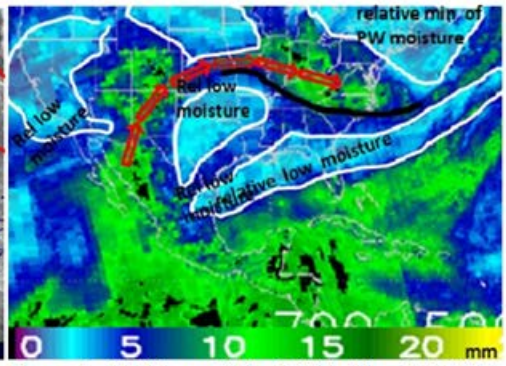


Figure 6. CIRA Layered Precipitable Water 3-5.5 KM 0300UTC Thu Jun 23

A NOAA HYSPLT 120 hour backward trajectory analysis from 1800 UTC, June 23 ending at 1000, 3000, and 5000 meters over KLWB (Greenbrier Airport, WV) shows the deep warm-air advection, the overall westerly airflow, and the deep ascent over the previous 18 hours for the trajectories ending at 3000 and 5000 m. This trajectory analysis indicates that air at 1000 meters, 3000 meters, and 5000 meters over the Greenbrier Airport likely originated over the Gulf Stream east of Cape Hatteras, over the central Gulf of Mexico, and over the Intermountain west, respectively (Fig. 7).

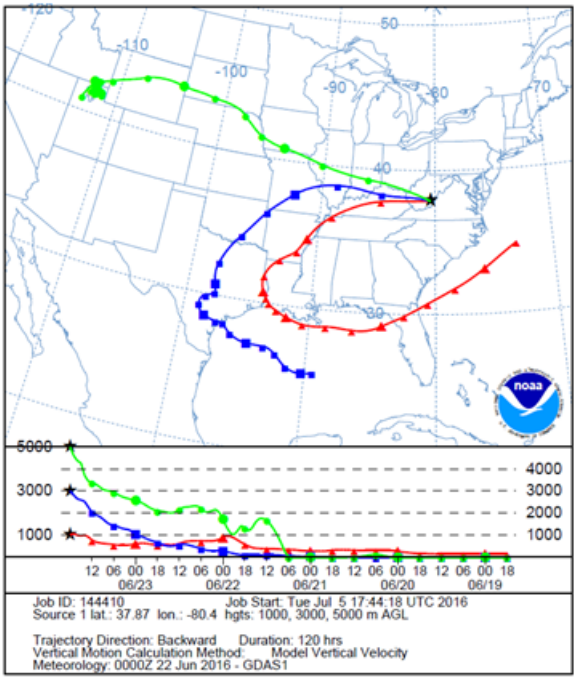


Figure 7. NOAA HYSPLIT Model Backward trajectories from the GDAS Analysis ending at 1800 UTC Thu Jun 23

In the meantime, less than two hours after WPC issued their 0345 UTC mesoscale precipitation discussion, the Charleston forecast office began severe weather warning operations as convection broke out across their Ohio counties (Fig. 8). The first severe thunderstorm warning was issued at 1:37 am Thursday, June 23 followed by a tornado warning at 2:04 am. Their first flash flood warning was issued at 2:24 am for counties in southeast Ohio. They continued issuing severe thunderstorm and flash flood warnings through 8:00 am until the first wave waned. Downstream of Charleston, WFO Blacksburg issued its first severe thunderstorm warning of the day at 5:29 am, but the more organized severe weather and flash flooding began shortly after 8:00 am (Fig. 9).

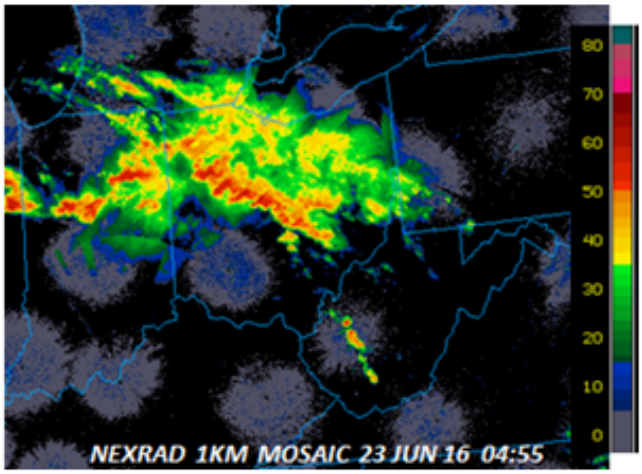


Figure 8. NEXRAD 1KM Mosaic Reflectivity 0455UTC Thu Jun 23

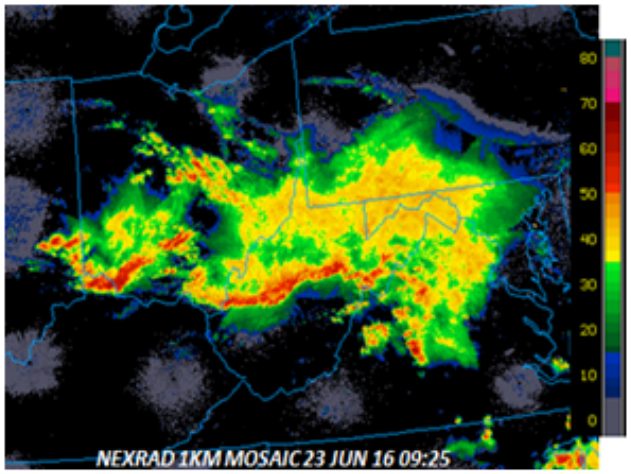


Figure 9. NEXRAD 1KM Mosaic Refelctivty 0925UTC Thu Jun 23

Convection continued to train over much of central West Virginia early in the afternoon. Hourly rainfall rates had maximized in the 1.50 to 1.75 inch range. Additional thunderstorm activity began to fire across southern Ohio and northeastern Kentucky. Those storms would migrate into saturated ground in West Virginia. WPC's mesoscale precipitation discussion Thursday afternoon 1743 UTC, June 23, highlighted the likelihood flash flooding would continue to be a threat as the thunderstorm training episode continued (Fig. 10)

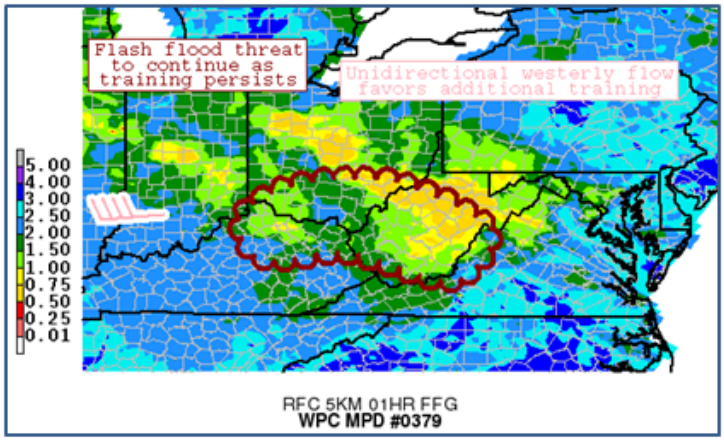


Figure 10. WPC Mesoscale Discussion MPD #0379 issued 1:44PM EDT Thu Jun 23

Mesoscale model performance was inconsistent. The operational High Resolution Rapid Refresh (HRRR) forecasts were slow to identify the magnitude of the additional convection over portions of West Virginia (Fig. 11). The HRRR did not identify the event until the 10-12 UTC runs which became available approximately 9:00 am June 23. The HRRR did have the rainfall mostly in the right place within 6 hours or so of the event, but rainfall amounts were underdone in comparison to the NCAR real-time mesoscale ensemble. The NCAR real-time mesoscale ensemble initialized at 0000 UTC June 23 did a pretty good job of forecasting a narrow corridor of very heavy rainfall (maximum > 12 inches) over WV but was too far north and east (Fig. 12).

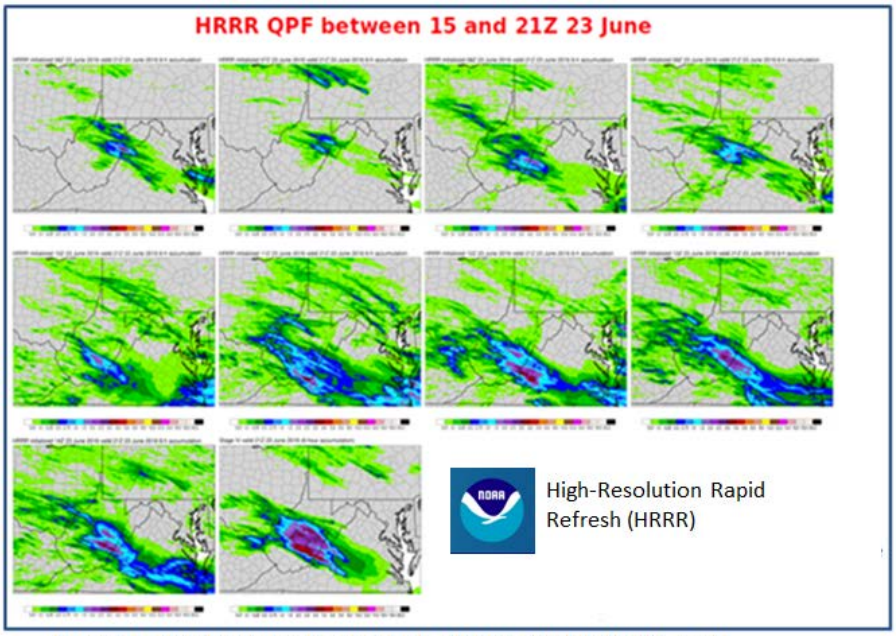


Figure 11. High Resolution Rapid Refresh (HRRR) QPF 12UTC Thu Jun 23

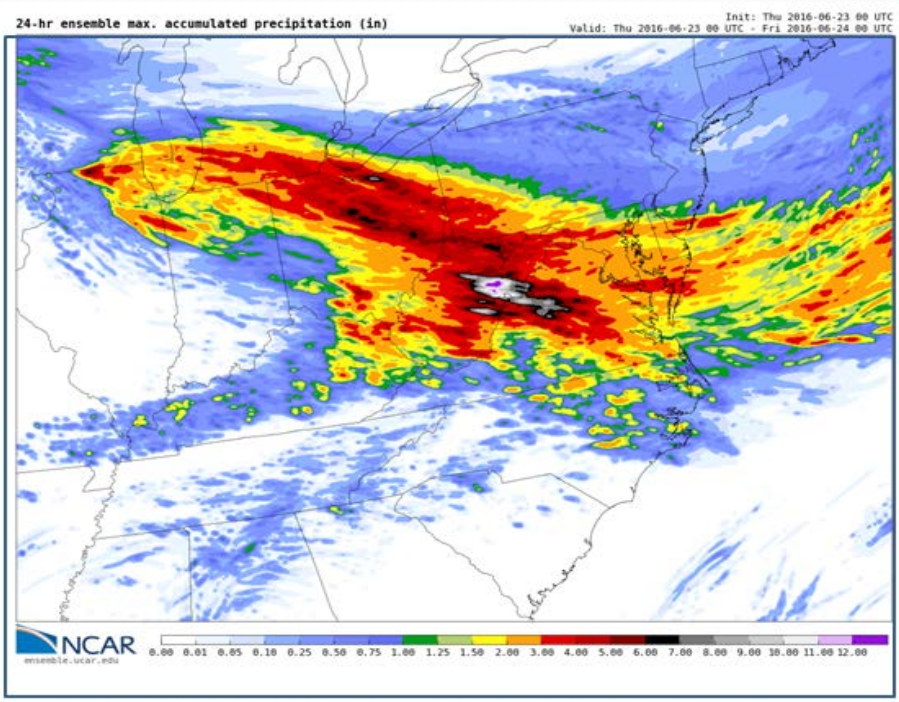
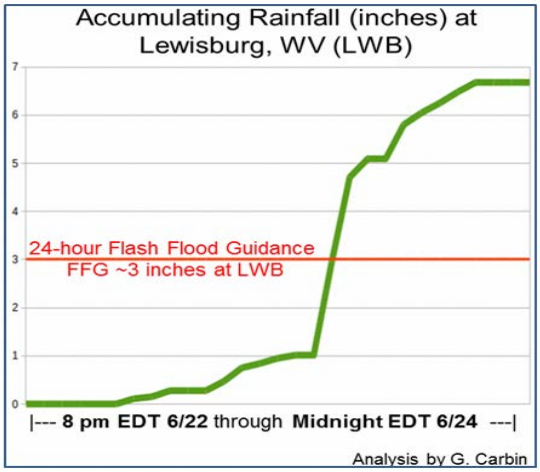
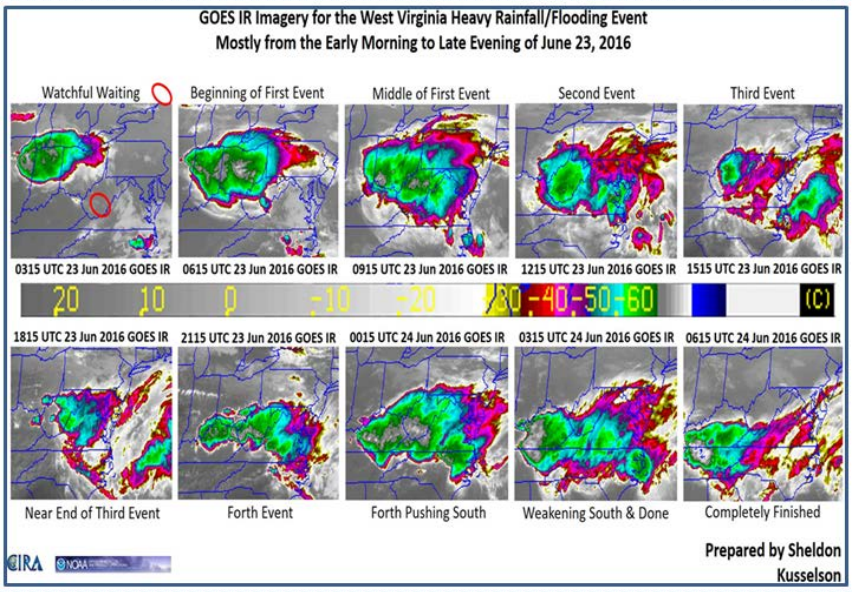


Figure 12. NCAR Real-Time Mesoscale Ensemble 00UTC Thu Jun 23 Valid 00-00UTC Thu Jun 23 – Fri Jun 24

There were four distinct waves of convection and heavy rainfall that moved across West Virginia on June 23 as seen in the accumulating rainfall plot report at Lewisburg, WV (LWB), the GOES IR imagery timeline and in the dual-polarization Doppler radar mosaic images (Fig. 13). The first wave moved across the state in the early morning hours around 2:00 am/0600 UTC. The second wave swept in from the northwest around 8:00 am/1200 UTC. The third wave, which began around 11:00 am/1500 UTC, is when the most significant amount of accumulated rainfall fell and set the table for the catastrophic hydrologic response. The fourth and final wave began to approach from Ohio around 5:30 pm/2130 UTC with the last of the convection and rainfall spreading southeast and exit the state around 11:00 pm/0300 UTC.





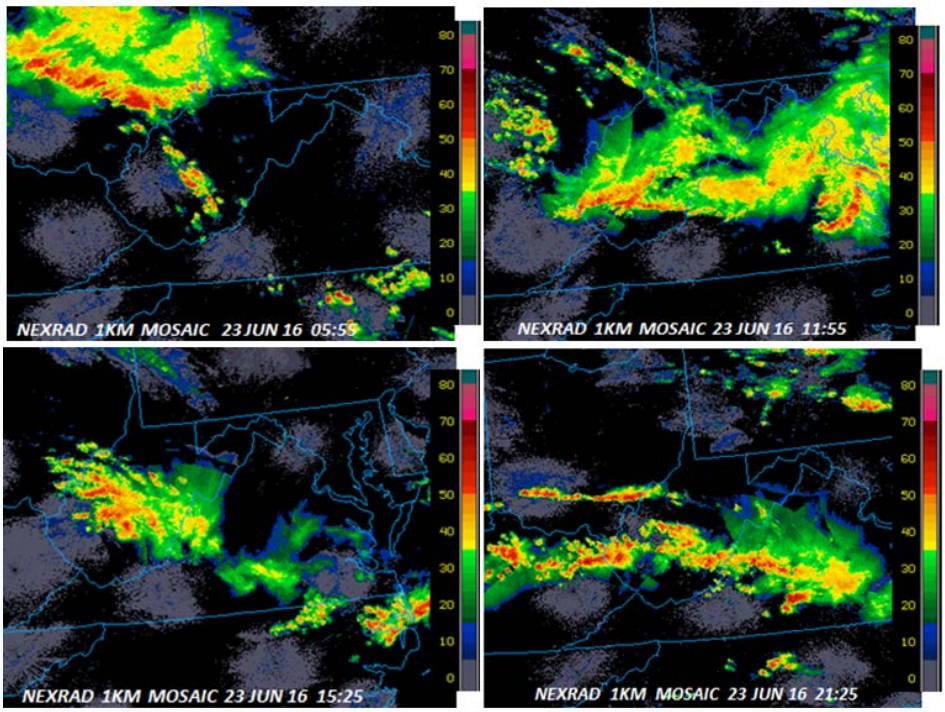


Figure 13. Accumulating Rainfall (inches) at Lewisburg, WV
GOES IR Imagery 0315UTC Thu Jun 23 – 0615UTC Fri Jun 24
NEXRAD 1KM Mosaic Reflectivity 0555UTC – 2125UTC Thu Jun 23

b. Antecedent Conditions

Antecedent conditions leading into June 23, 2016 were wetter than normal and therefore less conducive to effective infiltration and storage. West Virginia experienced greater than 150 percent of normal precipitation during the previous month (May 2016). Areas in the southern half of the state received 6-8 inches of precipitation during the month compared to an average 3-6 inches. Soil moisture conditions, an important indicator of infiltration capacity, were very moist as depicted in the NASA's Soil Moisture Active Passive (SMAP) Volumetric Soil Moisture (VSM) image (Fig. 14).

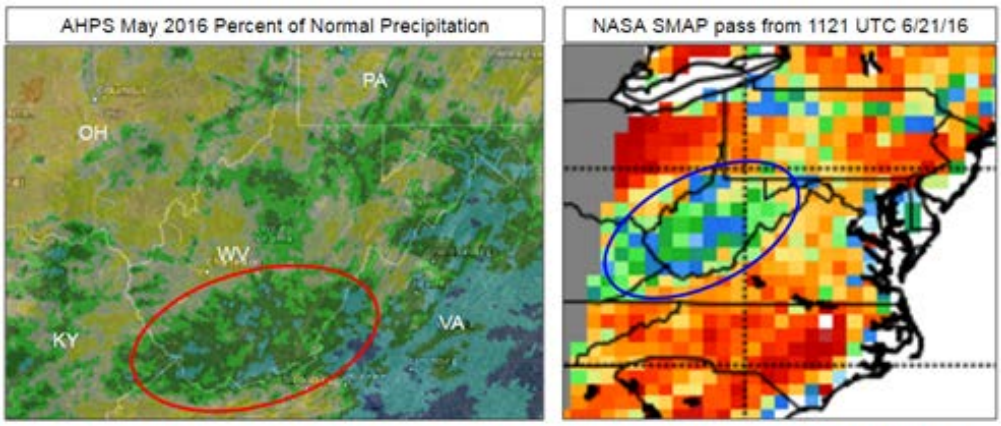


Figure 14. AHPS Percent of Normal Precipitation May 2016 and NASA SMAP Volumetric Soil Moisture 0-5cm 1121UTC Tue Jun 21

e. Impacts

Approximately 8 to 10 inches of rain fell in less than a 12-hour period in the most severely impacted areas of Greenbrier County, WV (Fig. 15). This equated to a 1/1000 year frequency of occurrence interval as analyzed by the Hydrometeorological Design Studies Center (HDSC) (Fig. 16). The greatest weather-related weather impact in the Blacksburg and Charleston county warning areas was due to flash flooding.

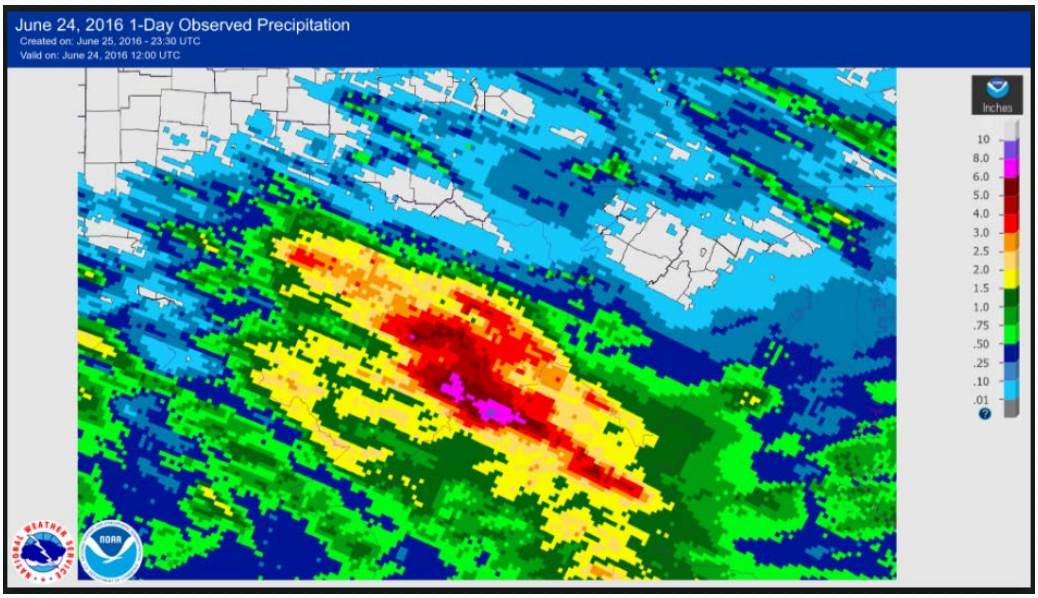


Figure 15. Quantitative Precipitation Estimates 1-Day Observed Precipitation Valid 1200UTC Wed Jun 23 to 1200UTC Thu Jun 24

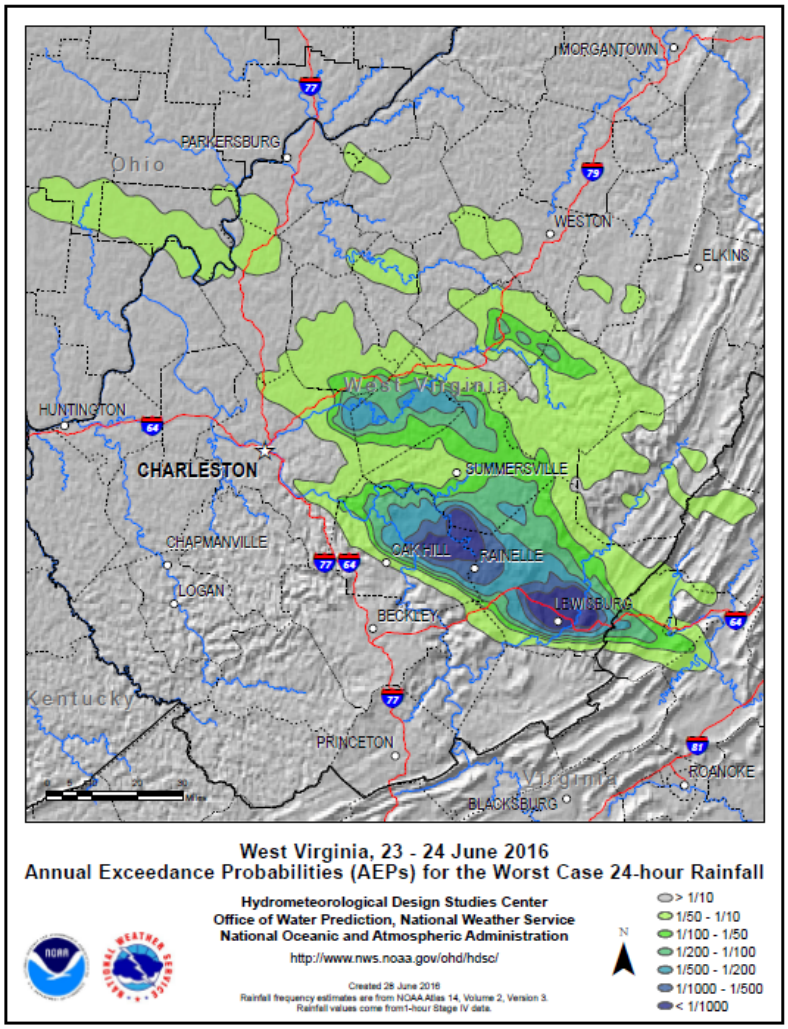


Figure 16. Hydrometeorological Design Studies Center Annual Exceedance Probabilities (AEPs) for the Worst Case 24-hour Rainfall - WV 23-24 Jun

Preliminary impacts include:

- 4000 residential homes damaged
- 1500 residential homes destroyed
- 234 businesses impacted
- 49 businesses destroyed
- 2500 people displaced (living with families, in shelter or other locations)
- 35 schools were affected or received damage
- 3 schools received major damage and will not be able to open in the fall (this will impact approximately 1400 students and faculty)

The State Emergency Operations Center (SEOC) was at full activation with the Governor declaring a State of Emergency on June 23 for 44 counties. However, this was later revised to 12 counties: Clay, Fayette, Greenbrier, Jackson, Kanawha, Lincoln, Monroe, Nicholas, Pocahontas, Roane, Summers, and Webster. Nine of those counties are in WFO Charleston's county warning area and three in WFO Blacksburg's.

A Federal Disaster Declaration was requested and granted by Governor Earl Ray Tomblin (FEMA-4273-DR). This declaration provides for Individual Assistance (IA), emergency protective measures (Category B) and direct federal assistance under the Public Assistance (PA) program for twelve counties. This includes emergency medical support, housing and addresses a number of immediate needs, to residents in those impacted counties. Federal Disaster Recovery Centers (DRCs) are operational in Clay, Roane, Summers, Nicholas, Greenbrier and Kanawha counties.

Seventy-two million dollars in federal disaster assistance have been approved to date (July 29). FEMA has approved nearly $29.8 million in housing assistance, more than $5.4 million in other needs assistance and $1.43 million in public assistance. In addition, the SBA approved 426 low-interest disaster loans totaling more than $27.9 million, and 939 NFIP claims have been filed totaling more than $7.5 million in payouts. A total of 8,034 households and businesses have applied to FEMA for disaster assistance.

Damage to roads and bridges was extensive. Barges broke loose and struck bridges causing damage. The Towns of Clendenin and Elkview were cutoff due to road and bridge washouts. In Elkview, a temporary bridge was built to rescue nearly 500 persons isolated at a shopping center. Mudslides and landslides wreaked havoc and closed a number of roads including Interstate 79 near mile marker 21 forcing a shutdown in both directions.

West Virginia Division of Highway's preliminary estimate of road and highway damage is $39.7 million (Table 2). [Updated 7/7/16 – flooding damage to roads tops $45 million].

County	District	Total FEMA Cost	Total FHWA Cost	Total
Clay	1	$8,058,500	$463,000	$8,521,500
Kanawha	1	$4,202,000	$1,577,500	$5,779,500
Lincoln	2	$428,450	$0	$428,450
Wayne	2	$334,700	$100,000	$434,700
Jackson	3	$452,000	$15,000	$467,000
Roane	3	$1,668,500	$1,045,500	$2,714,000
Braxton	7	$182,000	$25,000	$207,000
Gilmer	7	$244,250	$135,000	$379,250
Lewis	7	$151,500	$0	$151,500
Upshur	8	$119,000	$0	$119,000
Webster	8	$1,497,100	$457,350	$1,954,450
Pocahontas	8	$418,085	$291,550	$709,635
Randolph	8	$220,500	$25,500	$246,000
Fayette	9	$1,630,700	$1,417,500	$3,048,200
Greenbrier	9	$2,674,880	$2,859,200	$5,534,080
Nicholas	9	$4,305,985	$4,112,600	$8,418,585
Summers	9	$548,000	$80,000	$628,000
Total		**$27,136,150**	**$12,604,700**	**$39,740,850**

Table 2. WVDOH Preliminary Road Damage Estimates

In Alleghany County, VA three first responders were injured, one critically, while assisting with evacuations.

According to the Office of the Chief Medical Examiner, the number of deaths attributed to the floods remains at twenty-four (24).

Fatality totals by county:

- Greenbrier: 16
- Kanawha: 6
- Ohio: 1
- Jackson: 1

f. Hydrologic Response

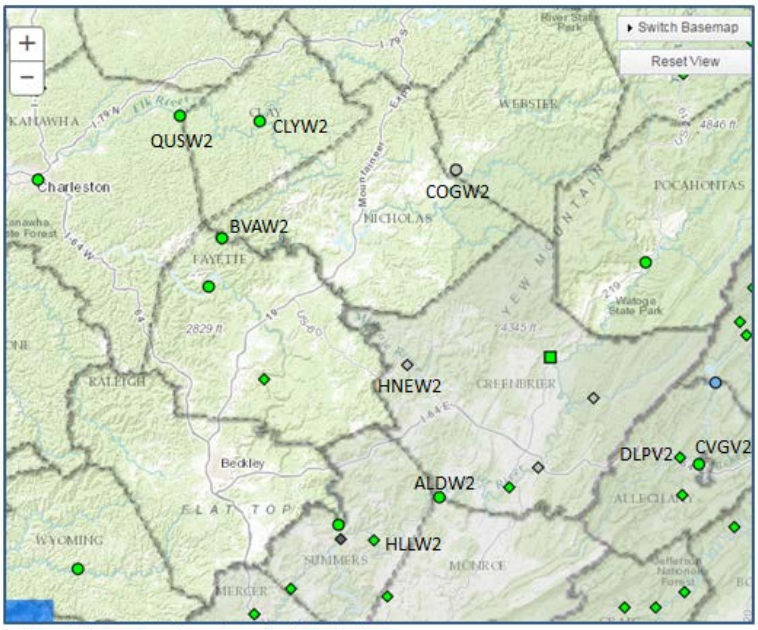
Catastrophic flash flooding occurred from repeated lines of intense convection producing a maximum of 8-10 inches of precipitation in a 12-24 hour period. The primary watersheds impacted in the federally declared disaster area were the Greenbrier, Elk and Gauley river basins, as well as numerous smaller watersheds. The rapid and steep vertical responses seen in the Advanced Hydrologic Prediction Service (AHPS) and U.S. Geological Survey (USGS) WaterWatch storm hydrographs are indicative of small watersheds overwhelmed by intense rainfall and rapid runoff.

Record flooding occurred on the Gauley River at Camden-on-Gauley, Dunlap Creek near Covington, and Elk River at Queen Shoals.

- Gauley River at Camden-on-Gauley (COGW2) reached 39.75 feet, breaking the previous height of 27.38 set in July 1932. Flood stage is 19 feet. Camden-on-Gauley is upstream of Belva (BVAW2).
- Elk River at Queen Shoals (QUSW2) reached 33.37 feet, breaking the previous height of 32.0 feet set in January 1888. Flood stage is 19 feet. Queen Shoals is downstream of Clay (CLYW2).
- Dunlap Creek near Covington (DLPV2) reached 16.49 feet, breaking the previous height of 15.65 feet set in June 1972. Flood stage is 9 feet.

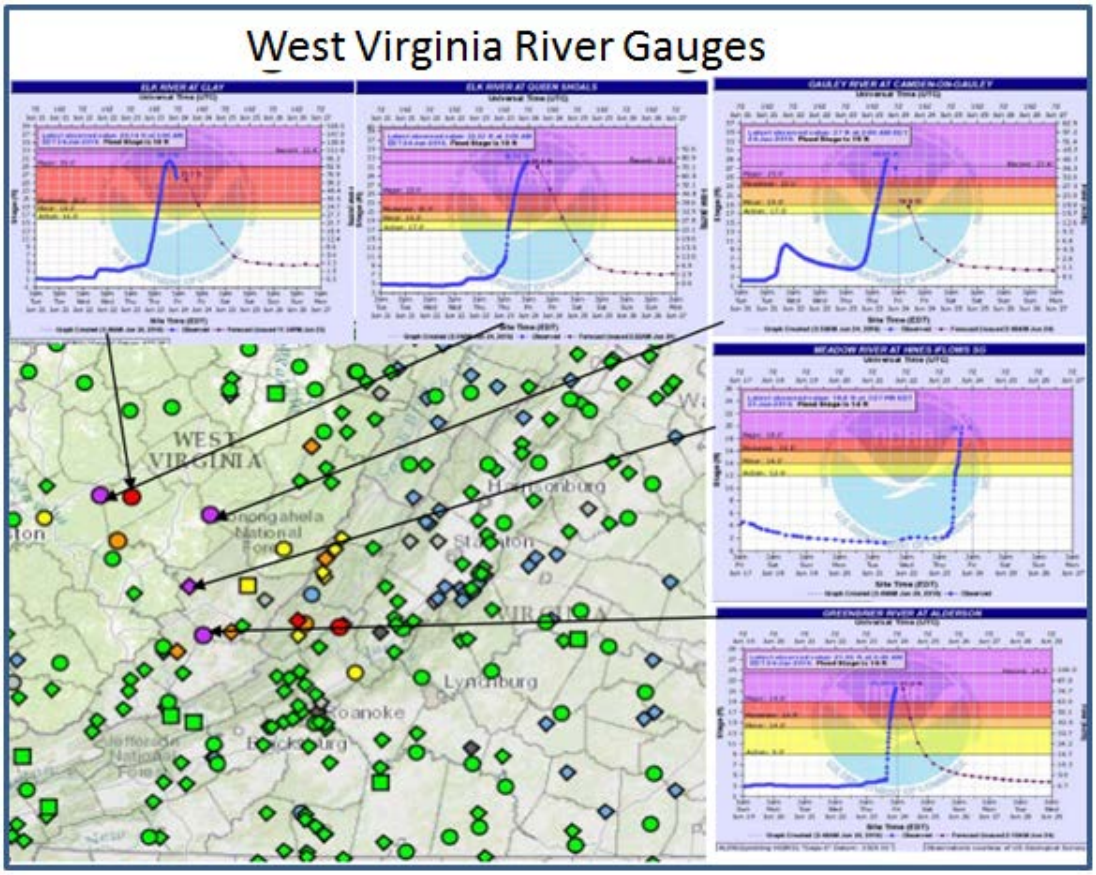
Major to near record flooding occurred on the Elk River at Clay, Gauley River at Belva, and Greenbrier River at Alderson and Hilldale.

- Elk River at Clay (CLYW2) reached 30.30 feet, making this the third highest crest on record; a level last seen in 1861 and 1918. Flood stage is 18 feet. Clay is upstream of Queen Shoals (QUSW2).
- Gauley River at Belva (BVAW2) reached 27.02 feet making this the second highest crest on record; a level last seen in 1932. Flood stage is 20. Belva is downstream of Camden-on-Gauley (COGW2).
- Greenbrier River at Alderson (ALDW2) reached 22.00 feet making this the third highest crest on record; a level last seen in 1985 and 1996. Flood stage is 14 feet. Alderson is upstream of Hilldale (HLLW2).
- Greenbrier River at Hilldale (HLLW2) reached 25.45 feet making this the third highest crest on record; a level last seen in 1985 and 1996. Flood stage is 16 feet. Hilldale is downstream of Alderson (ALDW2).
- Jackson River at Covington (CVGV2) reached its 22.33 feet making it the 3rd highest crest on record at the current datum and second highest since the completion of Gathright Dam in 1979. The November 1985 flood reached 23.31 feet. Flood stage is 17 feet.

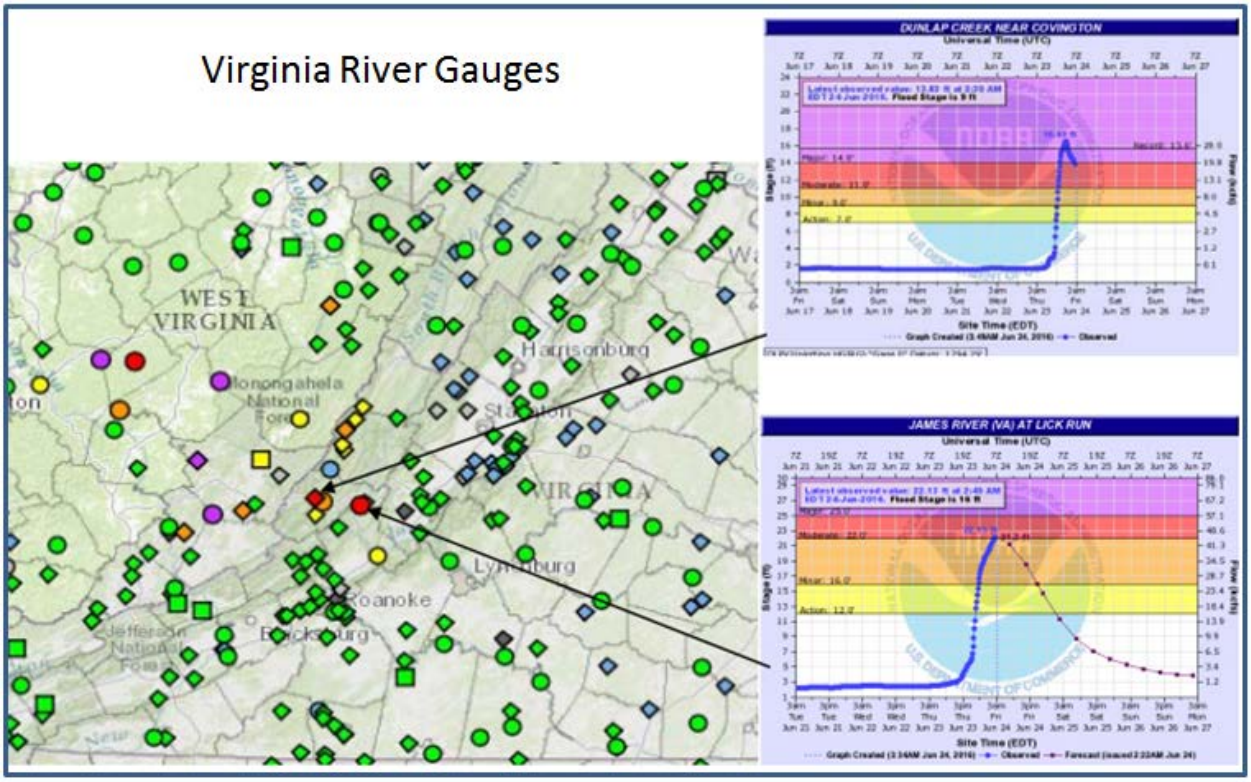


Map of AHPS River Locations in West Virginia

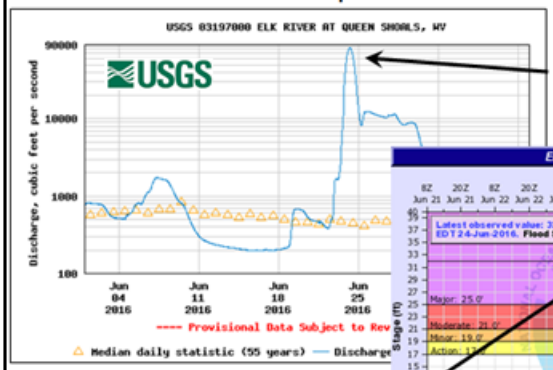
West Virginia River Gauges



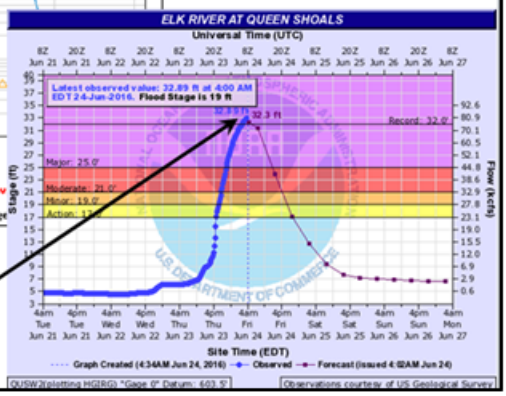
Virginia River Gauges



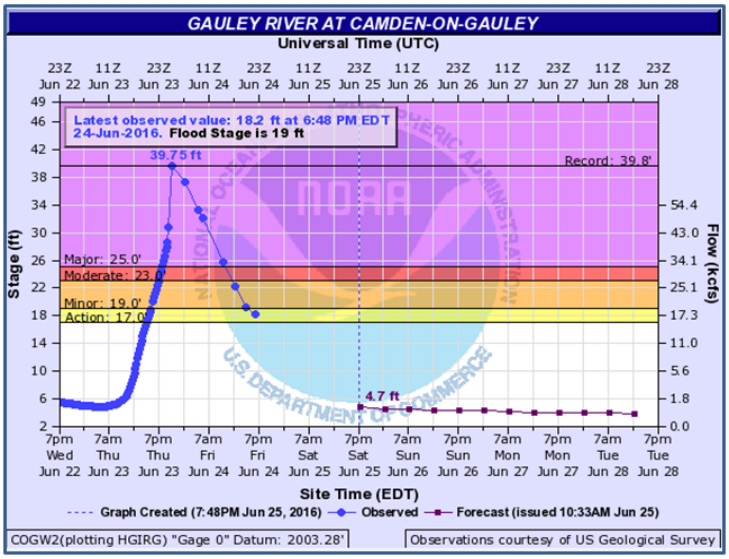
River Response to Extreme Rainfall

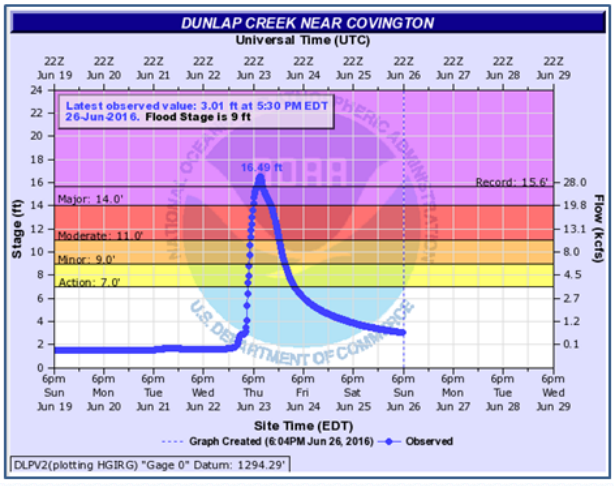


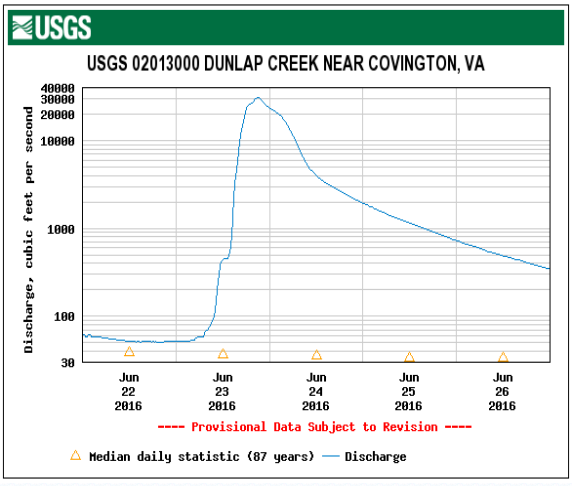
Elk River discharge (CFS) at Queen Shoals, WV on 6/24/16 reaching nearly 100X the historic median values △.

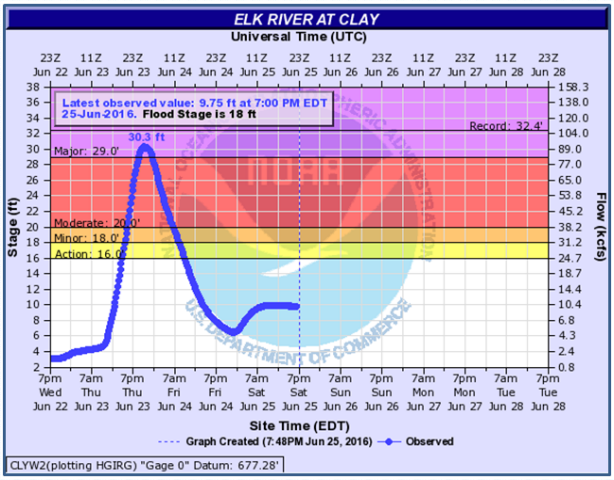


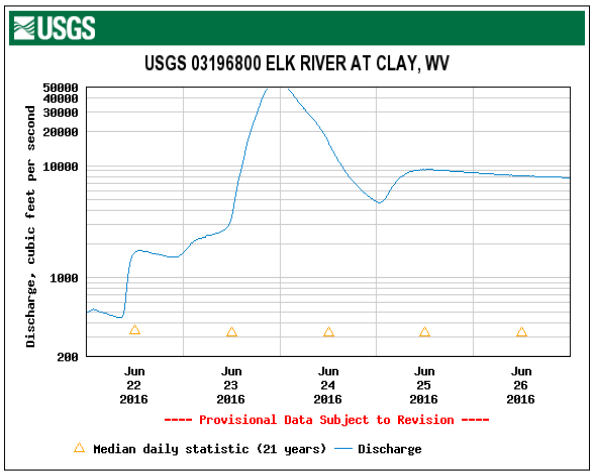
The Elk River at Queen Shoals reaching 32.89 feet, breaking previous record height of 32 feet set in January 1888. Flood stage is 19 feet.

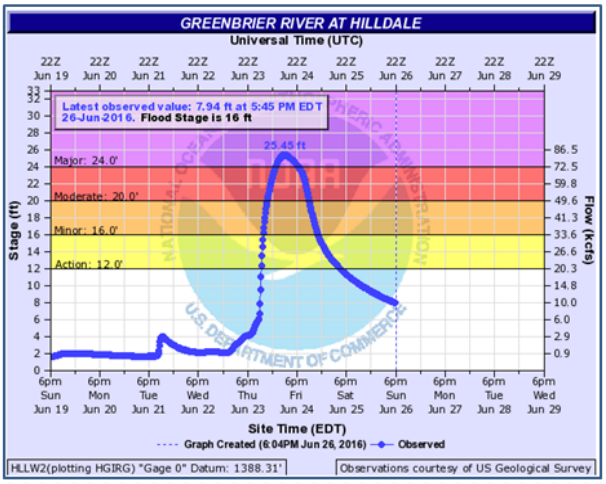


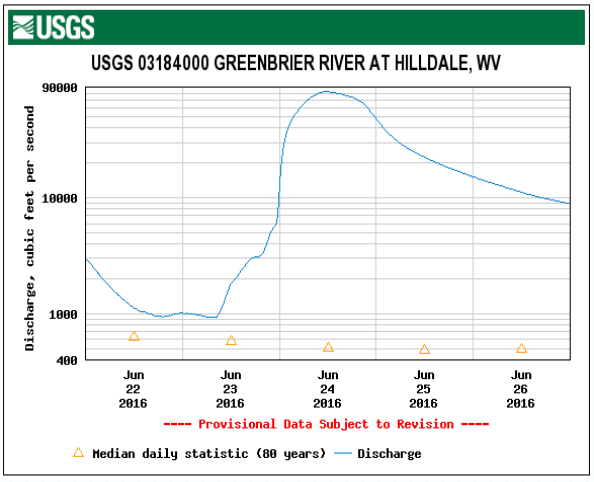


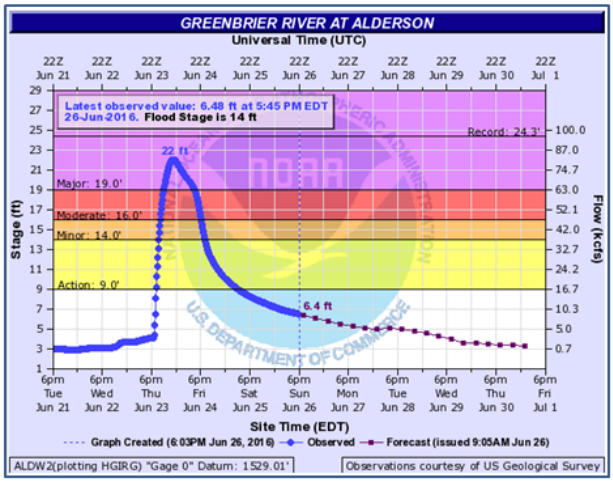


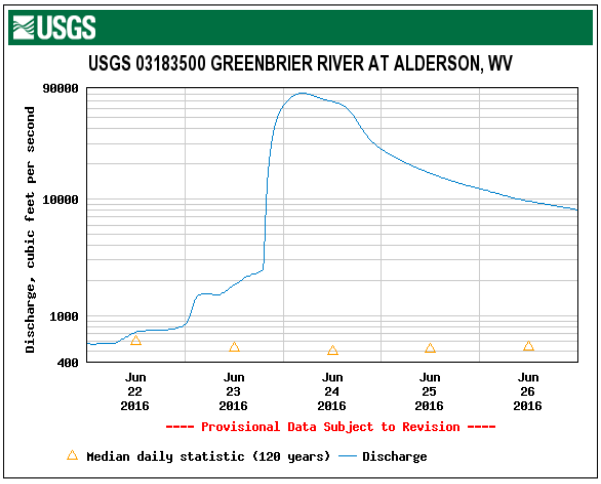

ELK RIVER AT CLAY
Universal Time (UTC)
Latest observed value: 9.75 ft at 7:00 PM EDT 25-Jun-2016. Flood Stage is 18 ft
Record: 32.4'
30.3 ft
Major: 29.0'
Moderate: 20.0'
Minor: 18.0'
Action: 16.0'
Stage (ft)
Flow (kcfs)
Site Time (EDT)
Graph Created (7:48PM Jun 25, 2016)
Observed
CLYW2(plotting HGIRG) "Gage 0" Datum: 677.28'

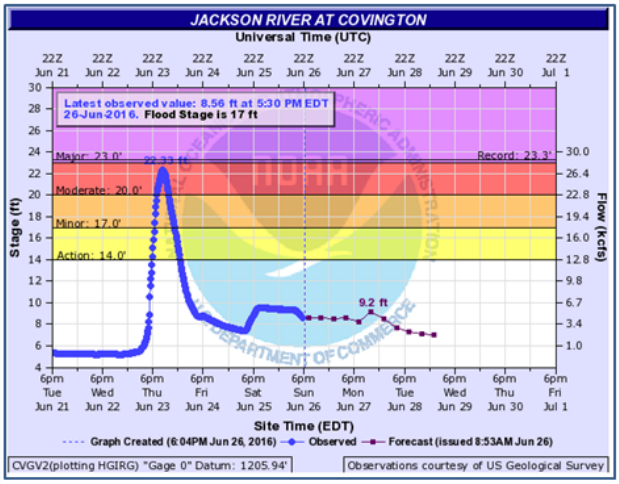

USGS
USGS 03196800 ELK RIVER AT CLAY, WV
Discharge, cubic feet per second
---- Provisional Data Subject to Revision ----
Median daily statistic (21 years)
Discharge

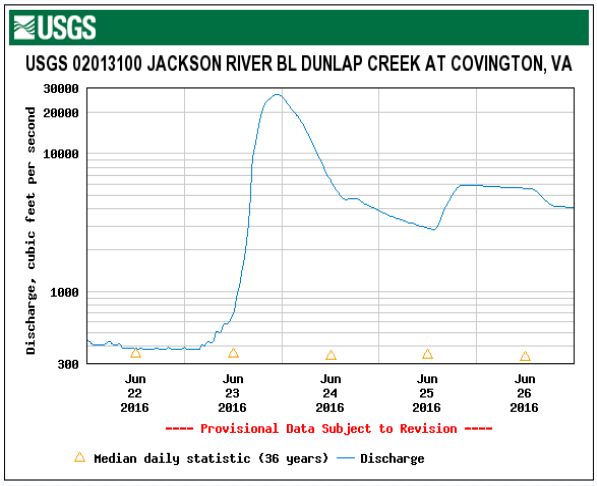

GREENBRIER RIVER AT HILLDALE
Universal Time (UTC)
Latest observed value: 7.94 ft at 5:45 PM EDT 26-Jun-2016. Flood Stage is 16 ft
25.45 ft
Major: 24.0'
Moderate: 20.0'
Minor: 16.0'
Action: 12.0'
Stage (ft)
Flow (kcfs)
Site Time (EDT)
Graph Created (6:04PM Jun 26, 2016)
Observed
HLLW2(plotting HGIRG) "Gage 0" Datum: 1388.31'
Observations courtesy of US Geological Survey

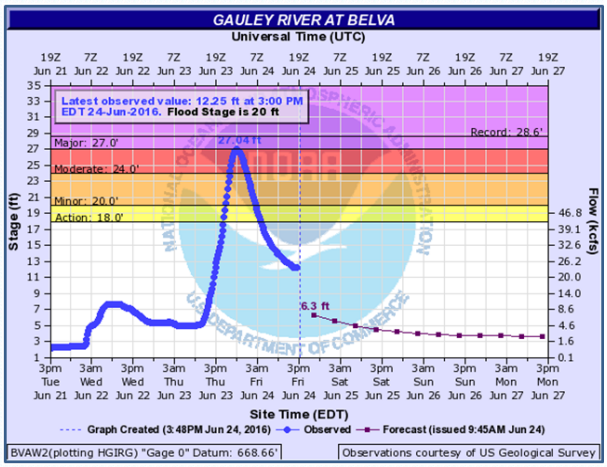

USGS
USGS 03184000 GREENBRIER RIVER AT HILLDALE, WV
Discharge, cubic feet per second
---- Provisional Data Subject to Revision ----
Median daily statistic (80 years)
Discharge

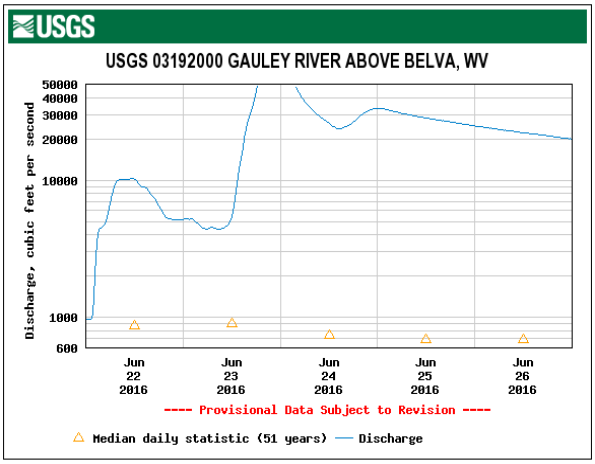

GREENBRIER RIVER AT ALDERSON
Universal Time (UTC)
Latest observed value: 6.48 ft at 5:45 PM EDT 26-Jun-2016. Flood Stage is 14 ft
Record: 24.3'
22 ft
6.4 ft
Major: 19.0'
Moderate: 16.0'
Minor: 14.0'
Action: 9.0'
Stage (ft)
Flow (kcfs)
Site Time (EDT)
Graph Created (6:03PM Jun 26, 2016)
Observed
Forecast (issued 9:05AM Jun 26)
ALDW2(plotting HGIRG) "Gage 0" Datum: 1529.01'
Observations courtesy of US Geological Survey


USGS
USGS 03183500 GREENBRIER RIVER AT ALDERSON, WV
Discharge, cubic feet per second
---- Provisional Data Subject to Revision ----
Median daily statistic (120 years)
Discharge









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