

April 2022

2021 ANNUAL HYDROLOGIC CONDITIONS REPORT

Technical Report No. 2022-2



Managing, Protecting and Improving
the Water Resources of the
Delaware River Basin since 1961



ACKNOWLEDGEMENTS

This report was prepared by the Delaware River Basin Commission staff: Anthony Preucil, Water Resource Scientist and Amy Shallcross, P.E., Water Resource Operations Manager. Anthony Preucil was the principal author of the report. Amy Shallcross, P.E., managed development, provided guidance, and offered technical recommendations.

SUGGESTED CITATION

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LIST OF ACRONYMS/ABBREVIATIONS

ACIS	Applied Climate Information System
AHPS	Advanced Hydrologic Prediction Service
DRB	Delaware River Basin
DRBC	Delaware River Basin Commission
NOAA	National Oceanic and Atmospheric Administration
USGS	United States Geological Survey

DEFINITIONS

Stage – The level of the water above some arbitrary point in the river (commonly measured in feet)

Crest – The level a river peaks at during a flood as it passes a particular point. Used synonymously with ‘peak.’

Water Level – The surface level of a body of water

Action Stage – the stage which, when reached by a rising stream, represents the level where the NWS or a partner/user prepares for possible significant hydrologic activity. The action taken varies for each gage location. Gage data should be closely monitored by any affected people if the stage is above action stage.

Minor Flood – minimal or no property damage, but possibly some public threat. Examples of conditions that would be considered minor flooding include: water over banks and in yards; no building flooded, but some water may be under buildings built on stilts (elevated); water overtopping roads, but not very deep or fast flowing; inconvenience or nuisance flooding. In remote areas with few specific impacts, floods with 5-10 year recurrence interval would be assumed to be causing minor flooding on streams in the area.

Moderate Flood – some inundation of structures, evacuations of people and/or require transfer of property to higher elevations (e.g., move cars, water rescues from flooded streets). During a moderate flood, water is deep enough over the road to make driving unsafe. In remote areas with few specific impacts, floods with 15-40 year recurrence interval would be assumed to be causing minor flooding on streams in the area.

Major Flood – Extensive inundation of structures and roads occurs. Significant evacuation and/or transfer of property to higher elevations are necessary. Multiple Homes flooded, moved off foundations. Extreme erosion occurs. In remote areas with few specific impacts, floods with 50-100 year recurrence interval would be assumed to be causing major flooding on streams in the area.

Statement on flood locations: Note that the flooding documented in this report refers to stream flooding and uses data from stream gages along the main stem of the Delaware River and several tributaries. While flooding likely occurred in many locations not included below, only the reported data was used. While flash flooding may have also occurred in several locations, the impacts of flash flooding are not detailed herein.

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1. MAIN HYDROLOGICAL EVENTS IN 2021

Hydrologic conditions ranged from a wet beginning to a dry end. Significant rainfall events led to record-breaking flooding in the summer and fall. However, drier than normal conditions developed at the end of the year. Highlights from the year are summarized below. More information about precipitation, storm events, flow, storage, and groundwater are presented in the sections that follow. References and links to data resources are listed under references section.

1.1 JANUARY 31 – FEBRUARY 2, 2021: WINTER STORM AND RIVER ICE IMPACTS

The first winter storm of the year occurred on January 31. Snow amounts were highest in northeast Pennsylvania, where some areas received more than 30 inches of snow over the three-day period. Figure 1 shows the map of snowfall totals in the DRB. Areas north of Trenton, N.J. received over 12 inches of snow. The combined snow and ice in the river led to minor ice build-up at several locations along the river. The time-series of the water level at Trenton, N.J. on January 30, presented in Figure 2, shows a rapid increase in elevation from near 9 feet to 15 feet in approximately 24 hours. A picture of the ice in the Delaware River at Trenton, N.J. is included below. The photo was taken off of Route 29 in New Jersey looking south towards the “Trenton Makes the World Takes” bridge. The ice cleared by February 2. A second period of ice



accumulation developed on February 2 in the evening and cleared by February 3. Flooding did not occur due to the ice build-up. ⁱ

1.2 MARCH 2021 – TOTAL SNOW ACCUMULATION AND SNOWMELT

The seasonal snowfall for the winter of 2020-2021 is shown in Figure 3. Areas north of Trenton, N.J. received more than 35 inches of snow. Some areas in the upper basin received more than 80 inches. Near the estuary, some areas received no measurable snow and other locations received up to 15 inches. Warmer temperatures resulted in snow melt occurring in late February and early March. Snowmelt did not lead to river flooding. Three peaks in flow were observed in March along the mainstem, as shown in Figure 4. The first and third peak in the mainstem were caused by snowmelt runoff only, and the middle peak was a combination of rain and snowmelt. Each event led to increases in flow in the mainstem to approximately 35,000 cfs at Trenton, N.J.

1.3 MAY 2021 – FULL RESERVOIRS

The three New York City (NYC) reservoirs were full, 267.4 billion gallons (BG), at the beginning of May as shown in Figure 22, a normal occurrence. Two rain events (1.0-1.5 inches on April 29, and 1.1-2.7 inches from May 3 to May 5) resulted in spills from each. Cannonsville Reservoir spilled approximately 9.3 BG from April 29 – May 15. Pepacton reservoir spilled approximately 5.0 BG from April 30 – May 16. Neversink reservoir spilled approximately 2.3 BG from May 1 – May 17. The daily amount of spilled water from each reservoir from April 29 – May 18 is shown in Figure 5.

1.4 JUNE 2021 AND AUGUST 2021 – WARM TEMPERATURES AND THERMAL RELEASES

In late June, high air temperatures in the upper basin resulted in the need for thermal mitigation releases from Cannonsville to reduce water temperatures downstream at Lordville, N.Y., the indicator location. The time-series of water temperature and flow in 15-minute intervals at the USGS gage in Lordville, N.Y. is shown in Figure 6. The three peaks in flow between June 26 and 30 are indicative of the thermal release pulses made overnight. The water used for thermal mitigation over the five-day period was 524 cfs-days for 339 million gallons (MG). The pulses were successful, except for June 30, when the maximum water temperature at the USGS gage at Lordville, N.Y. was 24.1 degrees Celsius (approximately 75.4 degrees F). Thermal releases were terminated after an increase in flow which reduced water temperature. Thermal releases were also needed in August for three days as shown in Figure 7.

1.5 JULY 8 – 9, 2021: TROPICAL STORM ELSA

During the summer of 2021, four tropical storms impacted the basin. Tropical Storm Elsa occurred July 8 - 9, and the basin received between 0.5 to 4 inches of rain as shown in Figure 8. The largest amounts of precipitation occurred in Delaware, Southern New Jersey, northeastern Pennsylvania and southeastern New York. Neversink reservoir, which received approximately 3 inches of precipitation, filled and began to spill on July 9. Another non-tropical storm which occurred on July

17 also contributed to the amount of water spilled (approximately 4.9 BG). Figure 9 shows the daily amount spilled from the three NYC reservoirs. Figure 10 contains the flow time-series (hydrograph) for three USGS gages along the main stem Delaware River (Montague, Belvidere and Trenton, all in N.J.) and the Schuylkill River at Philadelphia, Pa.

1.6 JULY 12: FLASH FLOOD IMPACTS IN LOWER BASIN

On July 12, a 100-year storm¹ event occurred in southeastern Pennsylvania when 6-10 inches of rain fell within 3 to 4 hours. As a result of the heavy localized rain, flash flooding occurred along Pennypack Creek at Philadelphia, Pa. The peak flood stage was 9.43 feet, which is considered a moderate flood stage. The peak flood stage at Frankford Creek at Philadelphia was 6.68 feet, considered action stage. Several flash floods were reported at other locations in the Schuylkill River basin, as well as the Neshaminy Creek basin. A supplemental report is available in Appendix A.

1.7 AUGUST 19 – SEPTEMBER 2: TROPICAL ACTIVITY

Three tropical storm events (Tropical Storm Fred², Hurricane Henri³ and Hurricane Ida⁴) caused widespread flooding in the basin. Record-breaking flooding occurred as the result of precipitation from Hurricane Ida after the wet antecedent conditions caused by Tropical Storm Fred and Hurricane Henri. The combination of rainfall from the tropical events (including Tropical Storm Elsa, in early July) is shown in Figure 11 and ranged from 5 inches in the upper basin and near the estuary to approximately 15 inches in New Jersey between Phillipsburg, N.J. and Trenton, N.J. The most precipitation occurred during Hurricane Ida in the lower-middle basin from Downingtown, Pa. through Easton, Pa. and Trenton, N.J.. Supplemental reports for Tropical Storm Fred, Hurricane Henri and Tropical Storm Ida are available in Appendices B, C, and D, respectively.

1.8 OCTOBER 26 – OCTOBER 30: NOR'EASTER AND FLOODING EVENT

On October 26, a strong Nor'easter storm system impacted the basin. A Nor'easter is a storm that occurs when strong winds are from the northeast. The northern half of the basin between 2.5 and 5 inches of rain over two days. Figure 12 shows a map of rainfall totals from the multi-day storm event. Flooding occurred at 15 flood forecast locations in basin tributaries, including the East and West Branches of the Delaware River, Callicoon Creek, the Beaver Kill at Cooks Falls, the Lackawaxen River, Neversink River, the Brandywine Creek, and the Christina River. In addition, action stage to moderate flooding occurred at three locations along the main stem Delaware River (at Callicoon, Barryville, Tocks Island). Five other locations reached Action Stage. Spilling occurred from Neversink Reservoir and is shown in Figure 13. A prolonged period of onshore winds occurred afterward and led to coastal flooding at six gages in the tidal Delaware, two locations in the tidal

¹ According to the precipitation Atlas for the northeast, the 100-year event for 6-years of precipitation is approximately 5.5 inches. https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=pa

² Tropical Storm Fred has no longer tropical in nature by the time it impacted the basin and was classified as the Remnants of Fred.

³ Hurricane Henri was categorized as a hurricane when precipitation from the storm began to impact the basin. The storm lost tropical characteristics over the two days it was impacting the basin and dissipated over the upper basin.

⁴ Hurricane Ida was no longer considered a tropical storm when it moved over the basin.

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Christina River and one location in the tidal Schuylkill River. The coastal flooding would likely have been worse, but the astronomical tides were unfavorable for high tide flooding. A record tide of 10.58 feet occurred at the Delaware River at Bridesburg, Pa. The previous record crest was 10.2 feet, on 9/1/2021 due to Hurricane Ida. National Weather Service Flood Forecast locations that experienced flooding listed in Appendix E, which also includes the flood stage hydrographs from the Advanced Hydrologic Prediction Service.

1.9 DRY NOVEMBER AND DECEMBER

After a wet summer and fall, the basin received less rainfall than normal from November through the end of the calendar year. Figures 14 and 15 show the departure from average precipitation for November and December⁵. Both months received precipitation amounts that were 2 to 3 inches below normal. The U.S. Drought Monitor released on December 28 as shown in Figure 16 shows that abnormally dry conditions, known as D0, were developing in the southern portion of the basin, including Delaware, counties in New Jersey south of Burlington County, and six counties in southeast Pennsylvania.

2. SUMMARY OF HYDROLOGIC CONDITIONS

The components of the hydrologic cycle that are measured and monitored are summarized below. The components are precipitation, streamflow, storage, groundwater and the salt front.

2.1 PRECIPITATION

Annual precipitation amounts varied by location within the basin. The largest amounts, more than 60 inches, occurred in portions of the upper basin and localized areas in southeastern Pennsylvania near Levittown. The least amount of precipitation occurred in the western part of the basin, where some areas only received 36 inches for the year.

Figure 17 presents maps of rainfall amounts and the departures from normal. As shown on the departure map, a corridor of dry conditions occurred in Luzerne County, Pa. (the western part of the basin), extending northeast towards Orange County, in New York. Some of these areas received between 10 to 15 inches below normal amounts of precipitation. In the northern part of the basin, annual precipitation was between 10 to 15 inches above normal.

The monthly precipitation at each location is shown in Figure 18. The wettest months were typically July or September, due to the influence of tropical systems and location in the basin relative to the storm. For Mount Pocono, Pa. the most precipitation occurred in August because it is located along the path of the heaviest precipitation for Tropical Storm Fred and Hurricane Henri, which both occurred in August. Among all the stations, November and December are the driest months of the year.

⁵ Average precipitation amounts are defined in 30-year periods by the National Oceanic and Atmospheric Administration (NOAA). Most recent period defining normal is 1981 - 2010

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Monthly precipitation compared to normal for twelve Hydrologic Unit Code (HUC) regions is included in Appendix F.

Table 1 lists rainfall, normal, departure and rank at nine weather stations in or near the basin⁶. The reported totals are at gages chosen to cover the basin, and may not reflect the range of precipitation amounts shown on the map in Figure 17, which are based on several sources including radar estimated precipitation and station data (both automated and manual reporting)⁷.

⁶ Source: Applied Climate Information System (ACIS)

⁷ See <https://water.weather.gov/precip/about.php> for more details

Table 1. Total Precipitation at Select Locations in the Delaware River Basin

Station	Number of Years Reporting	2021 Precipitation Total	Normal (based on 1990 – 2019)	Departure	Annual Rank (Lower = Wetter)
Reading, PA	26	41.82	45.21	-3.39	14
Callicoon, NY	11	56.10	50.22	+5.88	4
Allentown, PA	82	44.67	47.36	-2.69	39
Trenton, NJ	24	41.67	45.47	-3.80	17
Sussex, NJ	20	40.91	40.95	-0.04	10
Philadelphia, PA	82	43.81	44.11	-0.30	34
Wilmington, DE	73	38.03	45.33	-7.30	56
Mount Pocono, PA	21	60.80	50.22	+10.58	5
Millville, NJ	78	35.27	43.37	-8.10	70

2.2 STREAMFLOW

The average annual flow at Trenton for the year was the 16th highest on record based on 109 years of data. At Montague, that average annual flow was the 10th highest based on 82 years of information.

Lower flows occurred in April and at the end of the year due to early snowmelt and low precipitation respectively. Flows were approximately 50 percent of normal in April at the four locations displayed. This is due to snowmelt occurring in March rather than in April. Note that the March flows were typically 100 to 150 percent of normal.

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High streamflow occurred during early in the year due to a large storm event in the last week of 2020⁸ and late-August into early September due to three tropical storms impacting the basin. Monthly average streamflows were highest during September, when flows were approximately 400 to 500 percent of normal. Figure 19 shows the streamflow over the entire year at four gages in the Delaware River and the monthly streamflow as a percent of normal. At Montague, the highest peak daily flow occurred during the last days of October in the days following a heavy rain event. Although this was the highest daily peak of the year, the highest monthly stream flow compared to normal occurred in September due to Ida.

Flooding occurred in the mainstem and the tributaries as the result of tropical storms and the Nor'easter at the end of October.

2.3 RESERVOIR STORAGE AND RELEASES

Releases from Beltzville and Blue Marsh in the lower basin are used to support the Trenton Flow Objective, which was established to maintain freshwater flows in the estuary. Releases from Cannonsville, Pepacton and Neversink, are used to maintain the Montague Flow Objective. Storages in all five reservoirs were normal or above normal, for most of the year.

2.3.1 Lower Basin

Both Beltzville Reservoir (located on the Pohopoco Creek, a tributary of the Lehigh River) and Blue Marsh Reservoir (located on the Tulpehocken Creek, a tributary of the Schuylkill River) maintained their storage in the normal range during 2021. The Delaware River Basin Commission's (DRBC) Lower Basin drought operating plan was not implemented because the requirements (low water levels) were not met. No water was needed to support the Trenton Flow Objective. Beltzville and Blue Marsh remained near or above their normal pool elevations for most of the year, as shown in Figures 20 and 21. The temporary storage of floodwater from the tropical storm events in both reservoirs is also evident by the increase in pool elevations in August and early September.

Blue Marsh reservoir has a seasonal recreation pool that is filled in mid-March for use of the recreation pool and released in mid-October to provide the normal winter pool flood control space for spring runoff.

Merrill Creek Reservoir, located in Phillipsburg, N.J., was constructed by thermoelectric power utilities for the replacement of their consumptive use when the basin is under DRBC-declared drought operations. Releases were not made from Merrill Creek Reservoir during 2021.

2.3.2 Upper Basin

Releases from the three NYC Delaware River Basin (DRB) Reservoirs were made in accordance with the 2017 Flexible Flow Management Program. The Delaware River Master directed releases from the NYC reservoirs to meet the Montague flow objective. The volume of water released for Montague was approximately 1.8 BG, with all but one release in June, July, and August 2021. The release, not occurring in the summer, occurred on February 11 of approximately 141 million gallons

⁸ On December 24 and 25, a rain on snow event resulted in high flows from runoff and associated snowmelt.

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(MG). Water is reserved in two banks, the Thermal Mitigation Bank and the Rapid Flow Change Bank in accordance with the [Flexible Flow Management Program](#).⁹ Thermal mitigation releases were made for three multi-day events (10 days total) in June, July, and August. The total amount of water used from the Thermal Bank 423 MG (654 cfs-days). Rapid Flow Change releases were not needed during the calendar year 2021.

The combined storage in the New York City reservoirs is used to determine drought status in accordance with the Delaware River Basin Water Code (18 CFR Part 410) . Figure 22 presents the upper basin combined storage in 2021. On January 1, the combined storage was approximately 240 BG (90.0 percent) and increasing as a result of a large rain and snowmelt event on December 24, 2020. The combined storage decreased during January and February. The lowest combined storage for the year occurred on February 27th and was approximately 217.9 BG (81.5 percent). Storage increased steadily through March and April due to snowmelt and other runoff. The reservoirs were full by April 30 and remained above at or above 100 percent until May 20. The three reservoirs spilled a combined total of approximately 16.6 BG. The reservoir levels decreased through June. In July, runoff from Tropical Storm Elsa filled the reservoirs resulting a short period of spill from July 9 through July 24. The total amount spilled was approximately 6.5 BG from.

The combined storage decreased, with a few temporary increases from the tropical storm events, through October. A strong storm at the end of the month caused the combined storage to increase from 228.1 BG to 259.1 BG, approximately 31 BG in one week. During this period, Neversink Reservoir spilled an additional 1.7 BG. Through November and December, the combined storage decreased. At the end of the calendar year, the combined storage was approximately 228.5 BG (85.4 percent).

2.4 GROUNDWATER

Groundwater levels in the thirteen indicator wells were mostly in the normal or above normal range. Most wells experienced a decrease in groundwater levels starting from April through August, following the normal annual groundwater level pattern. A few wells in the western and southern parts of the basin were below normal and drought watch levels in June through mid-August before returning to normal after recharge from three tropical storms. At the end of 2021, most wells were in the normal range, with a few below normal due to the drier conditions in November and December. Figures 23 and 24 display the time series of groundwater levels at representative wells across the basin.

2.5 SALT FRONT

The salt front is defined as the seven-day average of the 250 parts-per-million isochlor. The salt front is used by DRBC as an indicator of salinity intrusion in the Delaware Estuary for reservoir operations. The location of the salt front moves downstream or upstream along the main stem Delaware River as streamflow increases or decreases, respectively. The long-term median mid-month locations range from river mile 67 in April (two miles downstream of the Delaware Memorial

⁹ https://webapps.usgs.gov/odrm/documents/ffmp/Appendix_A_FFMP-20180716-Final.pdf

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Bridge) to river mile 76 in September (two miles downstream of the Pennsylvania-Delaware State boundary)¹⁰.

In January of 2021, the salt front was below river mile 54. DRBC does not report the location of the salt front below river mile 54 because data needed for the calculation are not available. The most upstream location of the salt front in 2021 occurred on February 27, at river mile 76.5 (near Claymont, Del.). The salt front moved upstream into the normal range by April and remained there through August. At the beginning of September, the salt front was below Reedy Island as the result of the increased flow from tropical systems. In October, the salt front returned to the normal range. As flows began to decrease due to the lack of precipitation in November and December, the salt front moved upstream to river mile 69 (near the Delaware Memorial Bridge). Figure 25 presents the time series of the daily and seven-day average location of the salt front.

3. SUMMARY

The hydrologic conditions of 2021 can be described as relatively normal through the first half, wet through the summer and early fall and dry at the end. Groundwater followed the normal seasonal pattern with decreased levels during the early part of the summer and increased levels towards late fall and winter. Storages in individual reservoirs were normal to above normal for most of the year, except in late winter when water was contained in the snowpack. However, the year 2021 will be remembered for its three tropical storm events at the end of August and beginning of September, all within a two-week period. Precipitation and the associated runoff from Tropical Storms Fred, Henri and Ida resulted in record-breaking flooding in lower basin tributaries and minor flooding along the main stem. The salt front location was closely tied to the stream flow, and elevated flow in the aftermath of the tropical activity led to below normal values.

¹⁰ DRBC - <https://www.nj.gov/drbc/hydrological/river/salt-front.html>

4. FIGURES

Figure 1: Snowfall in the DRB and surrounding areas during a multi-day snow event at the end of January and beginning of February. Totals from the 3-day period ranged from less than 1 inch in the lower basin to over 35 inches in Northeast Pennsylvania.

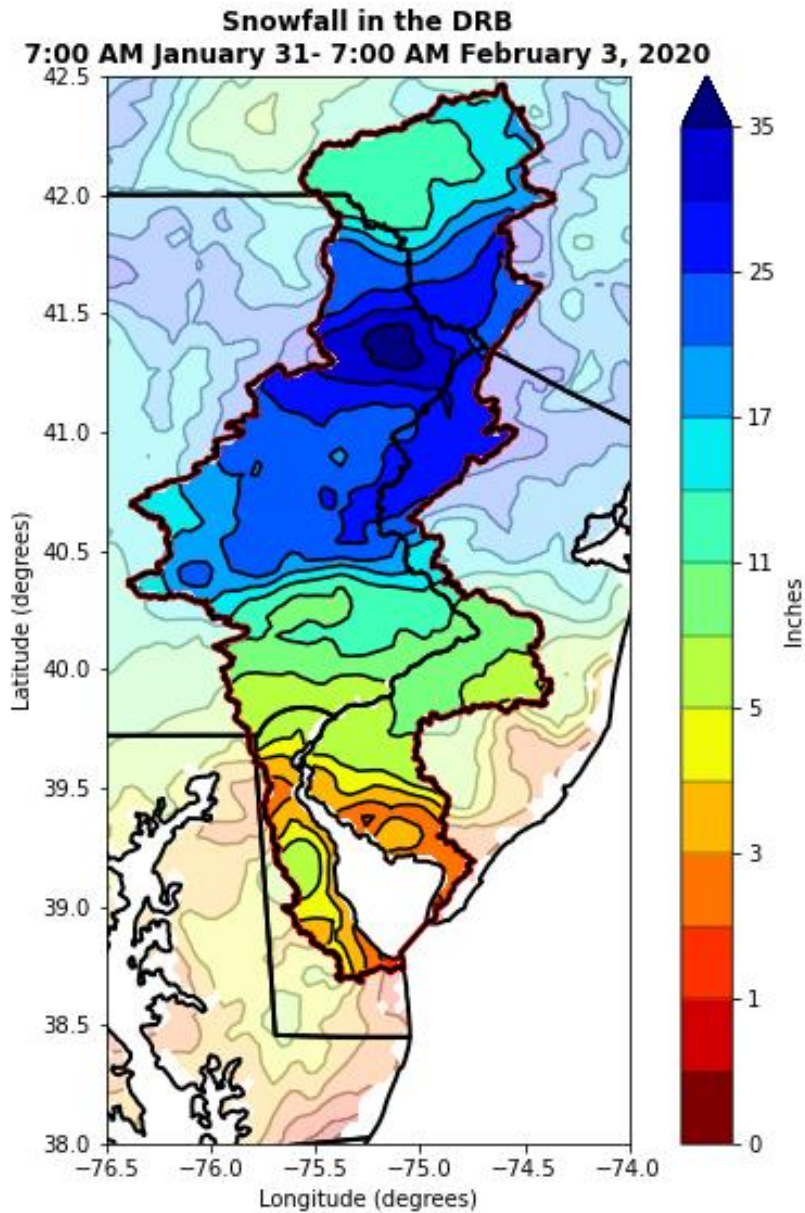


Figure 2: Gage Height at USGS 01463500 (Delaware River at Trenton, N.J.) from January 30 to February 03, 2021. The fast rise in stage is due to a non-severe ice jam that occurred near the gage.

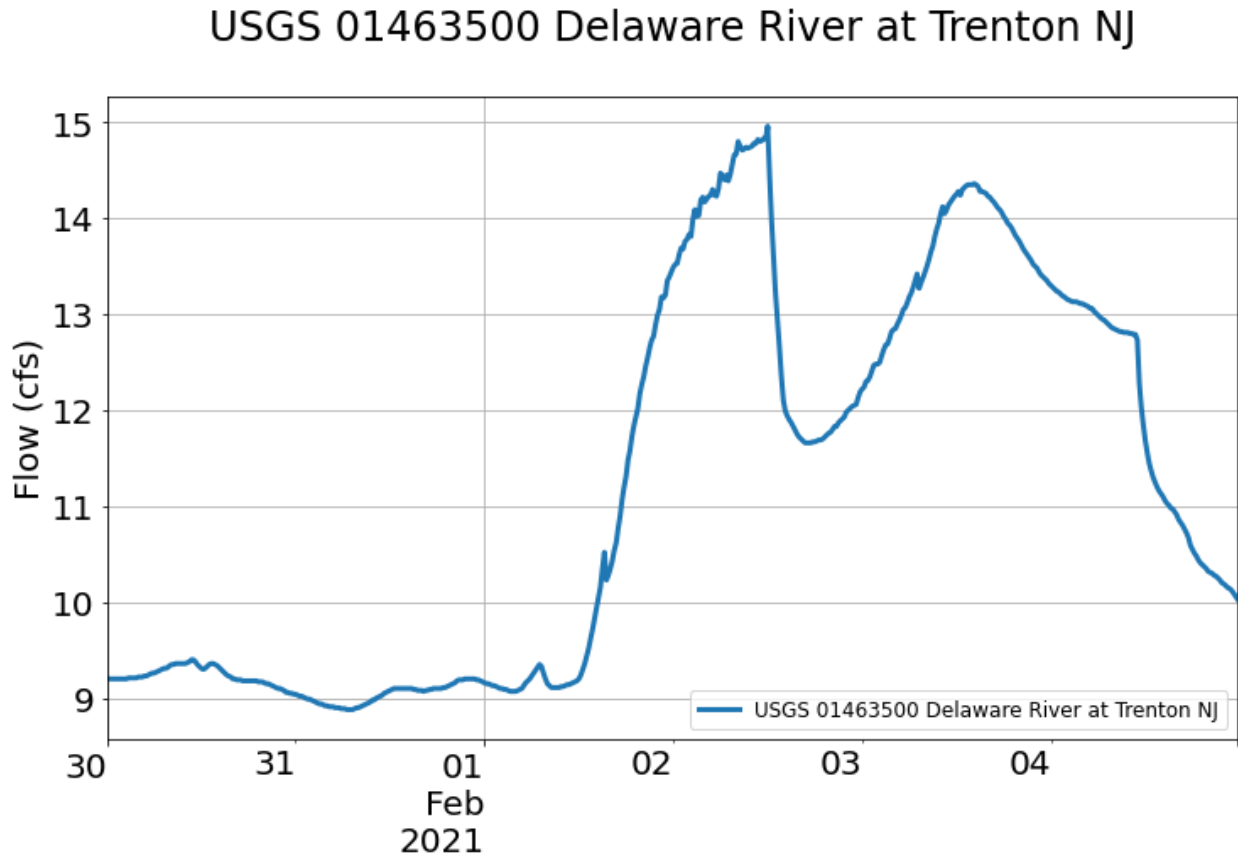
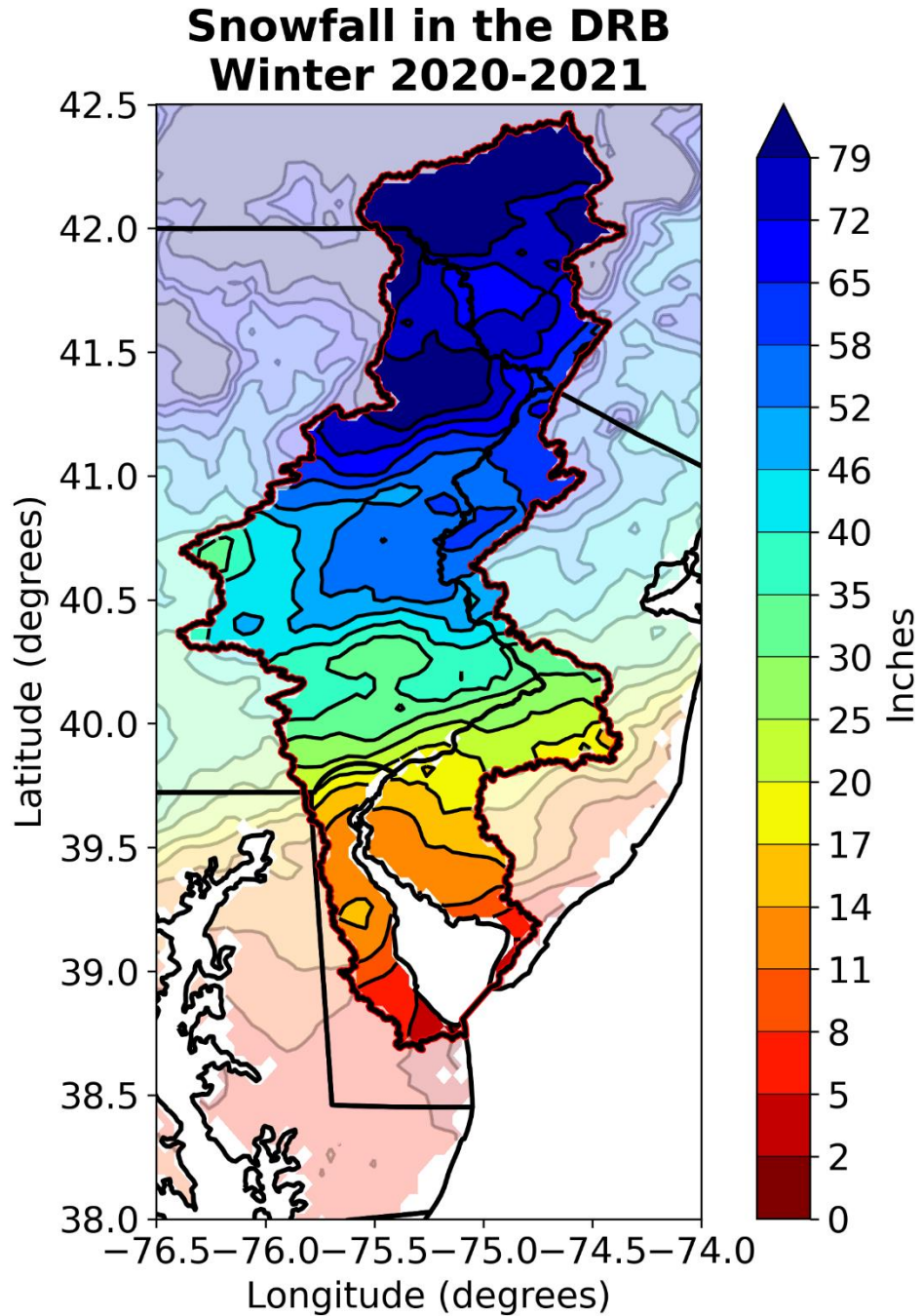


Figure 3: Seasonal Snowfall Total in Delaware River Basin.



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Figure 4: Streamflow with snowmelt at three USGS gages in the mainstem Delaware River. Trenton, N.J. (blue, 01463500); Belvidere, N.J. (orange, 01446500); and Montague, N.J. (green, 01438500).

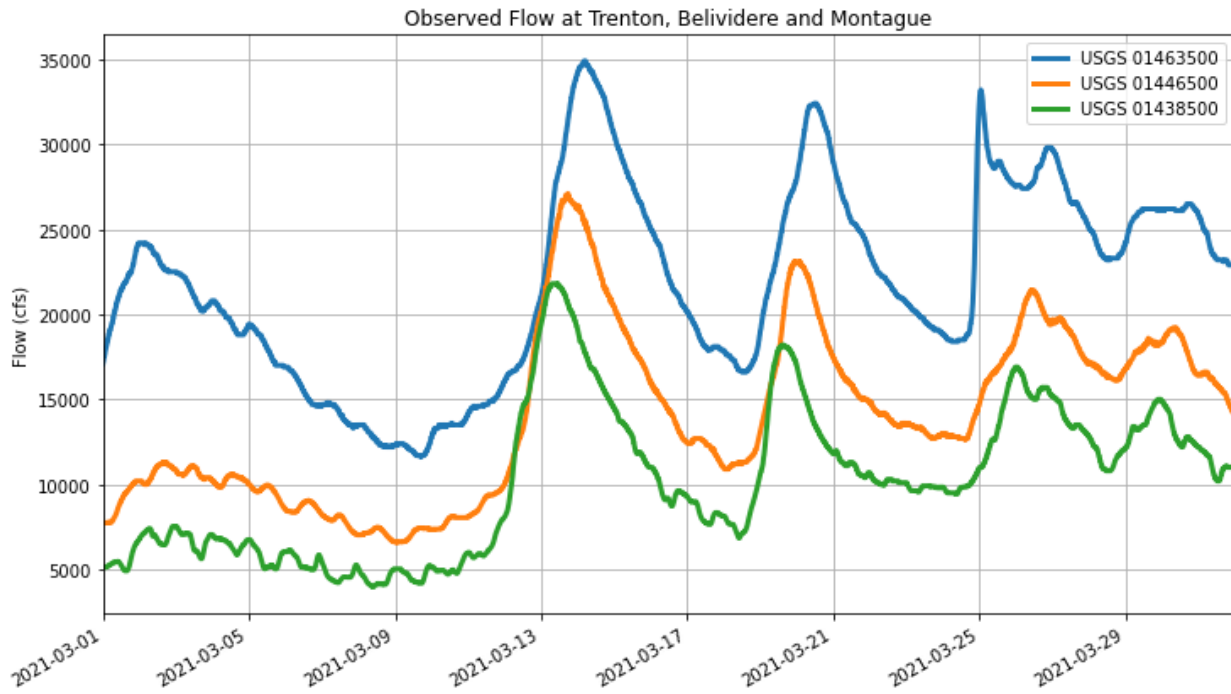
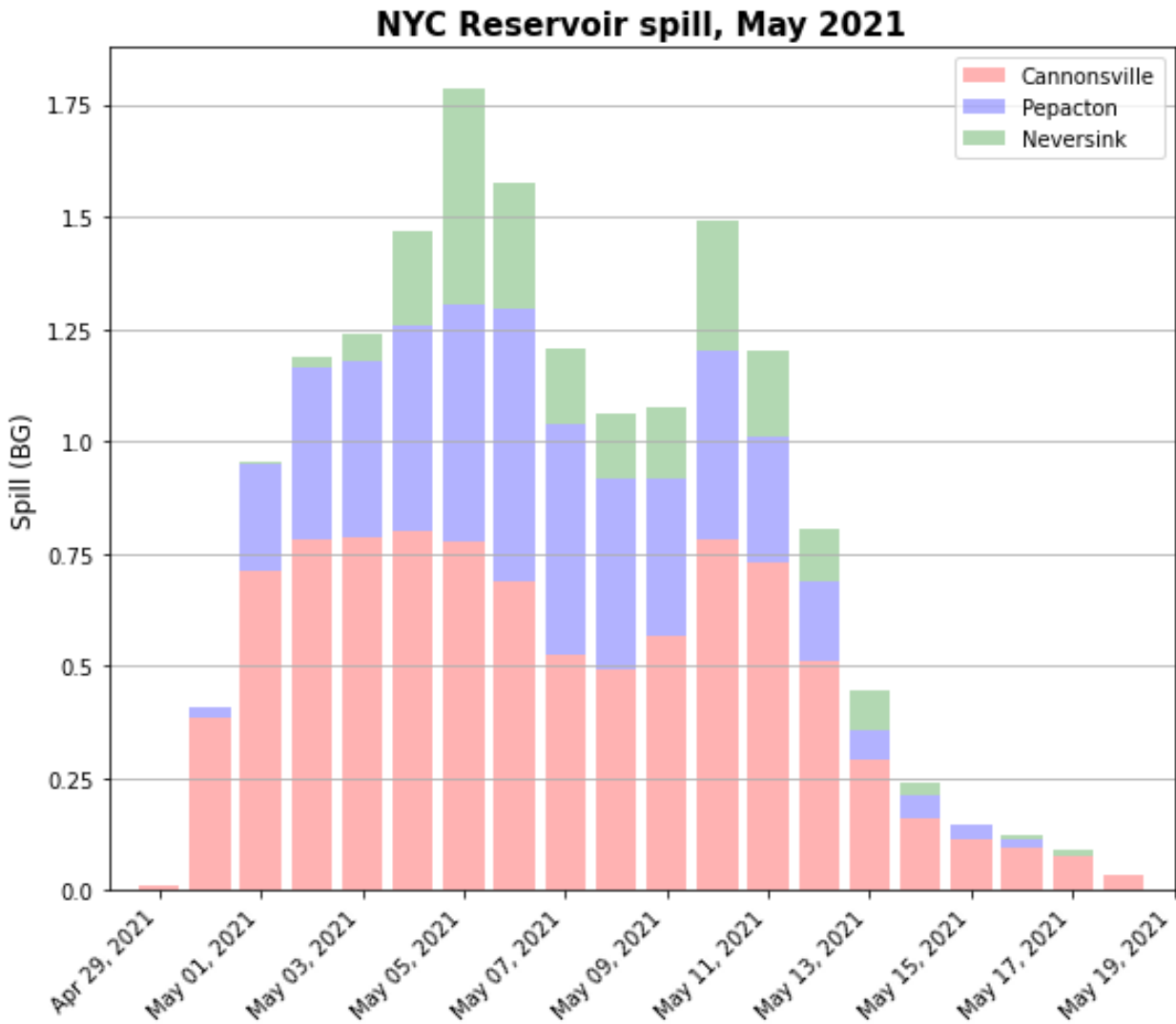
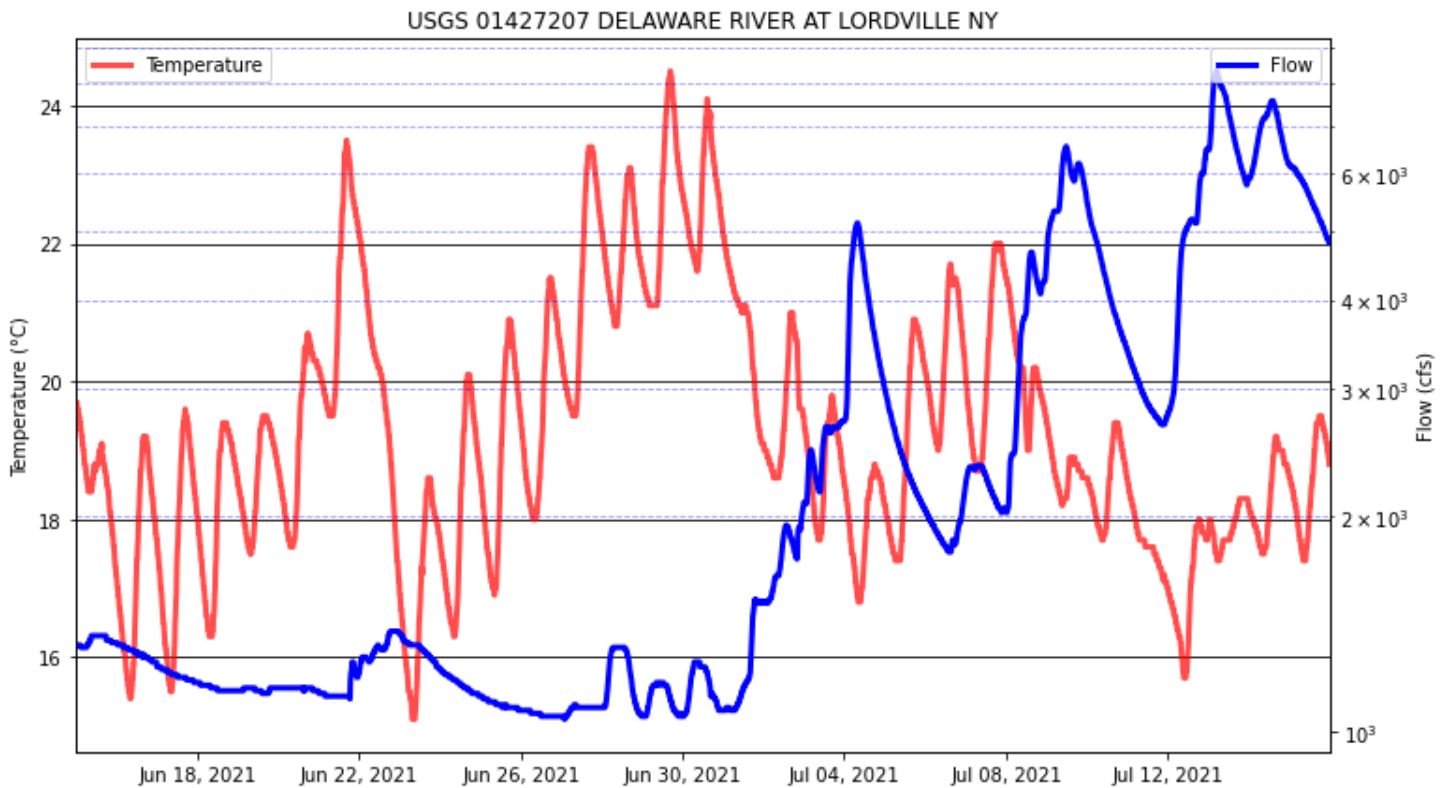


Figure 5: Volume of Spill (BG) from Cannonsville, Pepacton, and Neversink Reservoirs from April 29 – May 18, 2021.



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Figure 6: Temperature (red) and flow (blue) at USGS gage 01427207 (Delaware River at Lordville, N.Y.). During a stretch of warm water temperatures in late June, the maximum temperature surpassed 24°C on two days. An increase in the flow in July led to a decrease in the water temperatures at Lordville.



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Figure 7: Temperature (red) and flow (blue) at USGS gage 01427207 (Delaware River at Lordville, N.Y.). During a stretch of warm water temperatures in mid-August, the maximum temperature did not surpass 24°C.

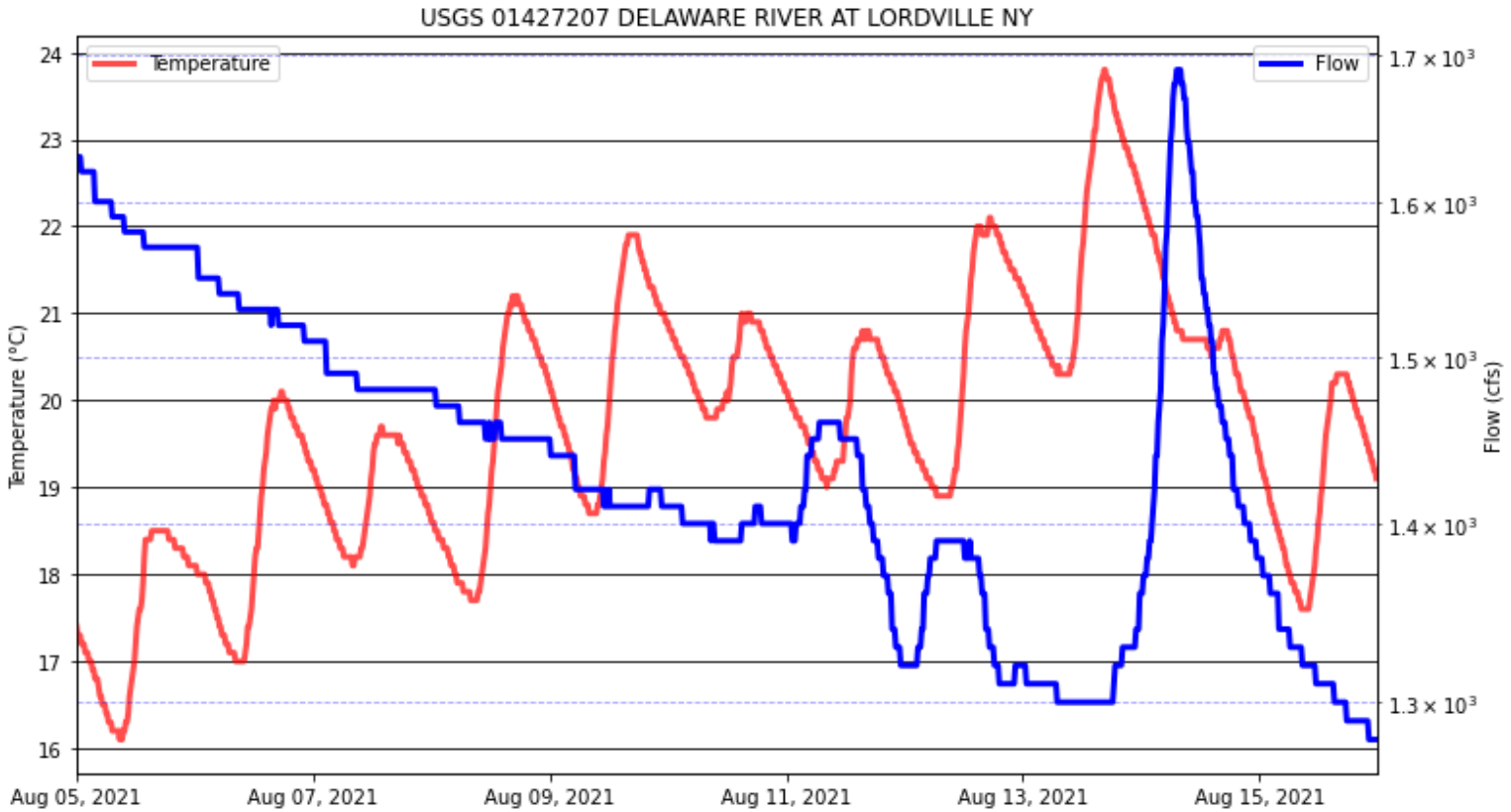


Figure 8: Total rain accumulation due to tropical storm Elsa on July 8-9, 2021. Amounts ranged from less than 0.5 inches in Pennsylvania to 4 inches in New Jersey and parts of the upper basin.

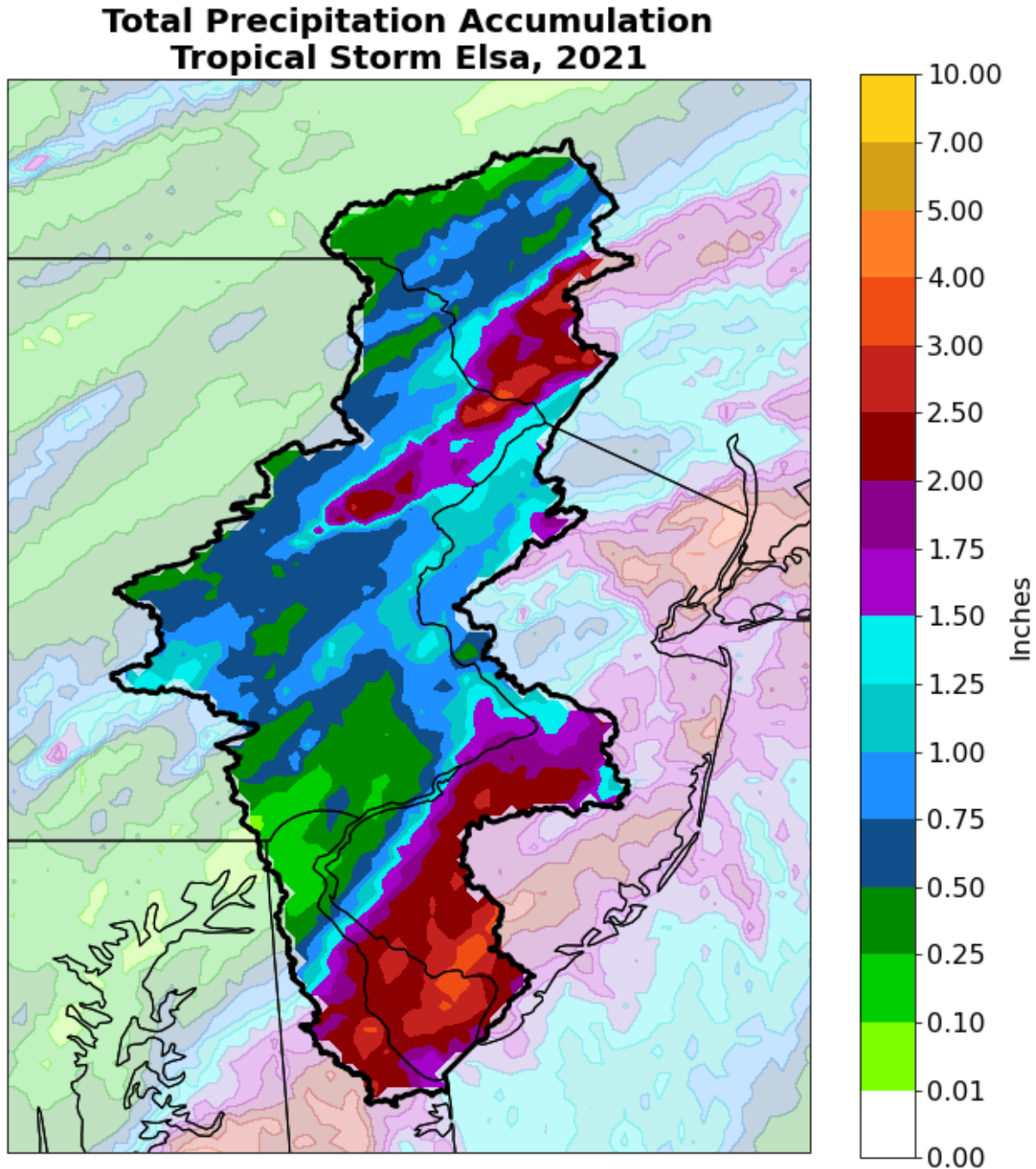


Figure 9: Daily spill amounts at the three NYC reservoirs due to Tropical Storm Elsa and second land-based system on July 17, 2021.

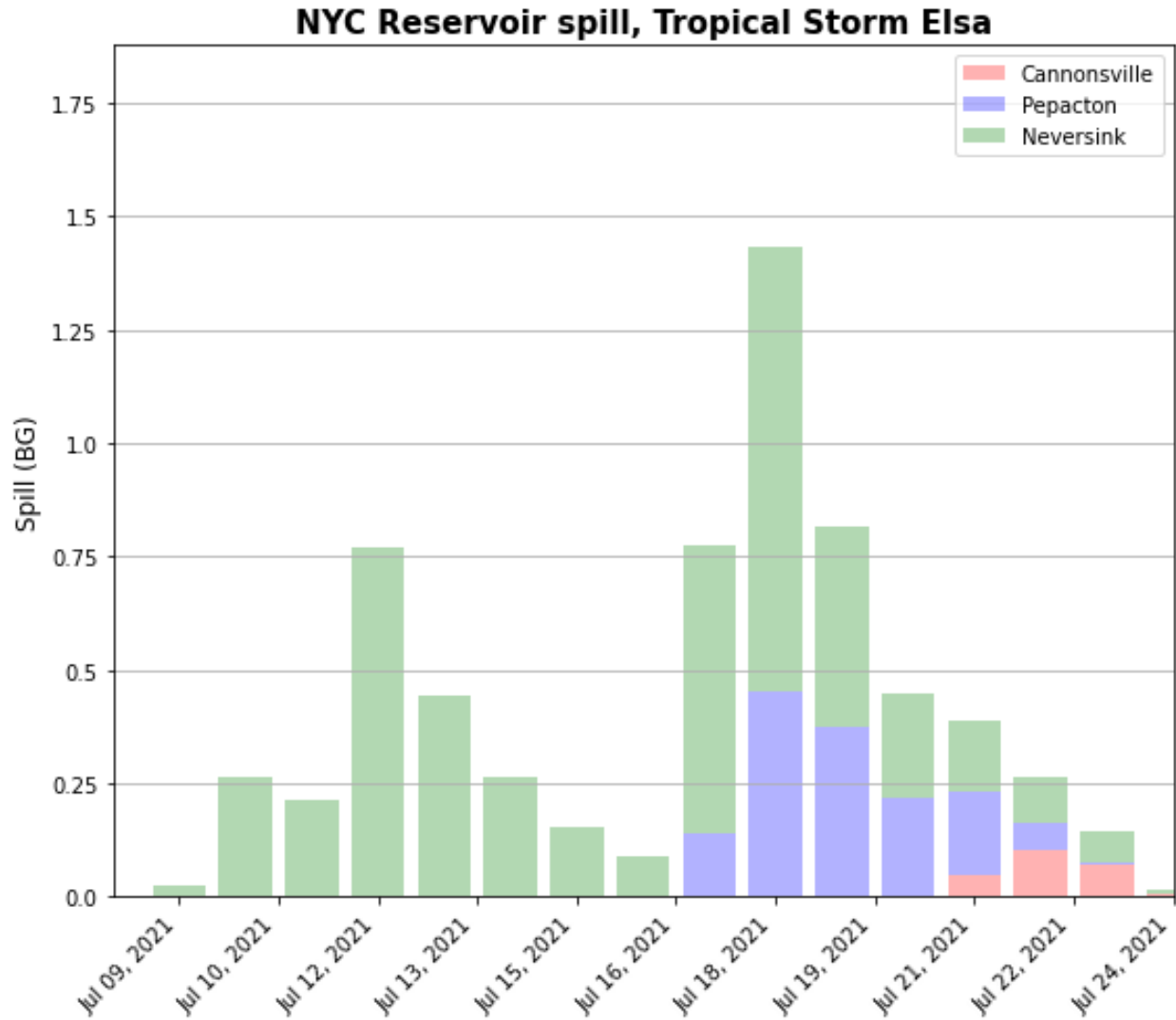


Figure 10: Mainstem streamflow response to Tropical Storm Elsa and other storms throughout July.

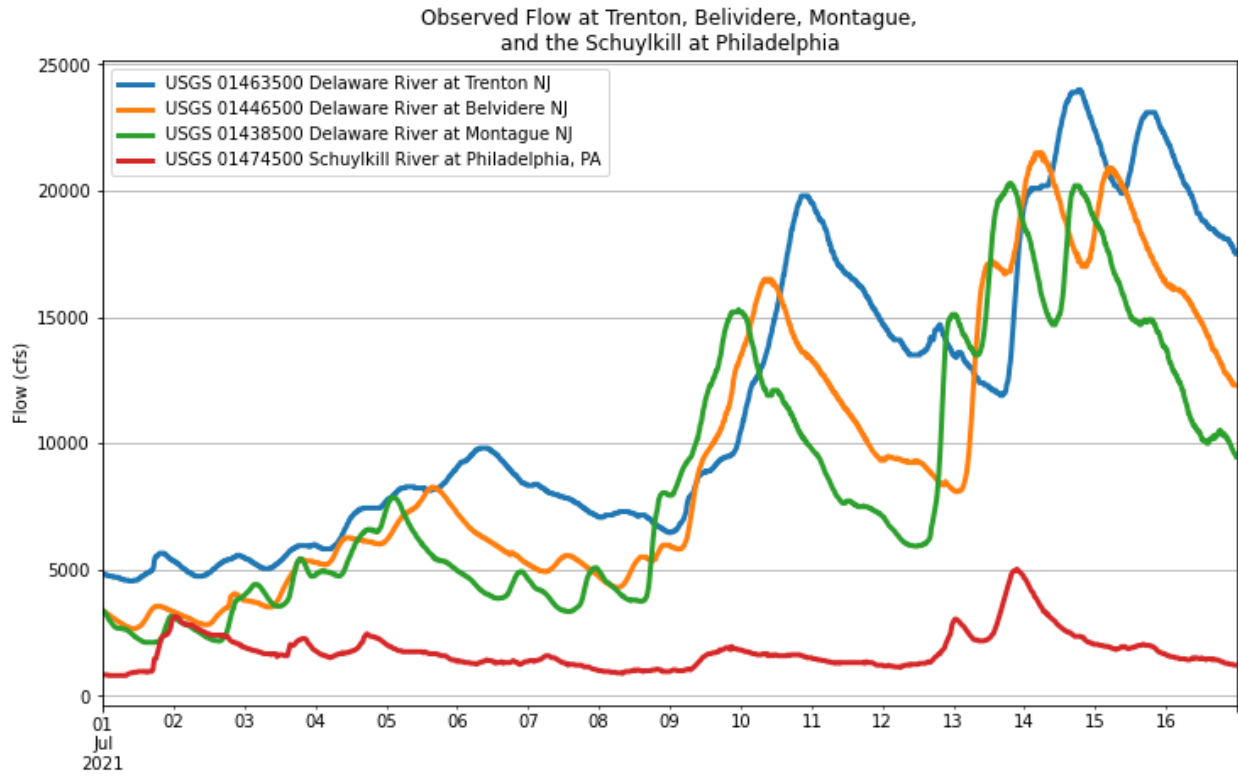


Figure 11: Total Precipitation from all 4 tropical storms (Elsa, Fred, Henri, and Ida).

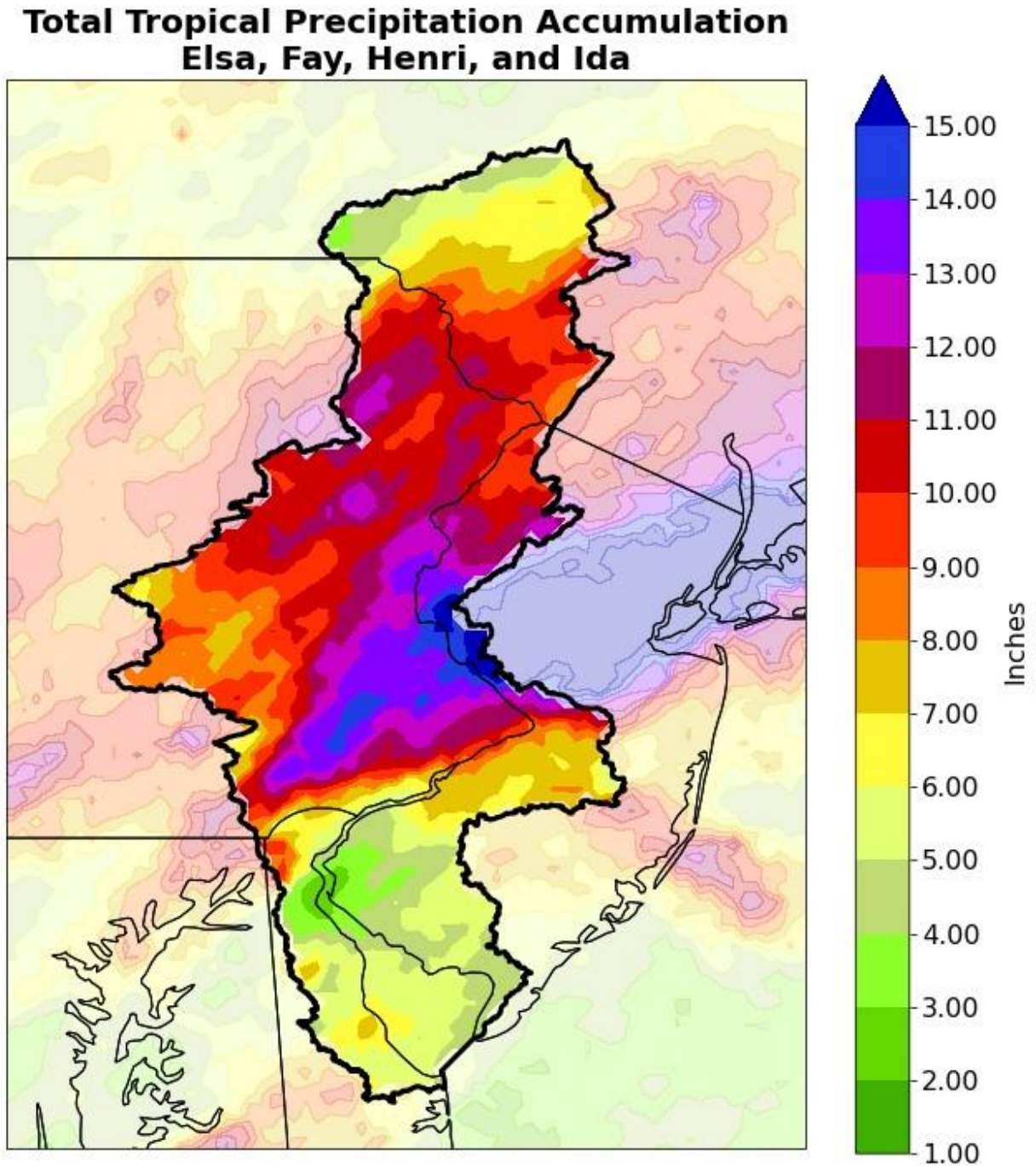


Figure 12: Total Precipitation across the basin from Nor'Easter storm event in late October.

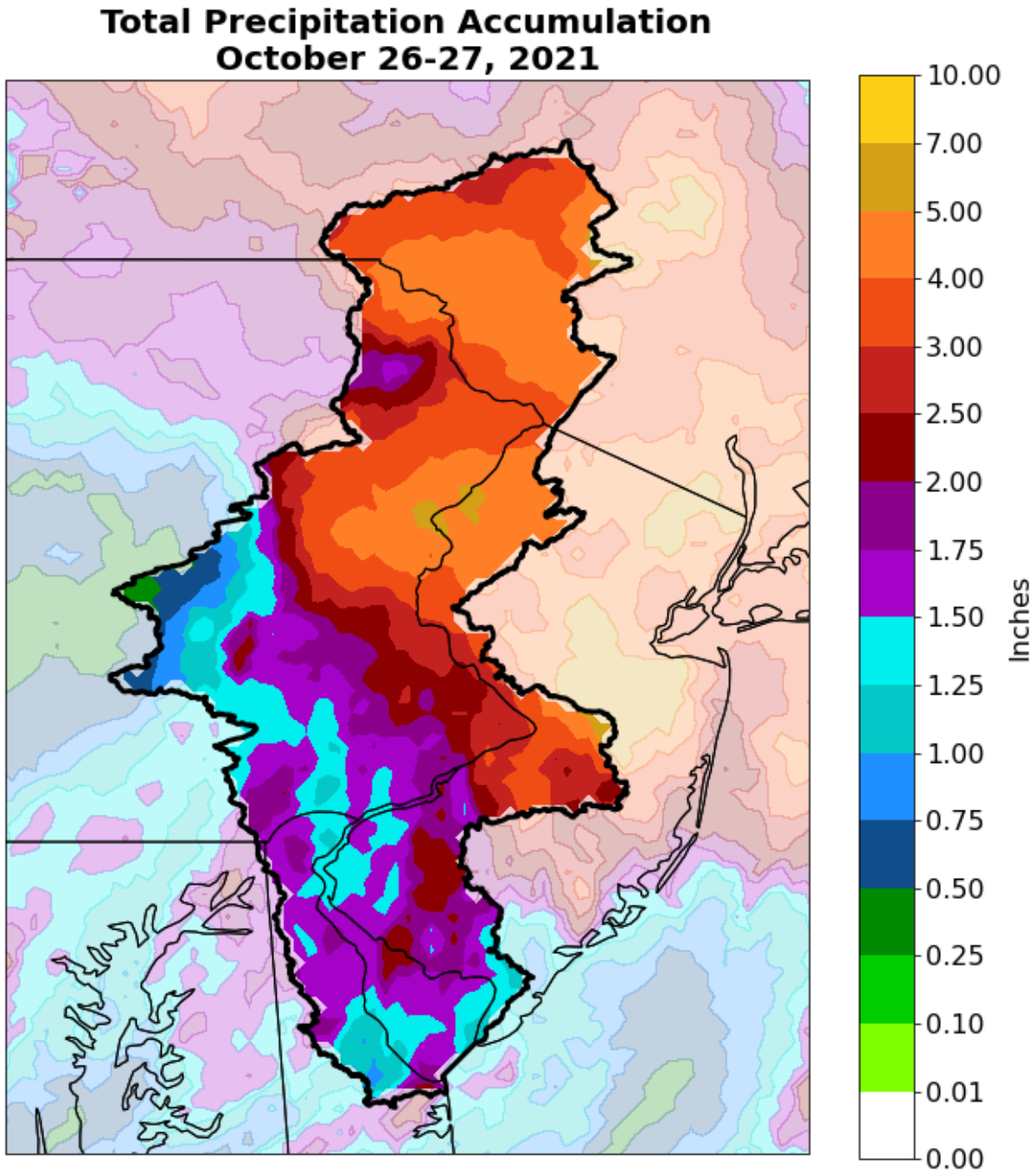


Figure 13: Spilling in Neversink reservoir due to the late October Nor'Easter storm event.

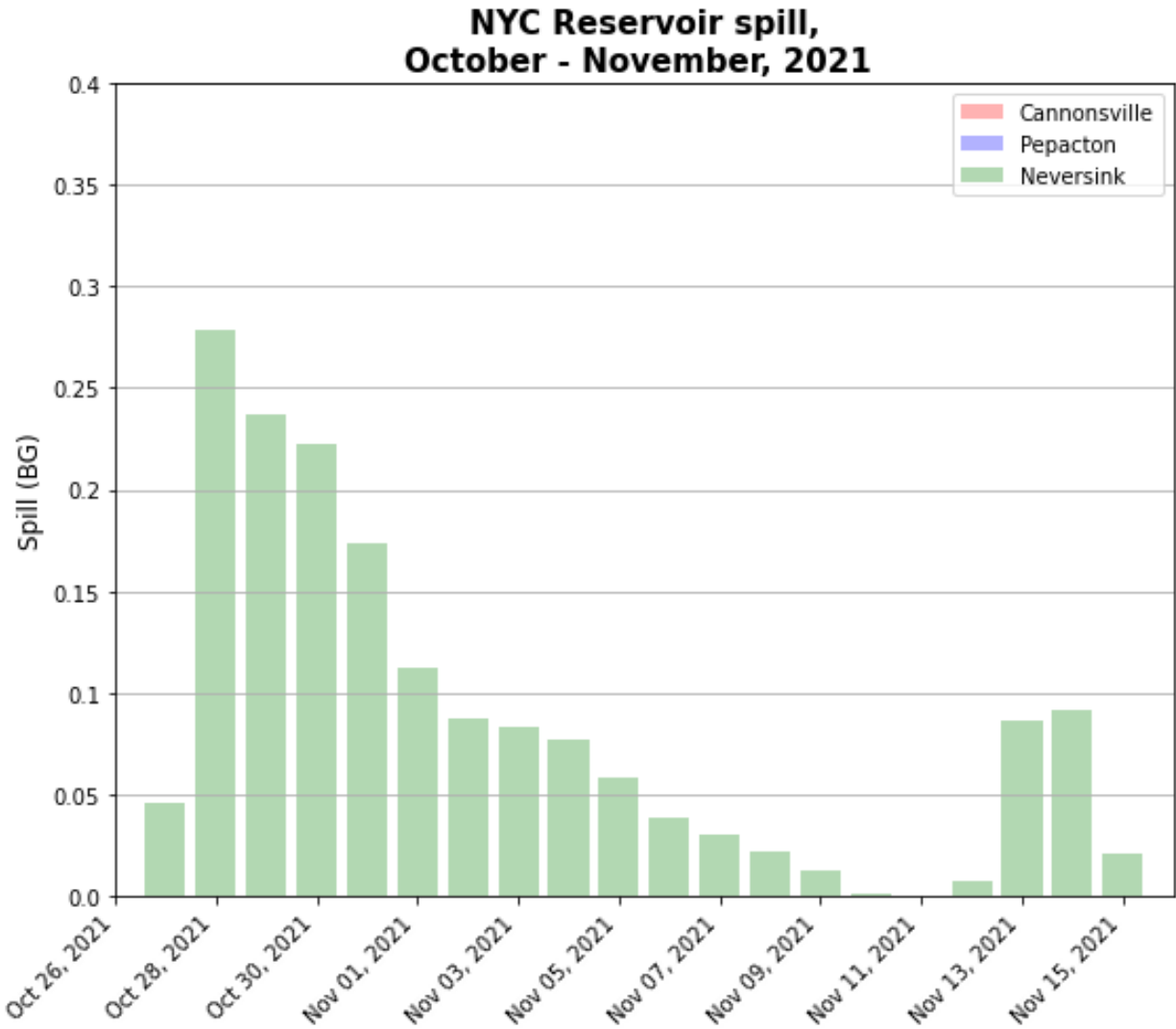


Figure 14: Departures from normal during November of 2021 were 1 to 3 inches below normal across most of the basin.

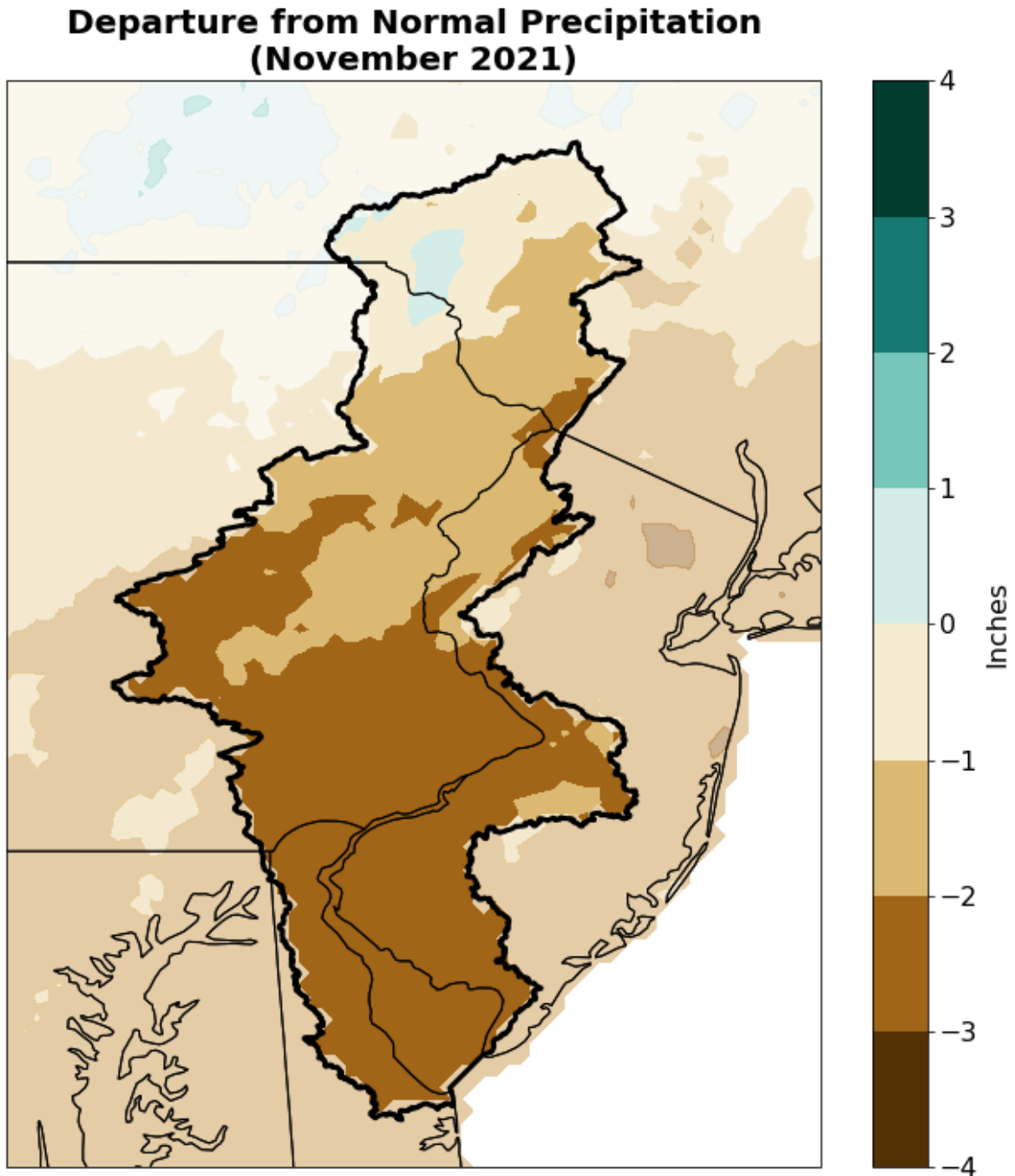


Figure 15: Departures over the basin in December were between 1 and 4 inches below normal.

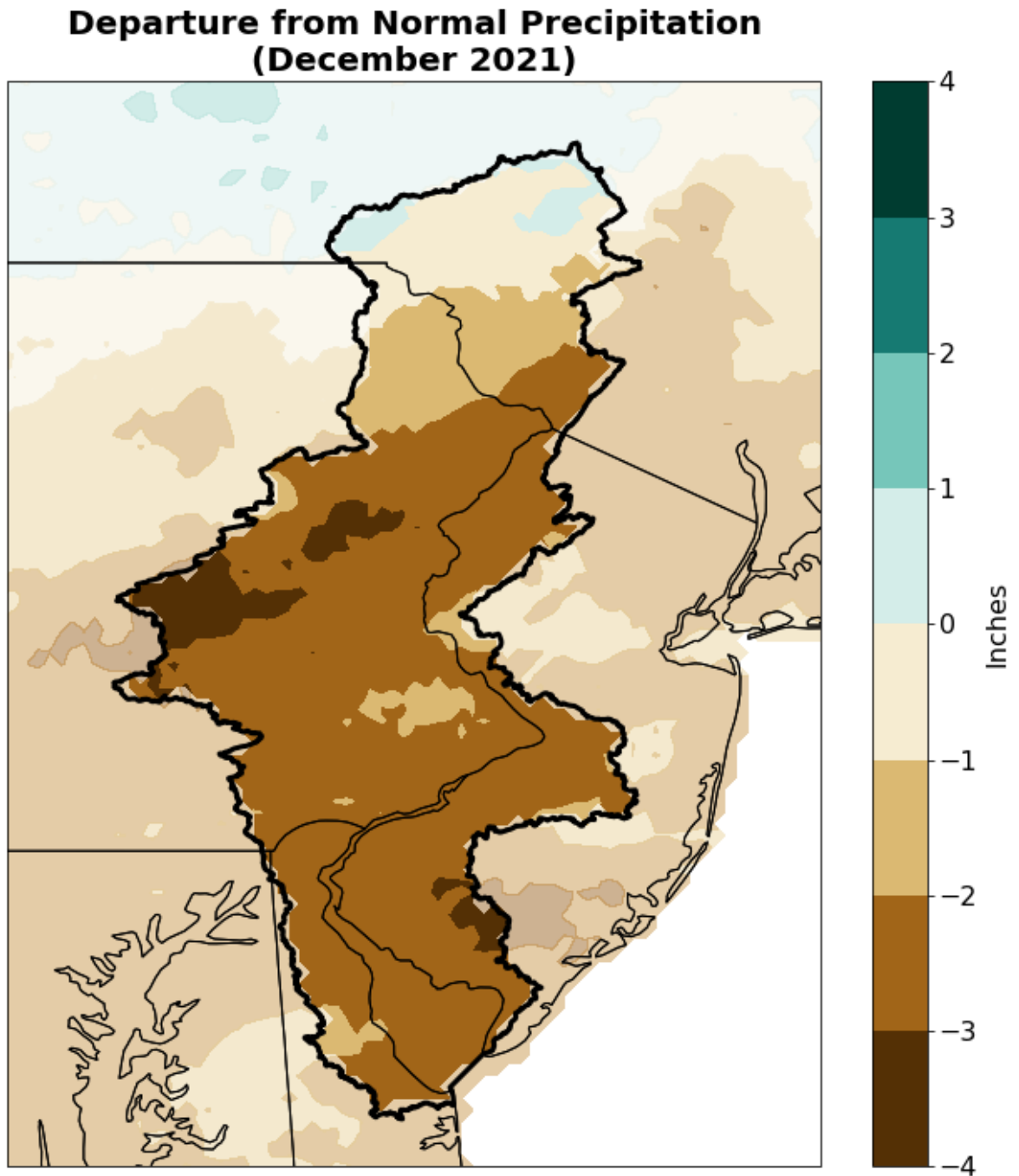


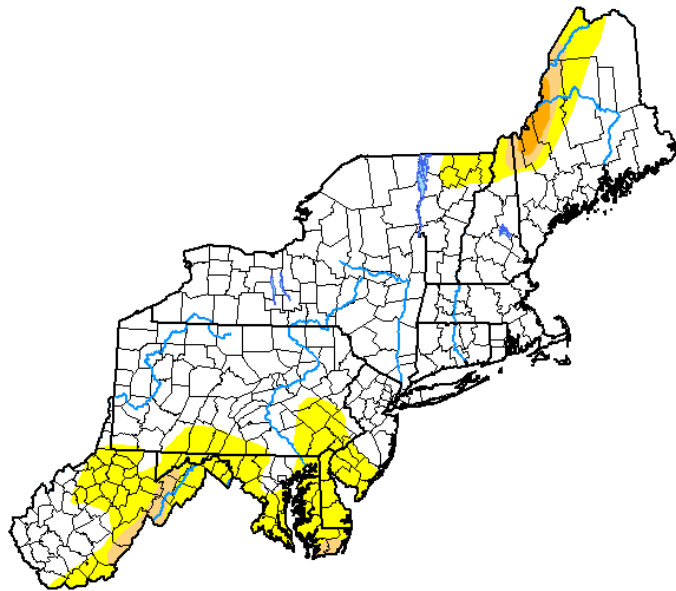
Figure 16: The U.S. Drought Monitor released on December 30, 2021

**U.S. Drought Monitor
Northeast**

December 28, 2021

(Released Thursday, Dec. 30, 2021)

Valid 7 a.m. EST



Drought Conditions (Percent Area)

	None	D0-D4	D1-D4	D2-D4	D3-D4	D4
Current	77.53	22.47	3.42	0.85	0.00	0.00
Last Week 12-21-2021	77.53	22.47	2.29	0.85	0.00	0.00
3 Months Ago 09-28-2021	90.30	9.70	3.14	0.80	0.00	0.00
Start of Calendar Year 12-29-2020	77.60	22.40	3.63	0.00	0.00	0.00
Start of Water Year 09-28-2021	90.30	9.70	3.14	0.80	0.00	0.00
One Year Ago 12-29-2020	77.60	22.40	3.63	0.00	0.00	0.00

Intensity:

- None
- D0 Abnormally Dry
- D1 Moderate Drought
- D2 Severe Drought
- D3 Extreme Drought
- D4 Exceptional Drought

The Drought Monitor focuses on broad-scale conditions. Local conditions may vary. For more information on the Drought Monitor, go to <https://droughtmonitor.unl.edu/About.aspx>

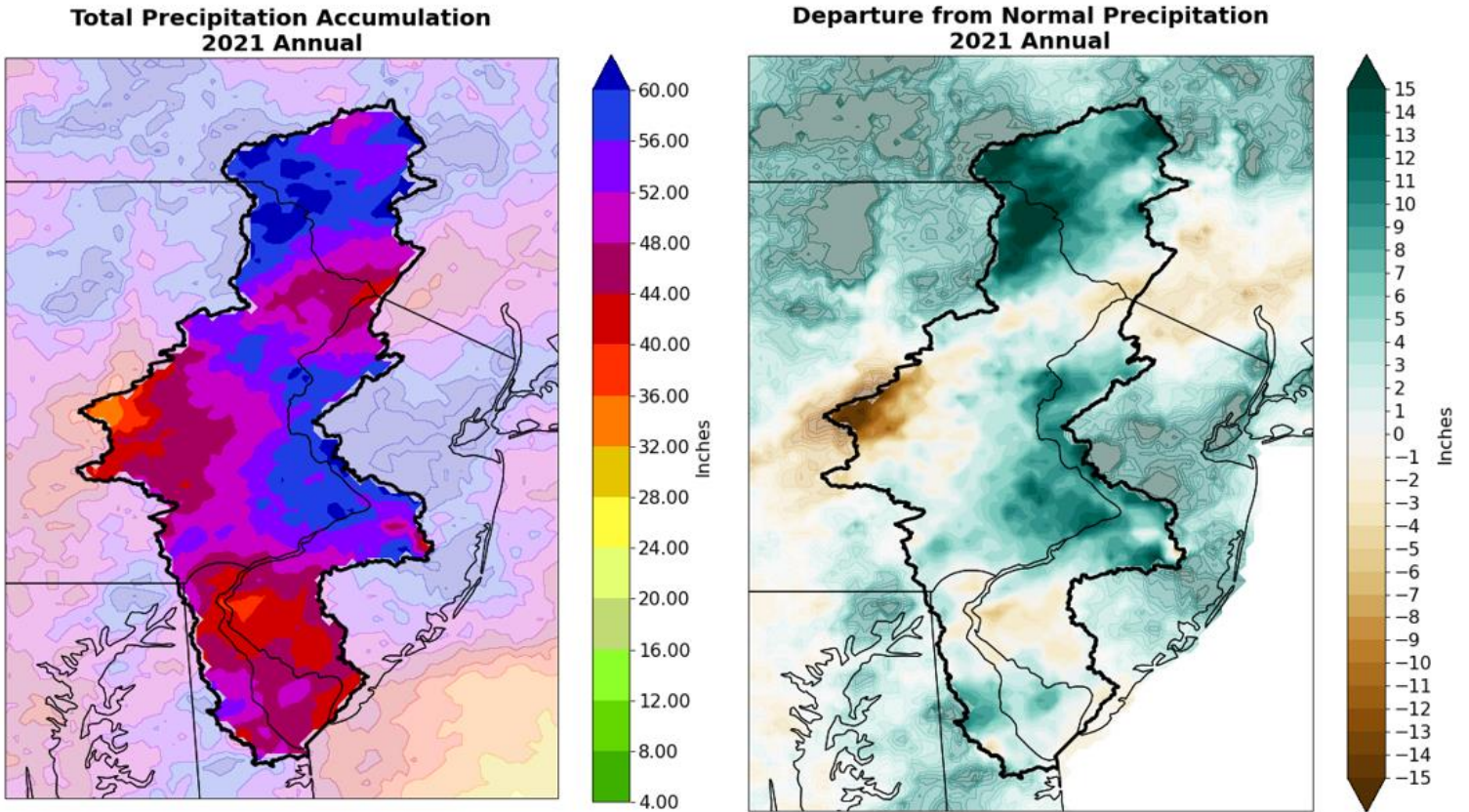
Author:

Brad Pugh
CPC/NOAA



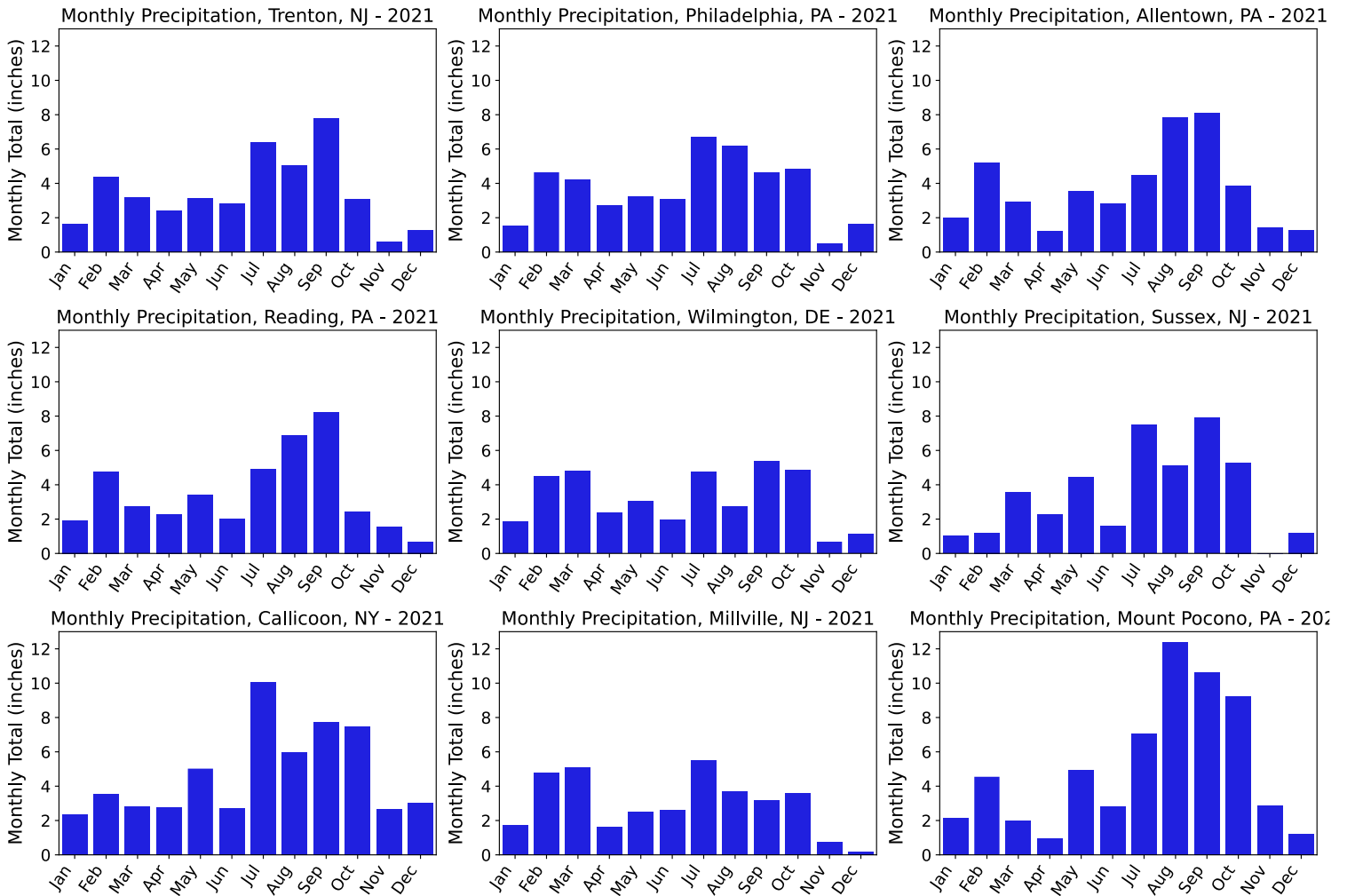
droughtmonitor.unl.edu

Figure 17: Total Precipitation and Departure from Normal (based on 30-year period 1980 – 2010).



Annual Hydrologic Conditions Report

Figure 18: Monthly Precipitation at Nine Representative Locations



Annual Hydrologic Conditions Report

Figure 19: Streamflow and percent of Normal at 4 locations in the Delaware River Basin

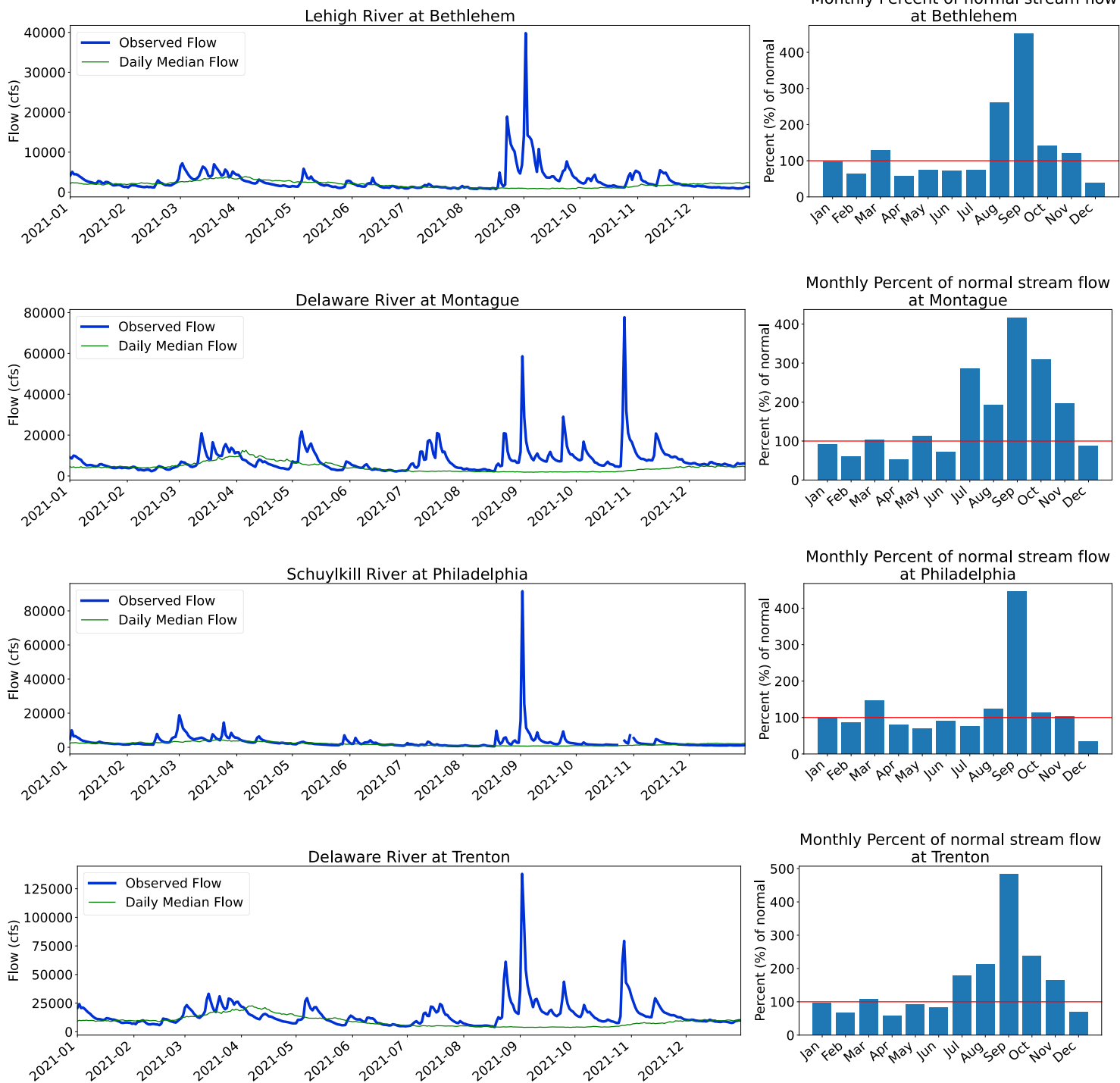


Figure 20: Storage in Beltzville Reservoir. Normal Pool is shown in black

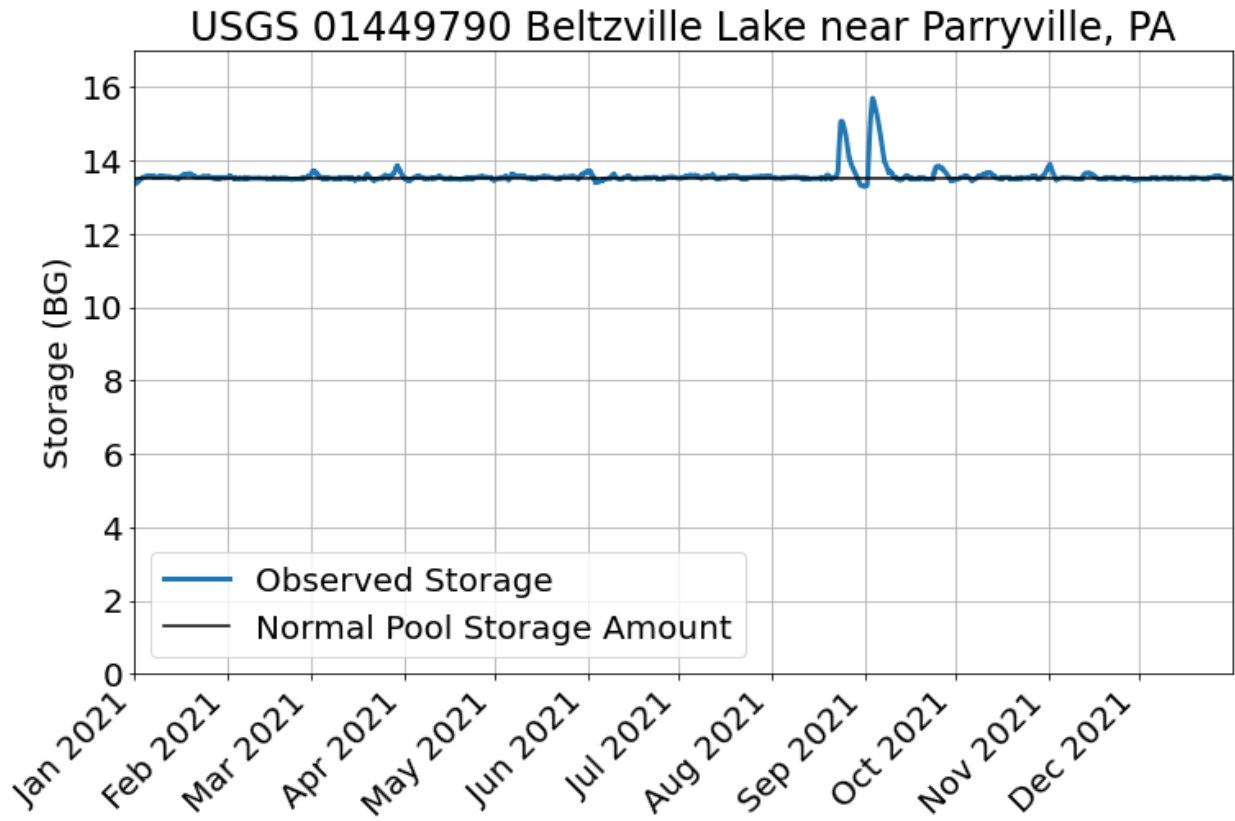


Figure 21: Storage in Blue Marsh Reservoir. Blue Marsh released water in the days preceding Hurricane Ida.

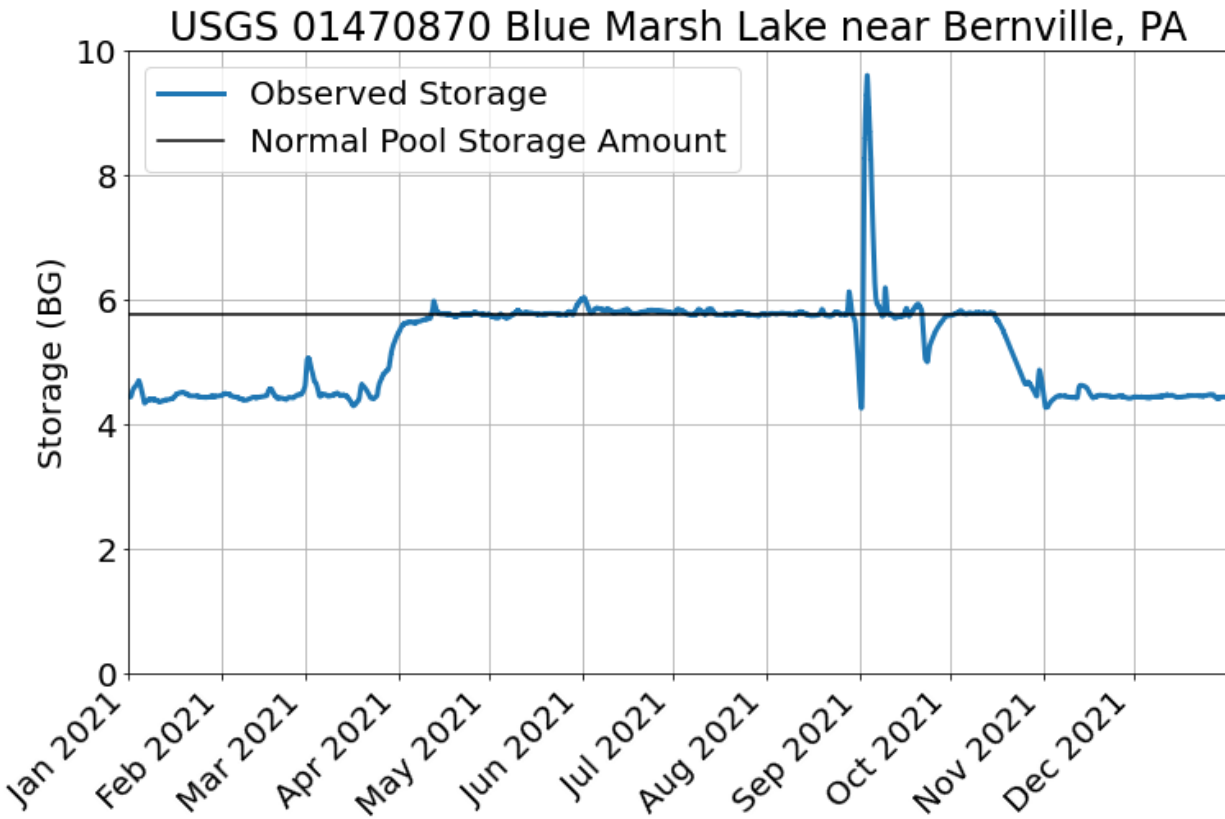
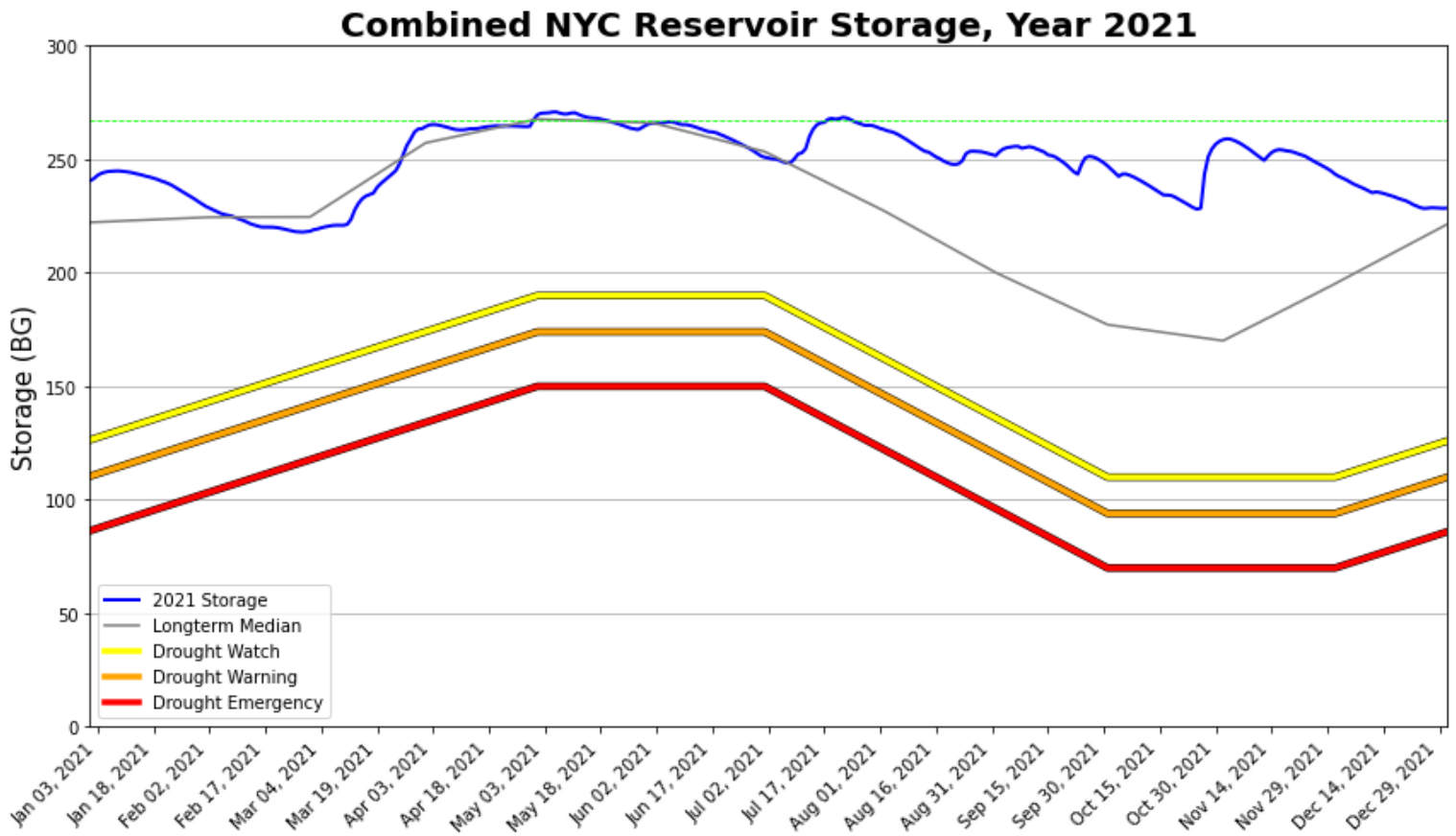
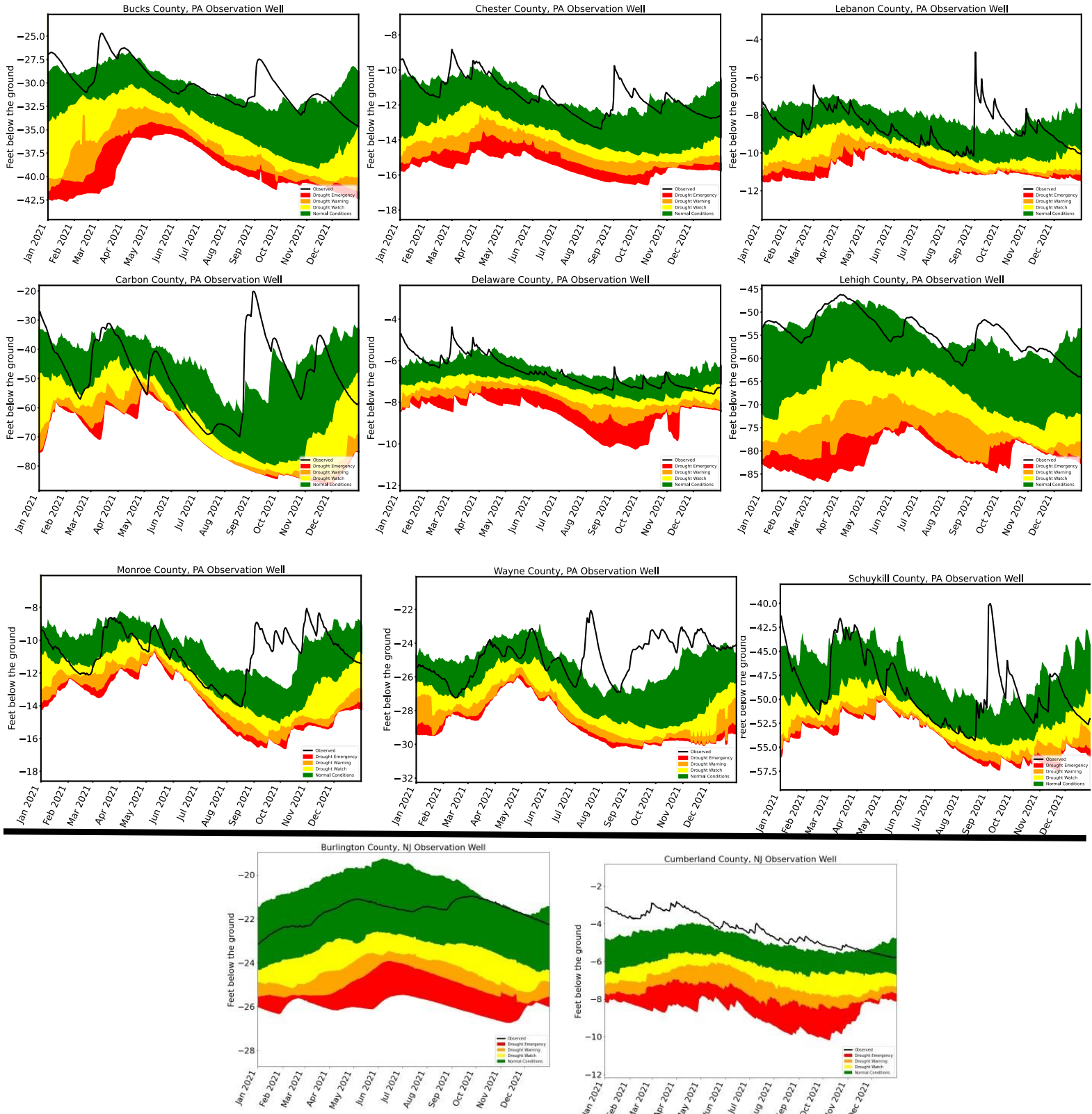


Figure 22: New York City combined reservoir storage.



Annual Hydrologic Conditions Report

Figure 23: Groundwater levels in indicator wells in Pennsylvania and New Jersey



Annual Hydrologic Conditions Report

Figure 24: Groundwater levels in indicator wells in Delaware and New York

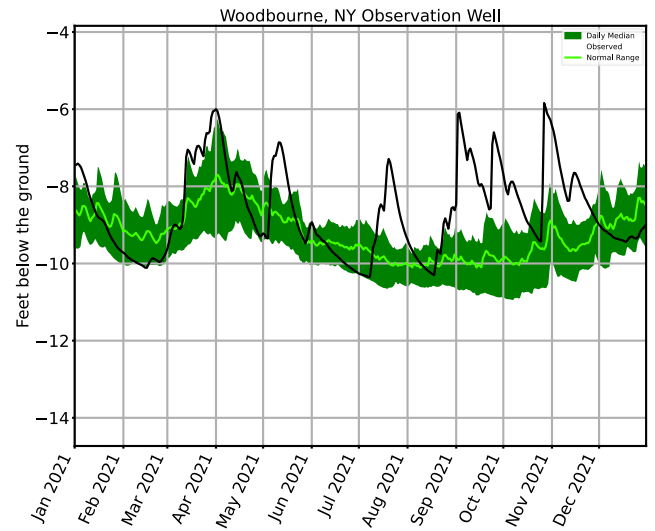
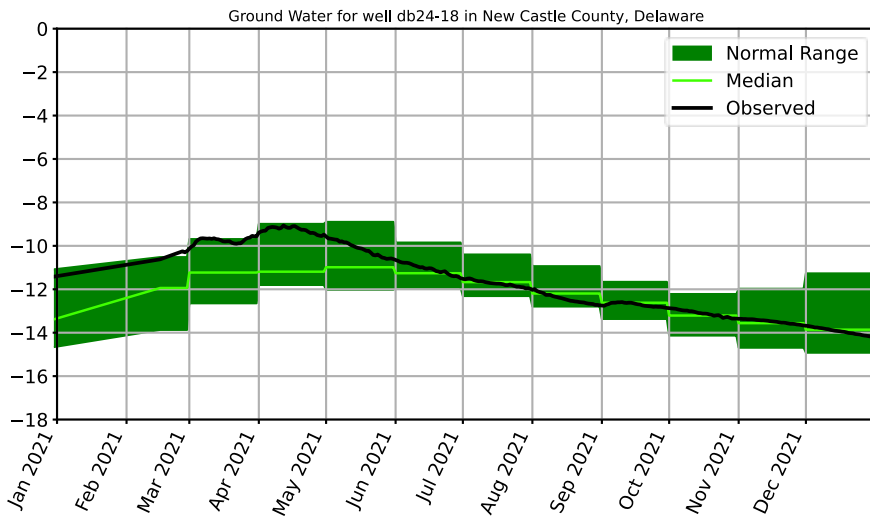
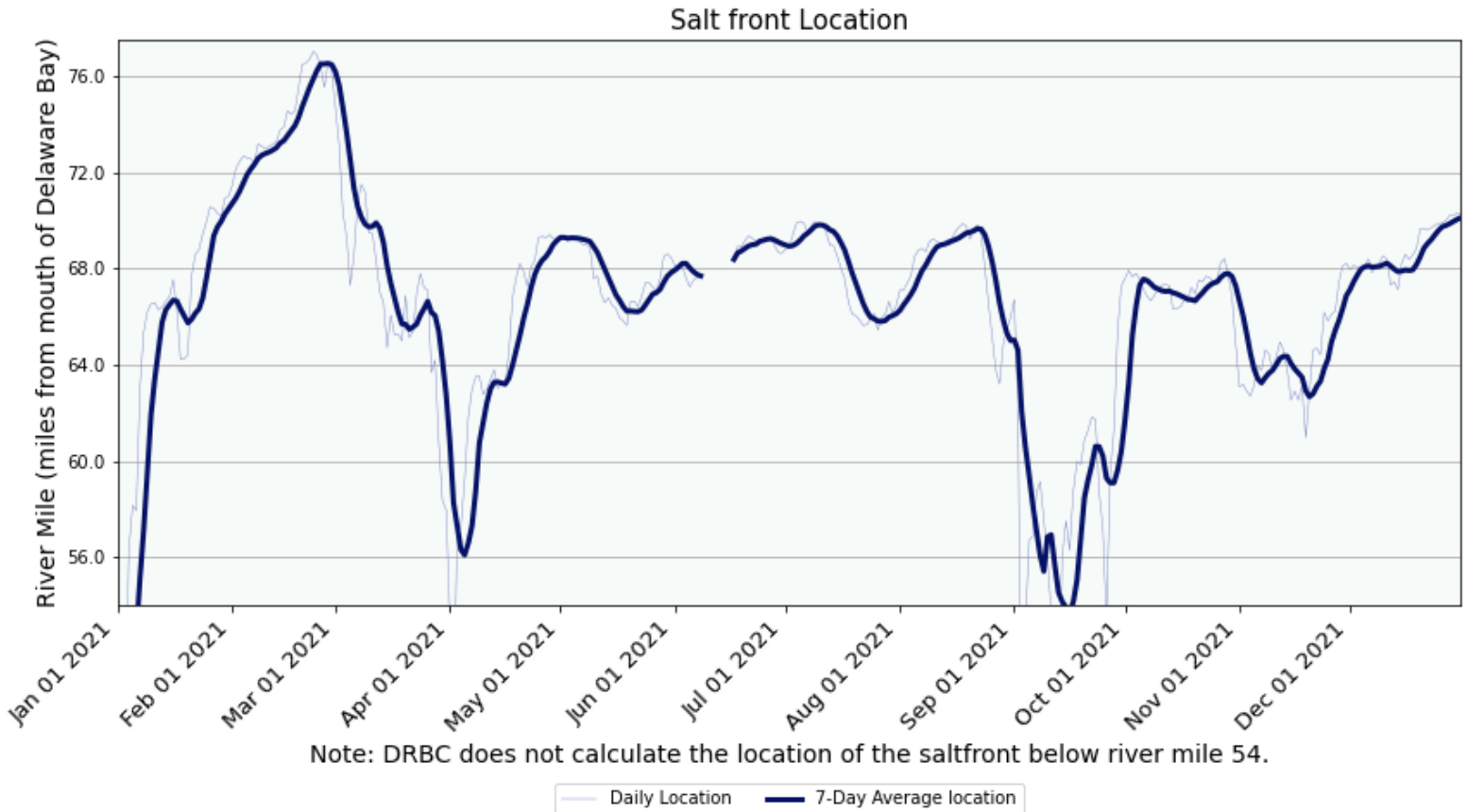


Figure 25: Time Series of the salt front during the calendar year 2021. The maximum seven-day average location was near river mile 76.5 in late February. Times when data was unavailable in July are not plotted.



REFERENCES

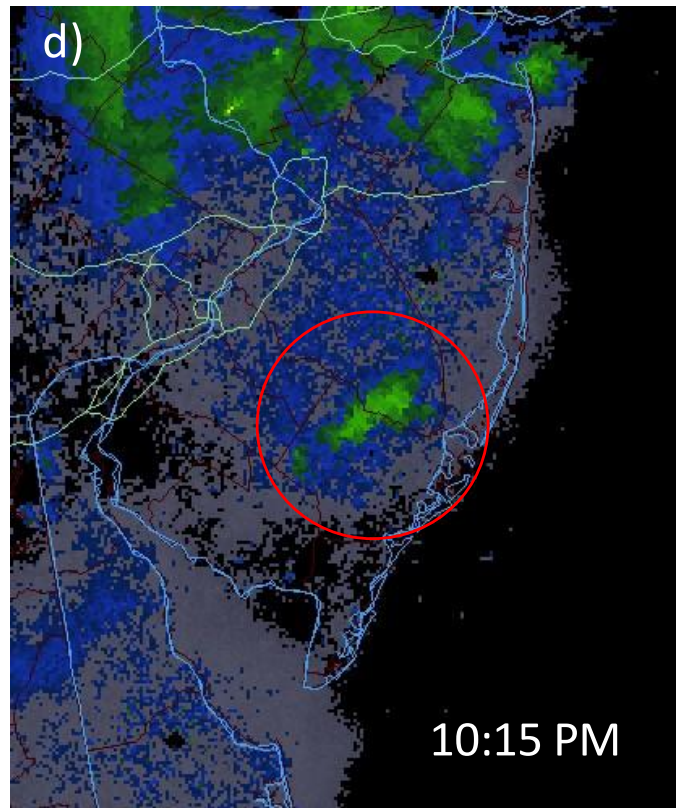
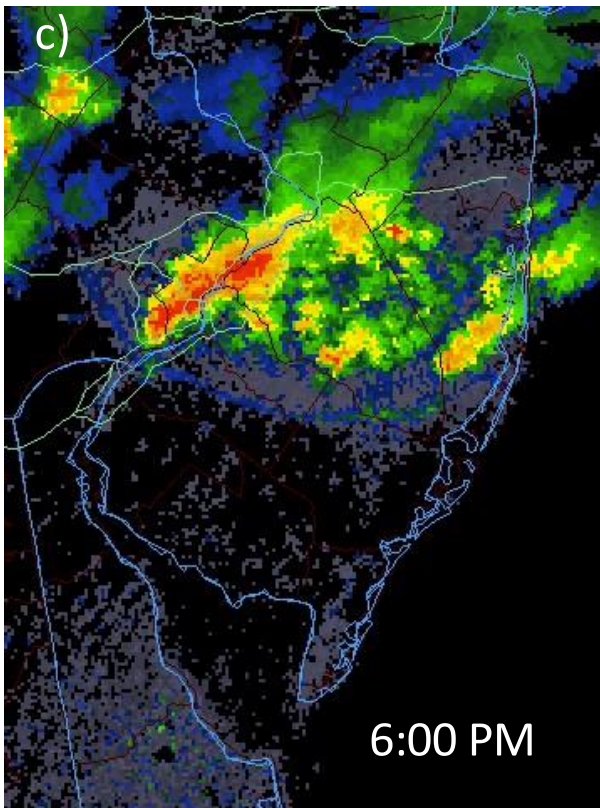
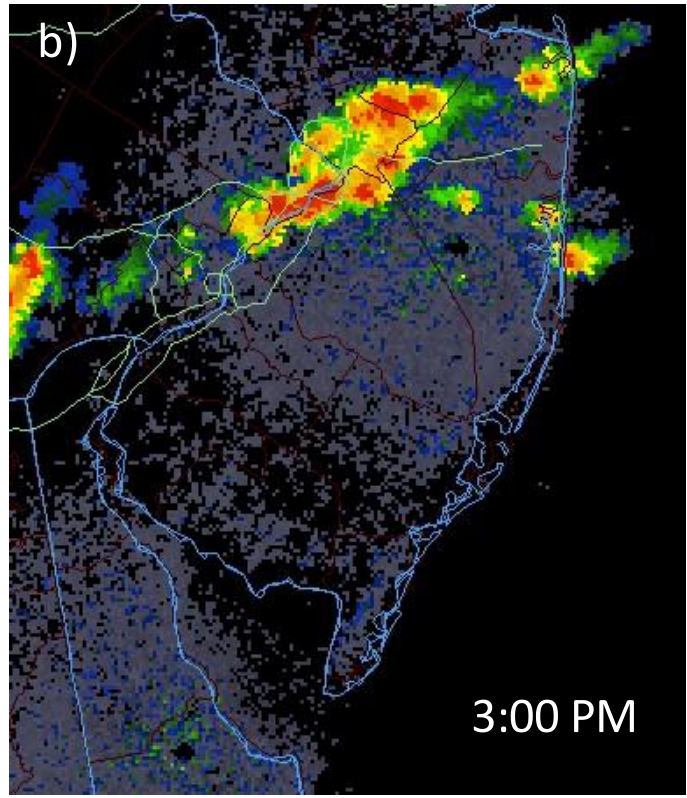
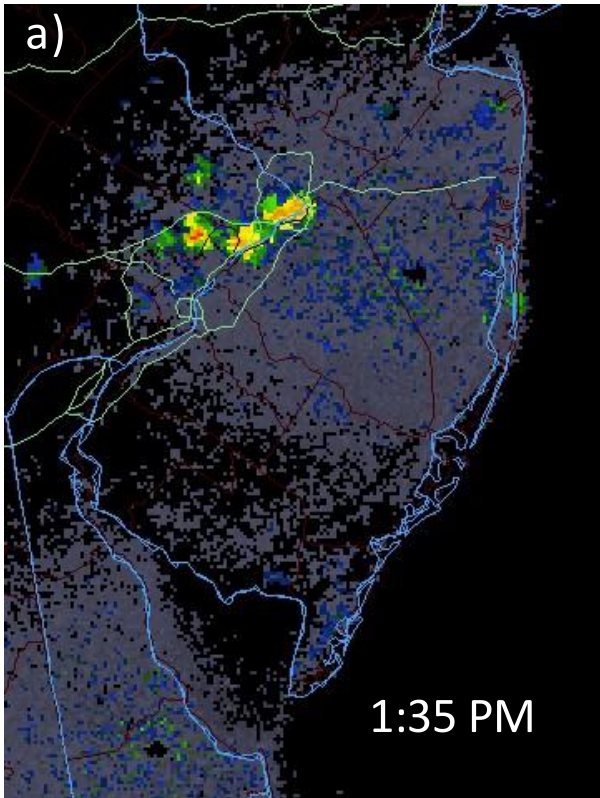
1. National Operational Hydrologic Remote Sensing Center (NOHRSC): Source for snowfall accumulation data
2. United States Geological Survey (USGS): Source for flow, stage, water temperature, groundwater, reservoir elevation, and specific conductance data at stream gages around the basin.
3. New York Water Supply Control Center (WSCC) : Source for information on New York City Delaware River Basin reservoirs, including storage levels and amounts spilled.
4. Office of the Delaware River Master (ODRM): Source for data on releases from reservoirs for thermal mitigation, rapid flow change mitigation, and releases for flow objectives.
5. Advanced Hydrologic Prediction Service (AHPS): Source for spatial rainfall data (including total accumulations and departures from normal) and flood stage graphs
6. National Oceanic and Atmospheric Administration (NOAA): Source for drought monitor map
7. Applied Climate Information System (ACIS): Source for rainfall data at selected stations across the basin.

APPENDIX A: BUCKS COUNTY FLOODING

*****Data Statement:** All data provided within this report is considered to be provisional, and is subject to change. All times noted are assumed to be Eastern Daylight Time (UTC-4) unless otherwise noted.

Meteorological Summary and Timeline: On July 12, 2021, a flash flooding event occurred in the south-central region of the basin, including Philadelphia, Pa., and extending approximately 20 miles northeast. The event began at approximately 1:20 PM when two thunderstorms began to develop near Northeast Philadelphia Airport in Pennsylvania. The two storms had combined to one storm by 1:45 PM. The storms expanded northeast towards Trenton, N.J. while continuing to develop in the same location. By 2:30 PM, the area of heaviest precipitation had been established including cities in Pennsylvania such as Bensalem, Bristol, and Croydon, and in New Jersey such as Delanco, Florence, and Burlington. At approximately 4:00 PM, the development region began to propagate slightly southwest towards Philadelphia. This seemingly uncommon storm movement is in fact a common occurrence in storms that produce large amounts of rainfall. The area of heaviest rain remained in the same location despite the slight storm movement until approximately 6:30 PM, when upper level atmospheric steering winds increased and began to push the storm southeast, combined with continued and rapid propagation of storm energy to the southwest towards Delaware. At approximately 8:15 PM, the storm dissipated over southern Burlington County, N.J. See radar updates below.

- a) **Storm formation**
- b) **Storm intensifies over Bucks County, Pa. and Burlington County, N.J.**
- c) **Storm begins to propagate southwest towards Philadelphia and Camden**
- d) **Storm dissipates over Southern Burlington County, N.J.**



Relevant National Weather Service Key Flooding Messages:

JULY 12, 2021

4:33 AM – Flash Flood Watch issued for northern counties of the basin.

11:23 AM – Flash Flood Watch expanded to include counties in south-central region of the basin

2:12 PM – Flash Flood Warning Issued for Northwestern Burlington, Southeastern Bucks, and Northeastern Philadelphia Counties, set to expire at 6:15 PM. Motorists are advised not to drive into flooded roadways or go around barricades.

3:08 PM – Flash Flood Statement Issued for the same three counties. Damage Threat is said to be considerable.

4:10 PM – Flash Flood Warning extended through 9:00 PM for the same three counties.

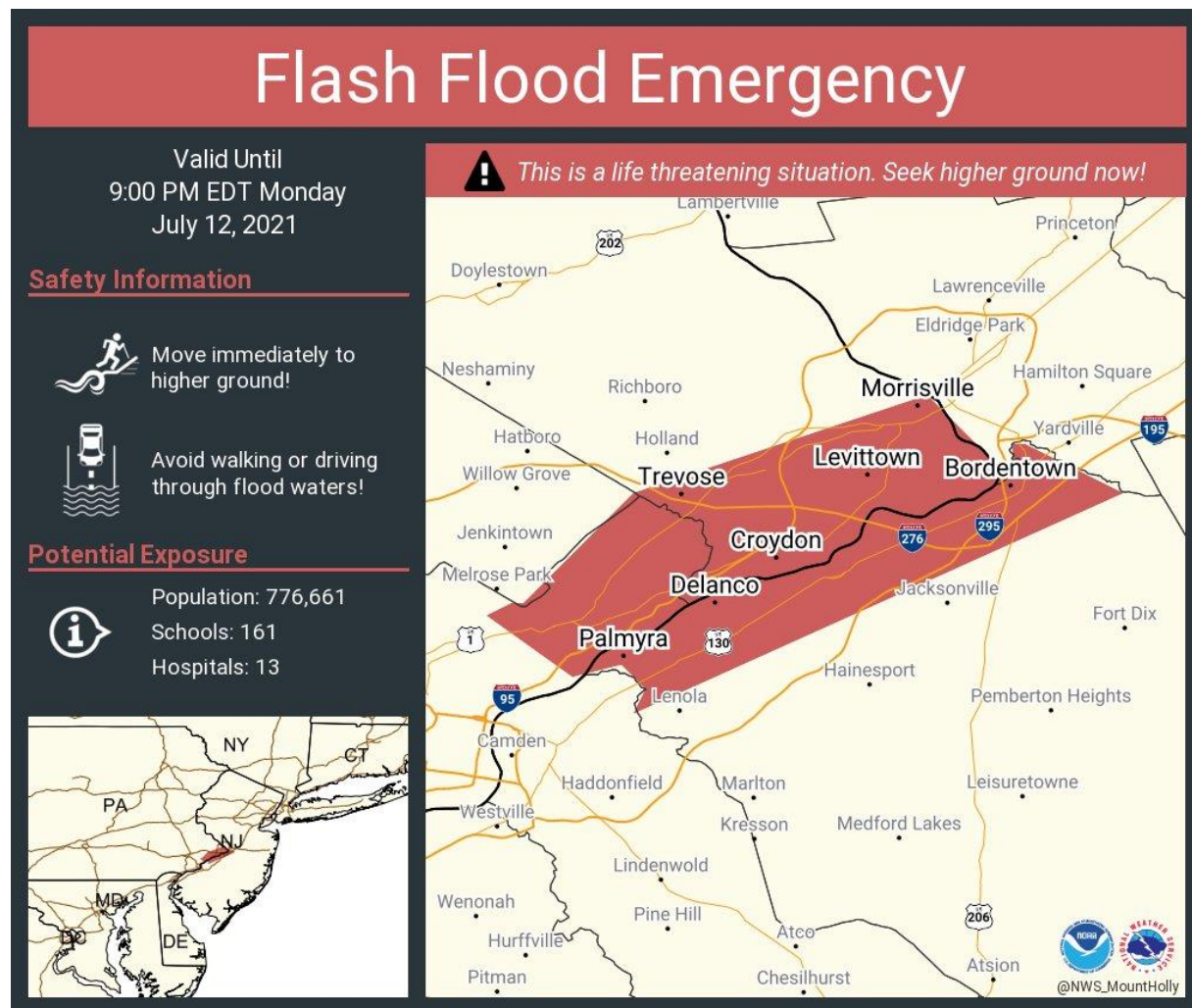
5:14 PM – Flash Flood Statement issued, qualified as a Flash Flood Emergency for Bensalem, Bristol, Florence, and Vicinity. Event classified as a particularly dangerous situation and damage threat is upgraded to catastrophic. Motorists advised not to travel unless fleeing an area of under evacuation order (see image below).

6:01 PM – Flash Flood Warning issued for Camden and Philadelphia Counties in NJ and PA, respectively, set to expire at 10:15 PM.

7:43 PM – Flash Flood Warning is cancelled for Camden and Philadelphia Counties.

9:00 PM – Flash Flood Warning is allowed to expire for Northwestern Burlington, Southeastern Bucks, and Northeastern Philadelphia Counties.

Note: There were several other Flash Flood Warnings, Flash Flood Statements, and Flood Statements issued that were not included in this list, as they were not relevant to the event. There were also severe thunderstorm warnings issued for damaging winds and small hail associated with the same storm that were not listed.



Graphic provided by NWS Mt. Holly

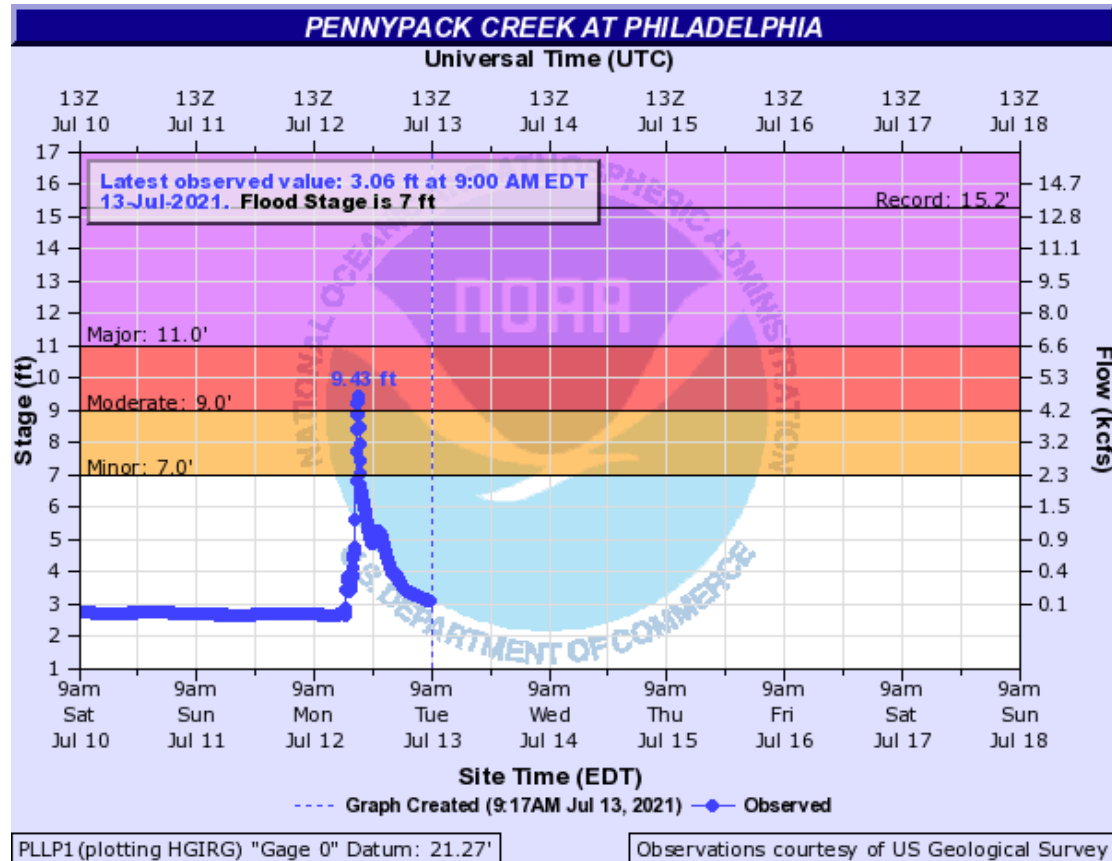
Hydrologic Impacts:

Moderate river flooding occurred on the Pennypack Creek in Pennsylvania. See graph below. The river began to experience minor flooding at approximately 5:35 PM and stopped flooding at approximately 6:35 PM. The peak stage at Pennypack was recorded to be 9.43 feet at approximately 6:05 PM. The creek rose from 4.76 feet to the crest of 9.43 feet in 40 minutes. This crest would rank as number 14 in the period of record, behind the crest of 9.74 feet on April 3, 2005. The crest on July 12, 2021 was higher than the crest due to Tropical Storm Isaias in August 2021, which caused the creek to rise to 8.31 feet.

Frankford Creek in Pennsylvania also experience a rapid water rise due to the flash flooding. The gage rose from 2.15 feet to a crest of 6.68 feet in 15 minutes starting at 5:35 PM. The gage was above action station for approximately 15 minutes between 5:45 PM and 6:00 PM. The recent crest ranks as number 27 among other historic crests.

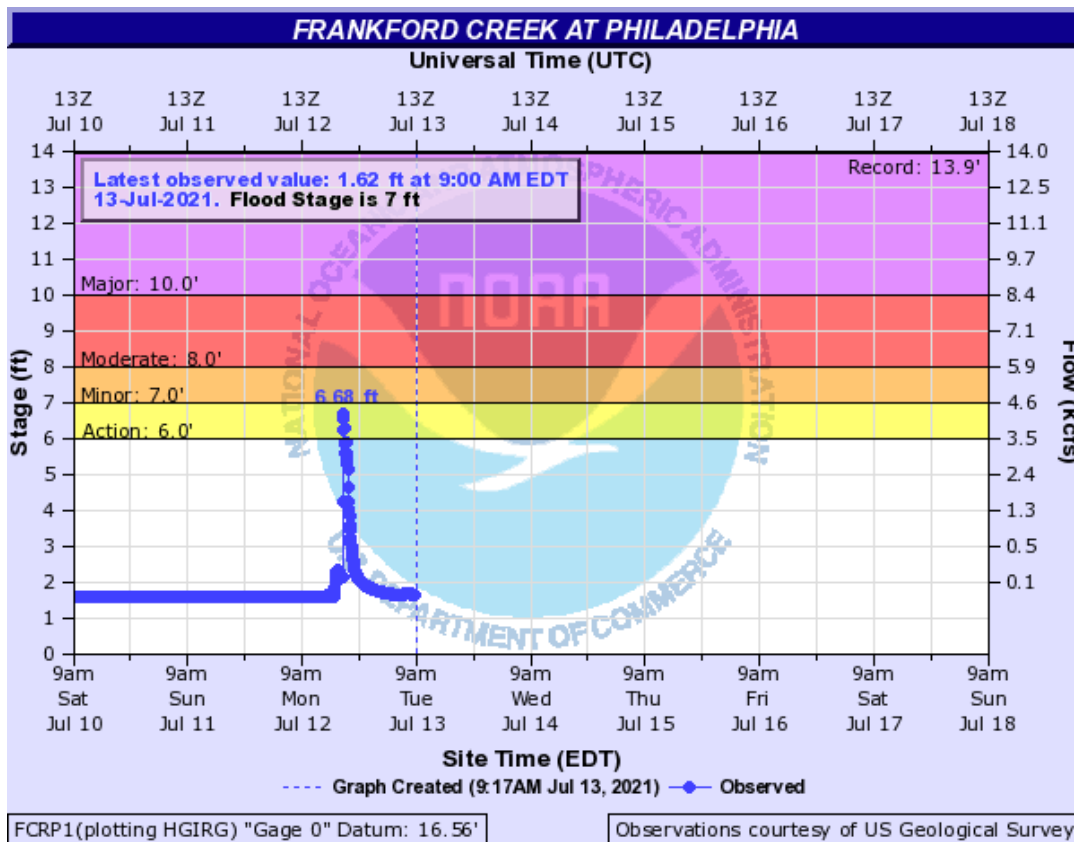
Annual Hydrologic Conditions Report

Neshaminy Creek near Langhorne, Pa. experienced a rapid river rise, but did not experience flooding. The stage rose from 1.31 feet to a crest of 4.67 feet in approximately 2 hours and 15 minutes. Action stage for this gage is 8 feet.



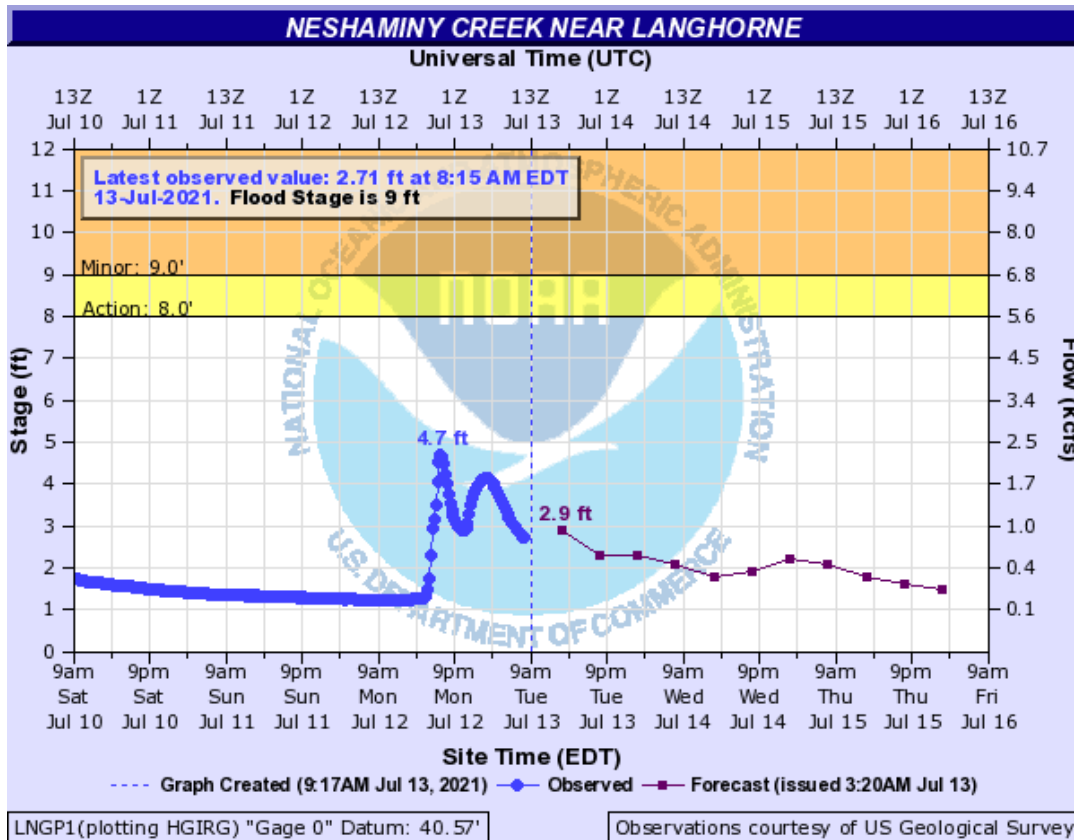


Annual Hydrologic Conditions Report



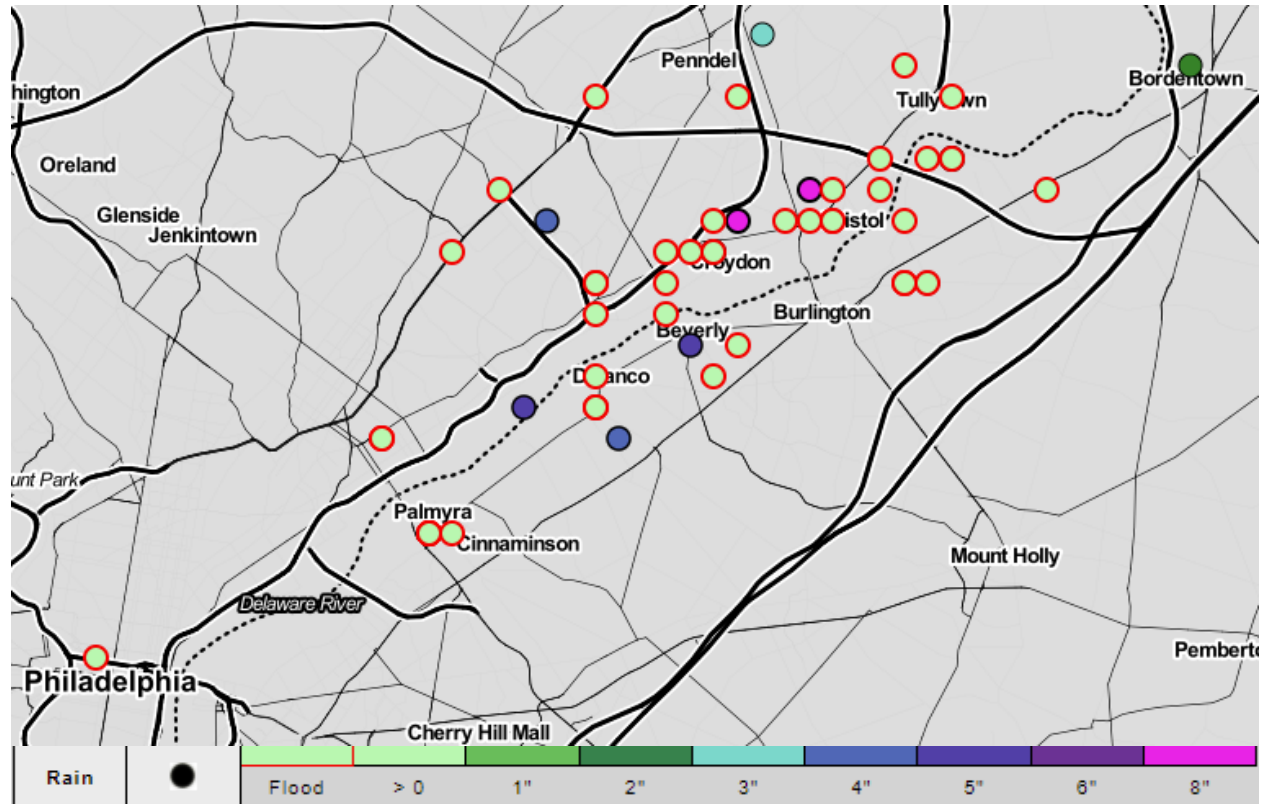


Annual Hydrologic Conditions Report

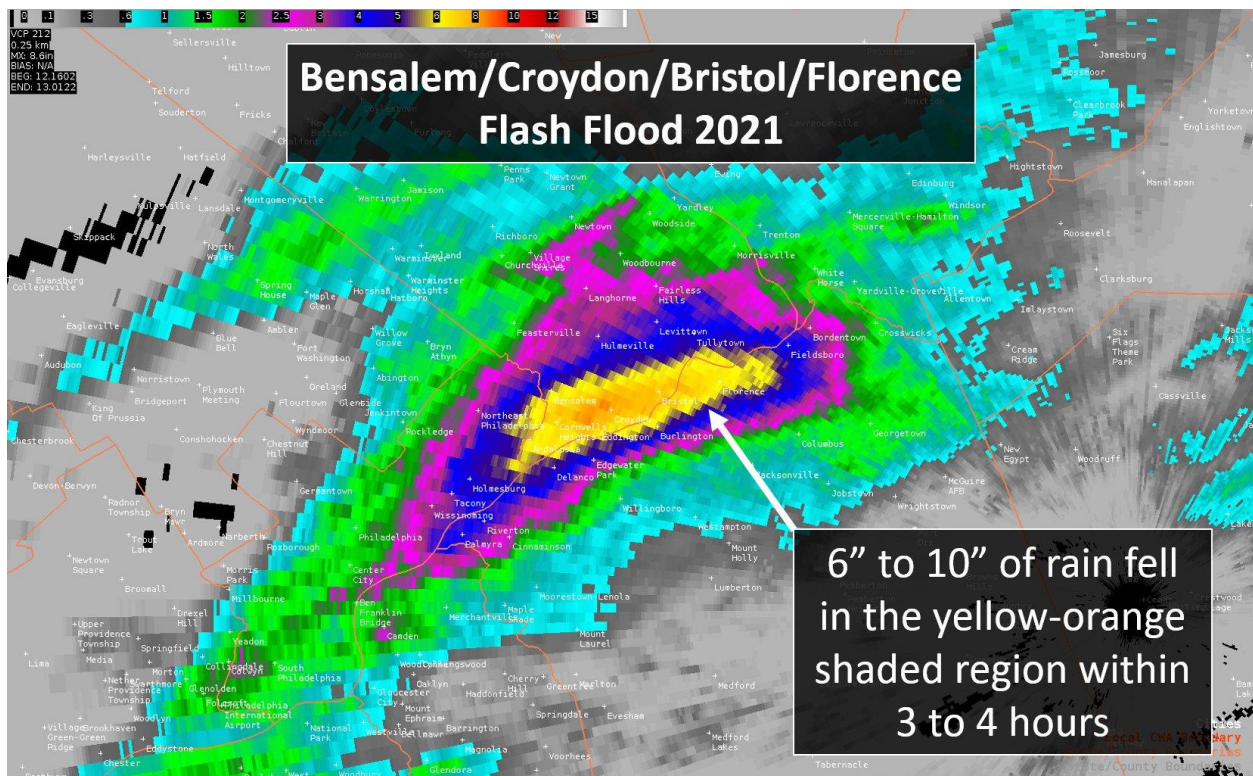


Storm Reports and Observations

Below is a map of storm reports that were compiled by the National Weather Service. The light green circles with red outlines represent flooding reports, while the colored circles represent rainfall total reports with the storm, as explained by the key. Two stations between Croydon and Bristol, Pennsylvania received totals in excess of 8 inches, with the station nearest Croydon reporting 10.67 inches.



Annual Hydrologic Conditions Report



Map Provided by NWS Mt. Holly

Data Sources:

Radar Data - College of DuPage: https://weather.cod.edu/satrad/?parms=local-New_Jersey-comp_radar-200-0-100-1&checked=counties-usint-map&colorbar=undefined

NWS Warning Information – Iowa Environmental Mesonet: <https://mesonet.agron.iastate.edu/nws/>

River Flooding – Advanced Hydrologic Prediction Service: <https://water.weather.gov/ahps2/index.php?wfo=phi>

Storm Reports – Weather Prediction Center: <https://www.wpc.ncep.noaa.gov/exper/lsr/lsr.php#>

Further Resources:

DRBC Flood Portal: <https://www.nj.gov/drbc/programs/flood/portal-flood.html>

Mid-Atlantic River Forecast Center: <https://www.weather.gov/marfc/>

NWS Mt. Holly: <https://www.weather.gov/phi/>

APPENDIX B: FRED

On Wednesday, August 18, 2021, the remnants of Tropical Storm Fred passed through the Delaware River Basin (DRB or Basin). Isolated areas of up to five inches of precipitation in portions of the lower Basin resulted in flooding. Moderate flooding¹¹ occurred on Frankford Creek in Philadelphia, Pa. Minor flooding occurred on the East Branch Brandywine and Pennypack creeks in Pennsylvania. The Schuylkill River and the Perkiomen Creek in Pennsylvania reached Action Stage, as did the Brandywine Creek in Pennsylvania and Delaware. Action Stage to minor tidal flooding occurred along the tidal Delaware River, the tidal Schuylkill River, and the tidal Christina River.

Tropical Storm Fred - Characteristics

Tropical Storm Fred made landfall in the Florida Panhandle but was no longer considered a tropical systemⁱⁱ when the center of the storm was near the Basin on August 18, 2021. Two bands of rain associated with the storm impacted the DRB in the evening of August 18, 2021, and into the early morning hours of August 19, 2021. Flash flooding, as well as minor to moderate river and stream flooding, occurred at 14 gages located in the middle to lower regions of the Basin.

As the center of the storm moved from west of the Basin to north of the Basin, two bands of heavy rain extended out from the center of the storm. The two bands are labeled with red lines in the radar imagery below. Within each band, high rainfall rates were fueled by high amounts of tropical moisture within the storm. While the motion of the entire storm system was from southwest to northeast, the motion of the individual storms within the heavier bands of rain was from south-southwest to north-northeast (indicated by the blue arrows in the figures below). This caused the storms within each band to “train” over the same areas for long periods of time (the storms moved like train cars with one storm following the motion of the previous storm). At approximately 8:35 PM, August 18, the first band was impacting regions in southeastern Pennsylvania. By 1:45 AM on August 19, the second band had moved into the Basin over the same area in southeastern Pennsylvania. By the late morning hours on August 19, the center of the storm was well north of the Basin, and rain had moved out of the region.

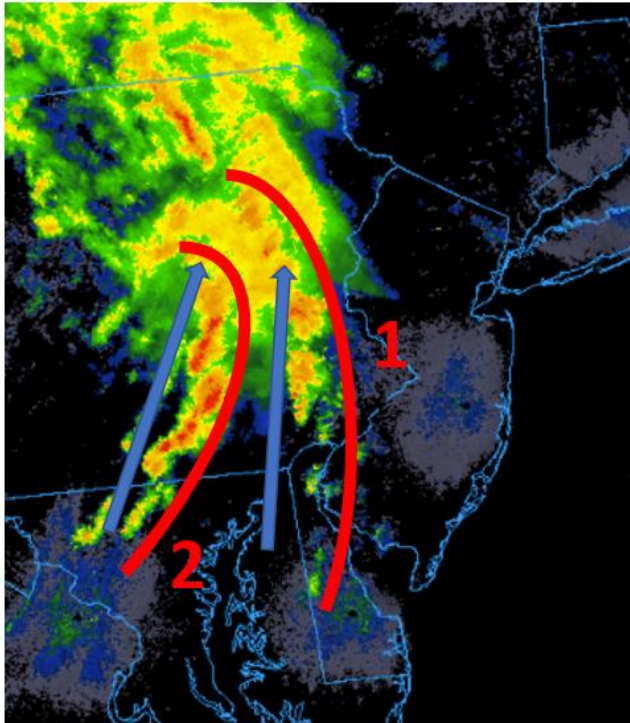
Precipitation

As shown in Figure 1, precipitation was highest in the Pennsylvania portion of the Basin. Isolated areas in southeastern and eastern-central Pennsylvania received approximately five inches of precipitation from the storm¹² Accumulated precipitation from Tropical Storm Fred is shown in Figure 2 below (Mesonetⁱⁱⁱ).

¹¹ Definitions for flood stages are provided in the ‘Definitions’ section.

¹² Data Source: Advanced Hydrologic Prediction Service

8/18/21 8:35 PM EDT



Radar Images from College of DuPage

8/19/21 1:45 AM EDT

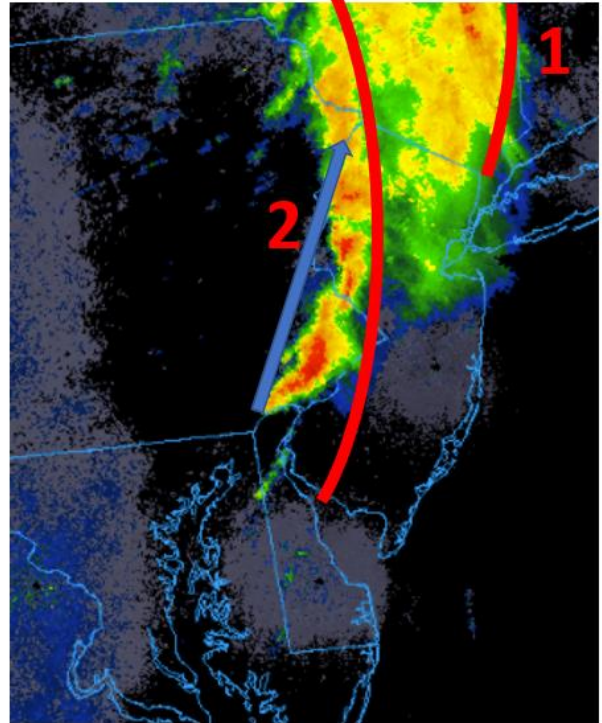


Figure 1. Total Precipitation from Tropical Storm Fred

Total Precipitation Accumulation Tropical Storm Fred (August 18-19, 2021)

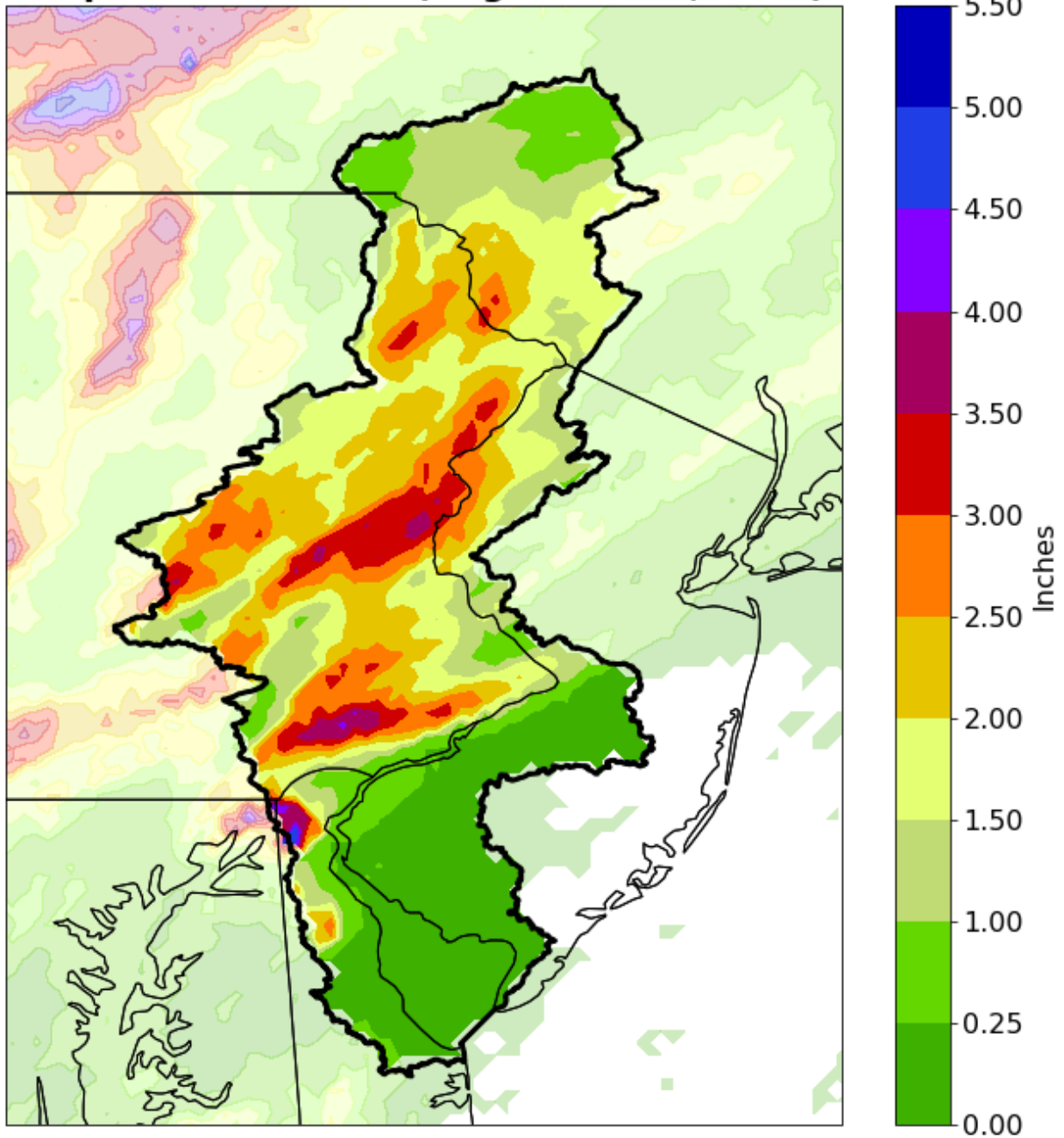
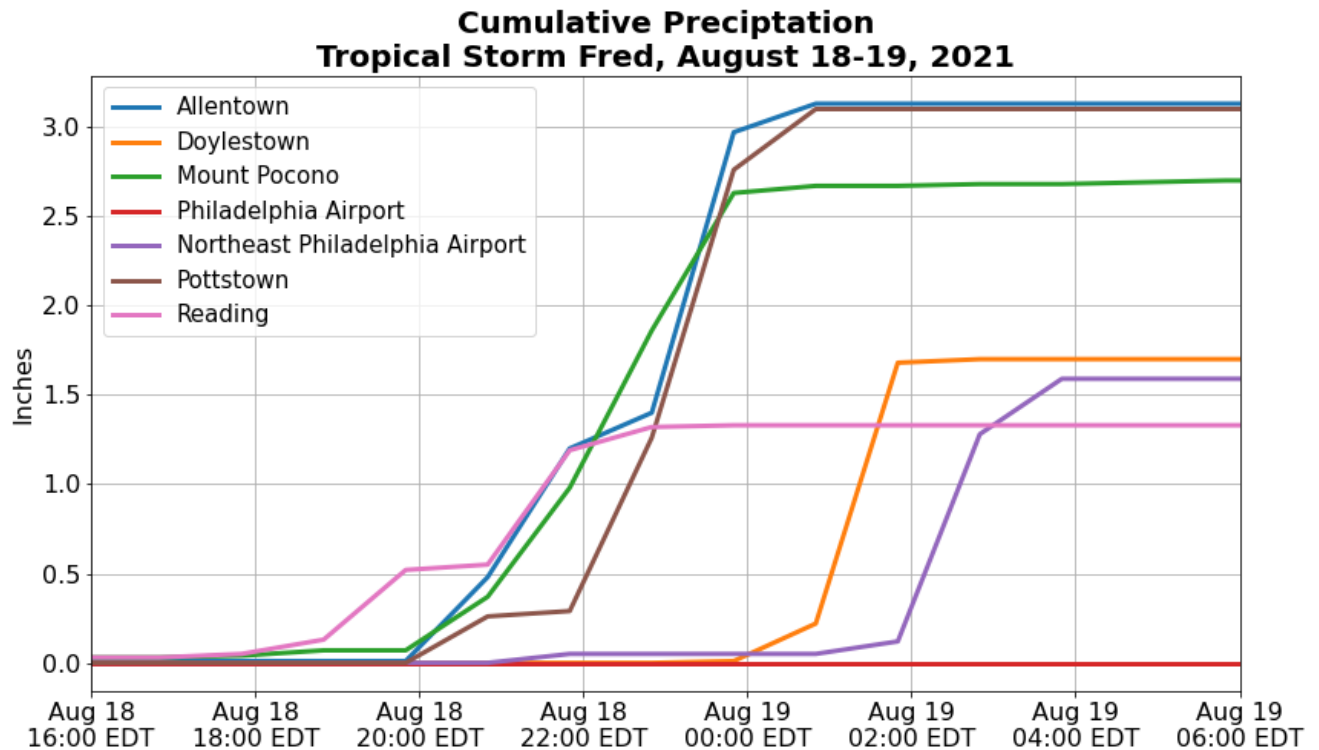


Figure 2. Accumulated Precipitation at Pennsylvania Locations



Flooding

Flooding associated with the two bands of rain and storms occurred overnight Wednesday, August 18, 2021, into Thursday morning, August 19, at 14 locations in the Basin. Seven of the locations that experienced flooding were on streams, and the other seven were tidal. Of the seven stream gages, five reached Action Stage, one reached Minor Flood Stage and one reached Moderate Flood Stage. All tidal gages reached Minor Flood Stage, with exception of the Schuylkill River near Philadelphia, Pa. near 30th Street, which reached Action Stage.

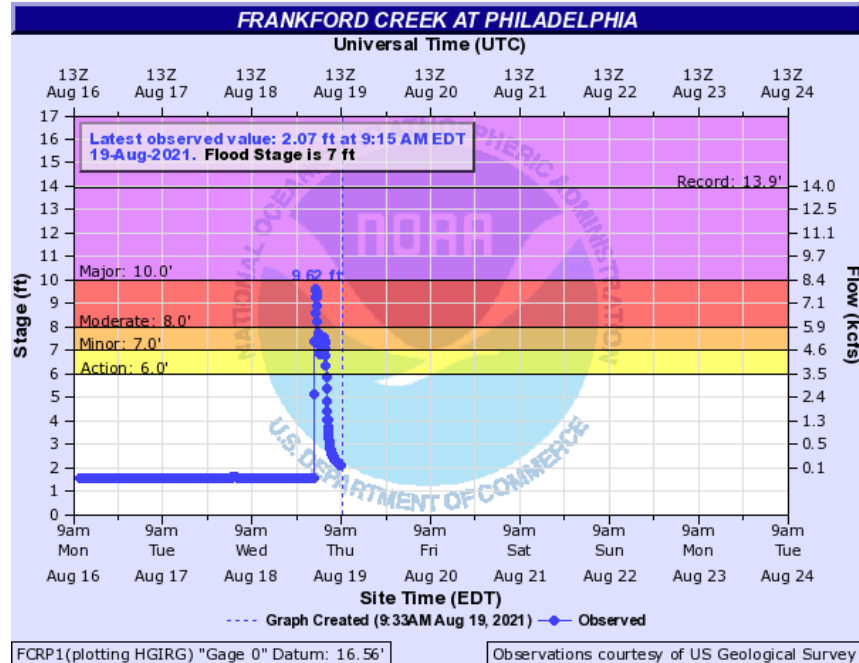
Annual Hydrologic Conditions Report

<u>National Weather Service Flood Forecast and Observation Location</u>	Water Type	Body	Peak Stage	Flood Type
Frankford Creek at Philadelphia	Stream		9.62 feet	Moderate
Pennypack Creek at Philadelphia	Stream		8.04 feet	Minor
Schuylkill River at Landingville	Stream		7.76 feet	Action
Perkiomen Creek at East Greenville	Stream		3.27 feet	Action
East Branch Brandywine Creek Below Downingtown	Stream		7.91 feet	Minor
Brandywine Creek at Chadds Ford	Stream		8.39 feet	Action
Brandywine Creek at Wilmington	Stream		14.6 feet	Action
Delaware River at Marcus Hook	Tidal		7.76 feet	Minor
Delaware River at USCG station Washington Street	Tidal		8.33 feet	Minor
Delaware River at Burlington	Tidal		9.33 feet	Minor
Delaware River at Bridesburg	Tidal		8.55 feet	Minor
Schuylkill River near Philadelphia near 30th Street	Tidal		5.25 feet	Action
Christina River at Newport	Tidal		7.32 feet	Minor
Christina River at Wilmington	Tidal		7.56 feet	Minor

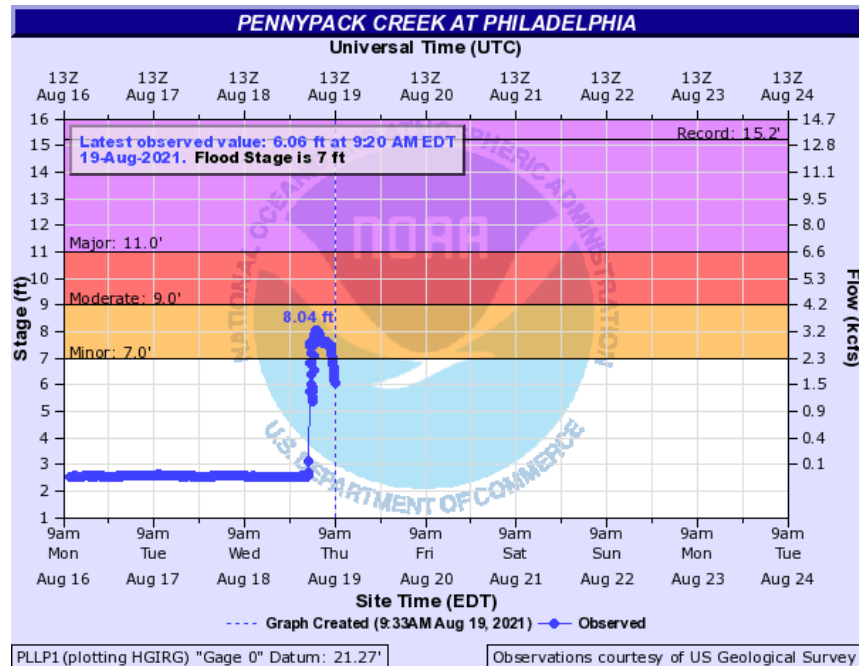
Annual Hydrologic Conditions Report

Flooding Locations and Hydrographs

The locations that experienced flooding from Tropical Storm Fred are below. A hydrograph, which is a plot of water level or stage over time, for each location is provided.

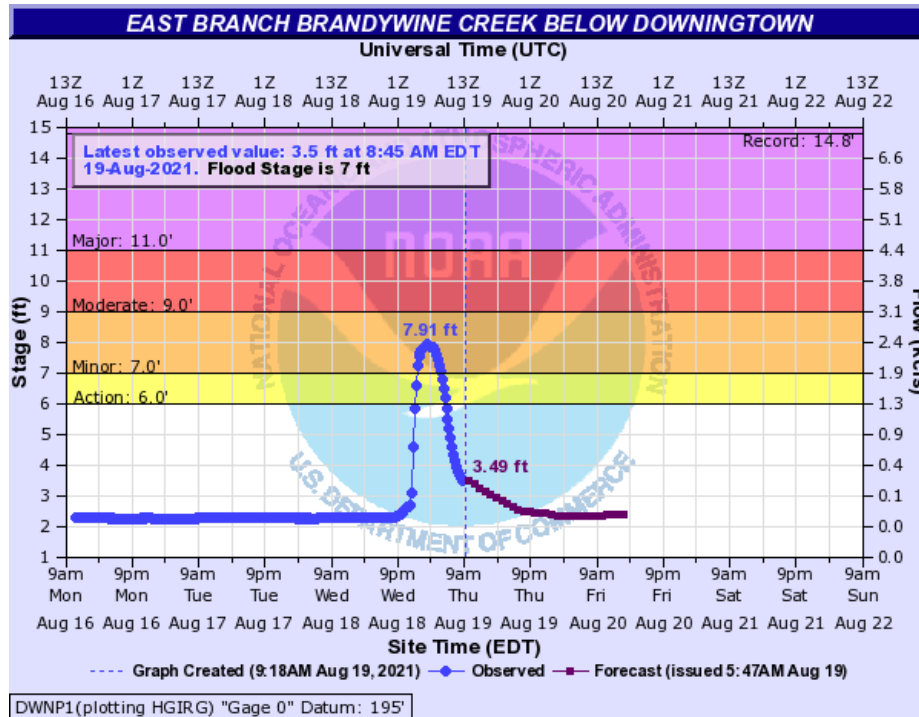


Frankford Creek, Moderate Flood Stage, Peak 9.62 feet.

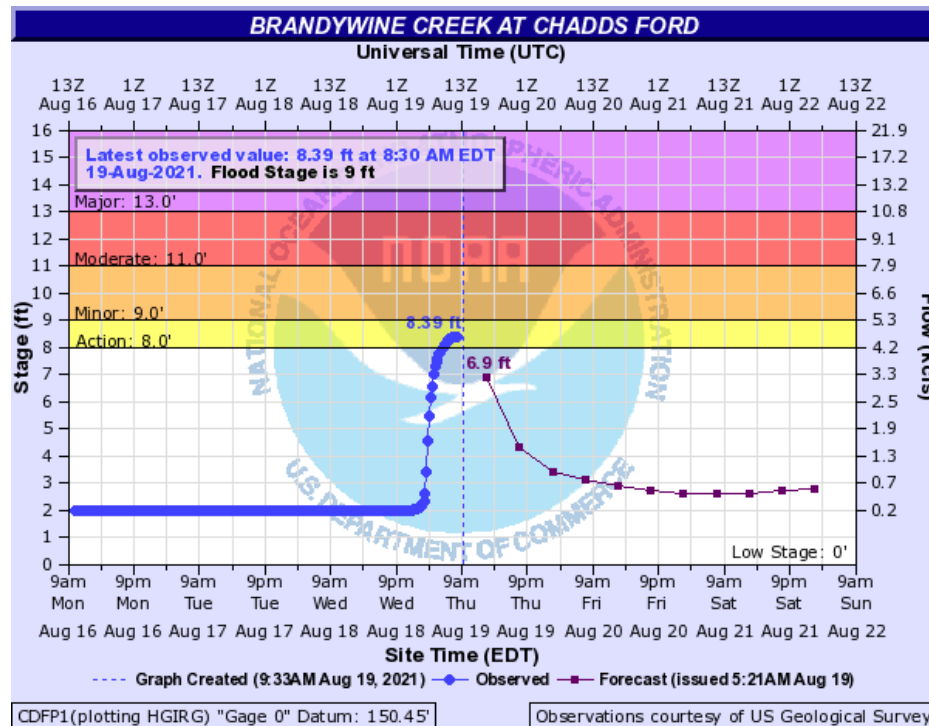


Pennypack Creek, Minor Flood Stage, Peak 8.04 feet.

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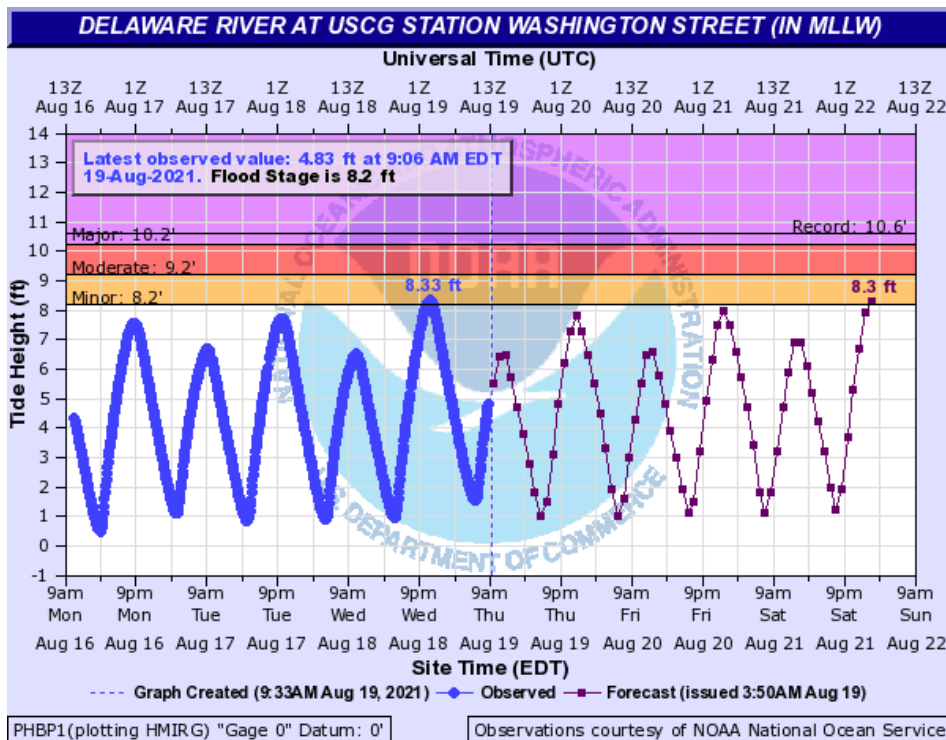


East Branch Brandywine Creek below Downingtown, Minor Flood Stage, Peak 7.91 feet.

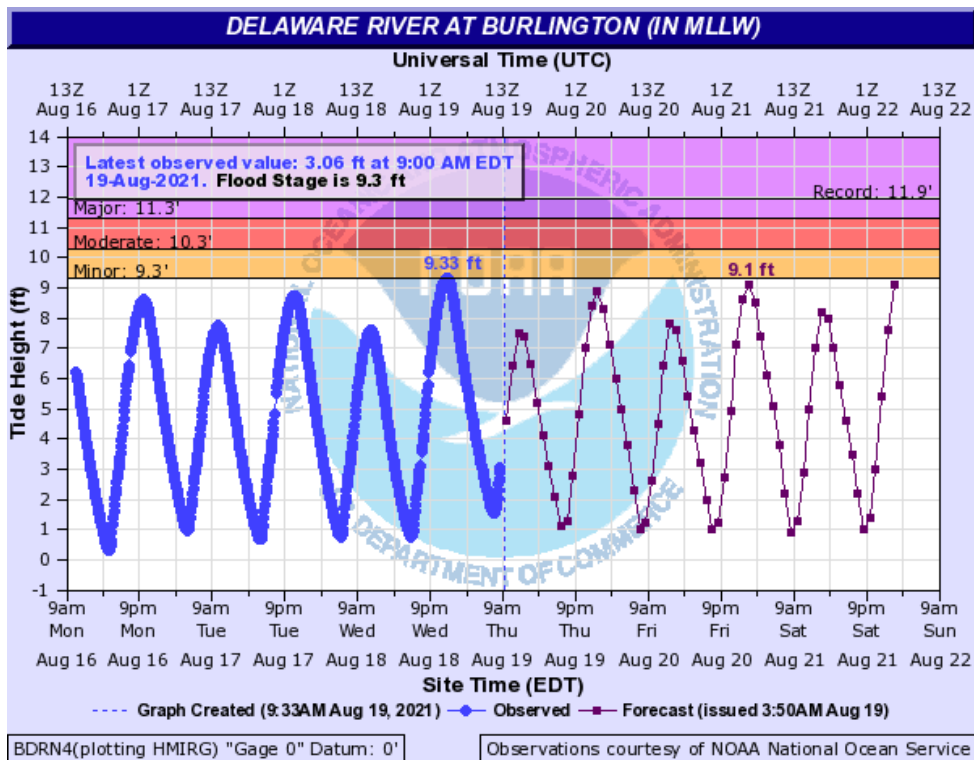


Brandywine Creek at Chadds Ford, Action Stage, Peak 8.39 feet.

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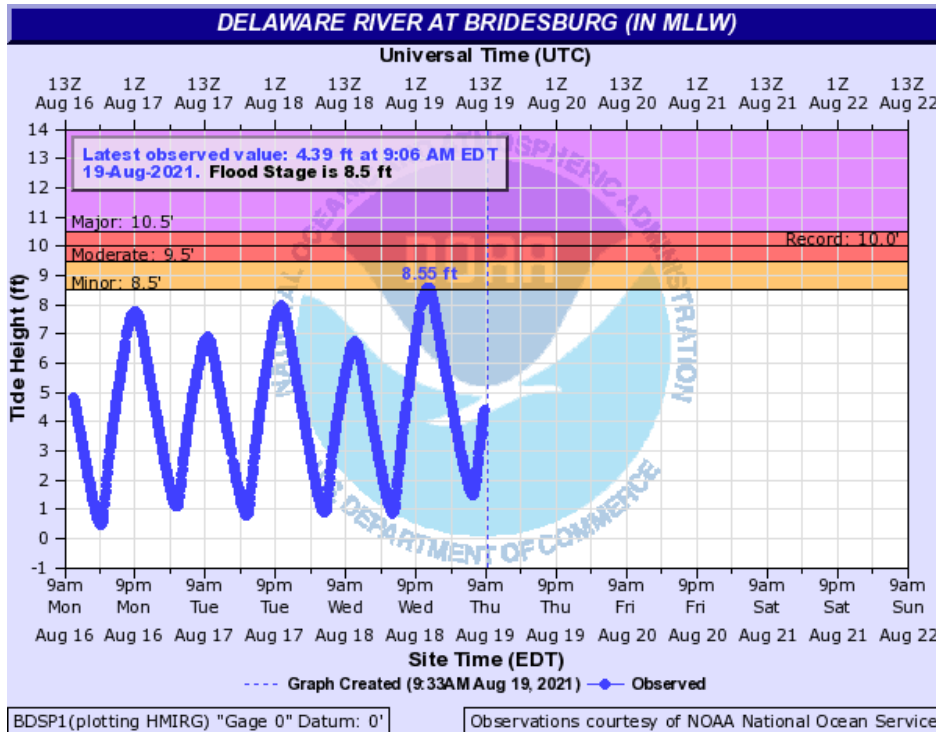


Delaware River at Washington Street (tidal), Minor Flood Stage, Peak 8.33 feet.

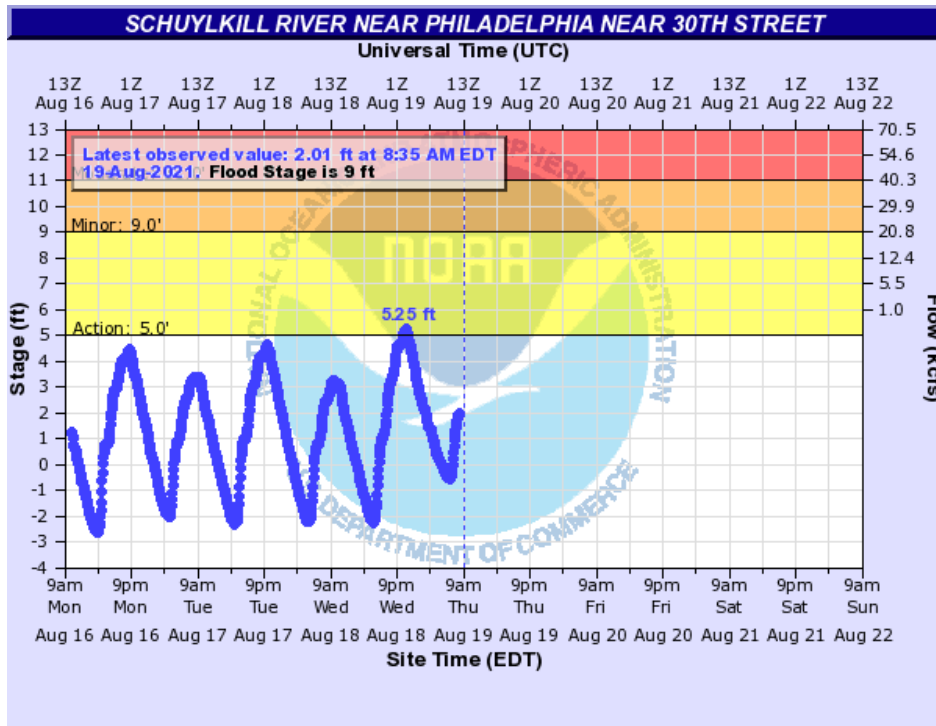


Delaware River at Burlington, Minor Flood Stage, Peak 9.33 feet.

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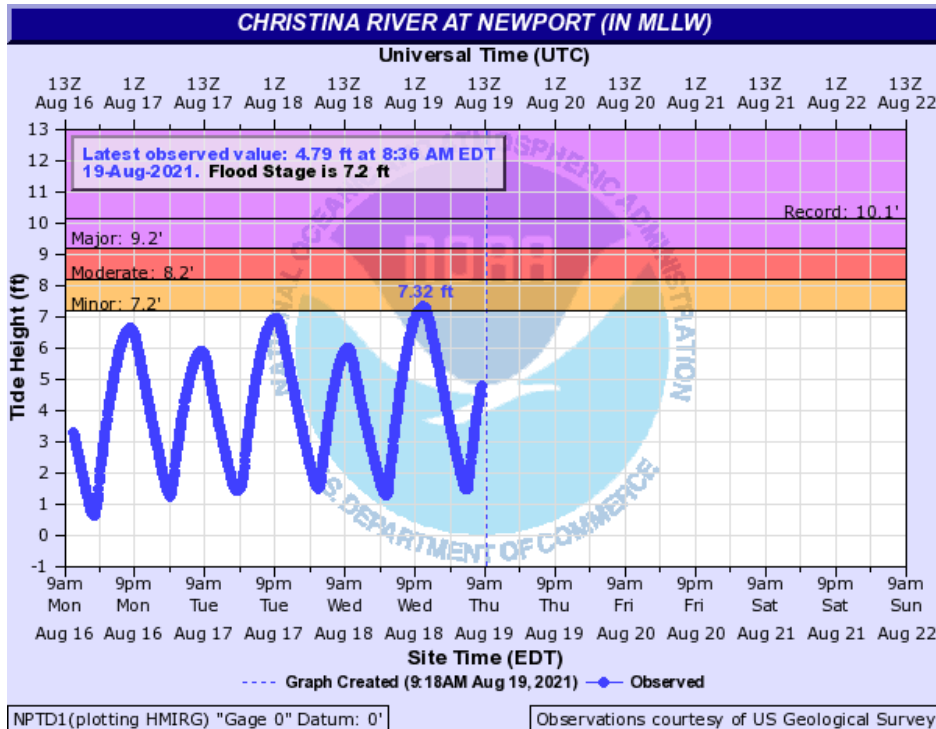


Delaware River at Bridesburg (tidal), Minor Flood Stage, Peak 8.55 feet.

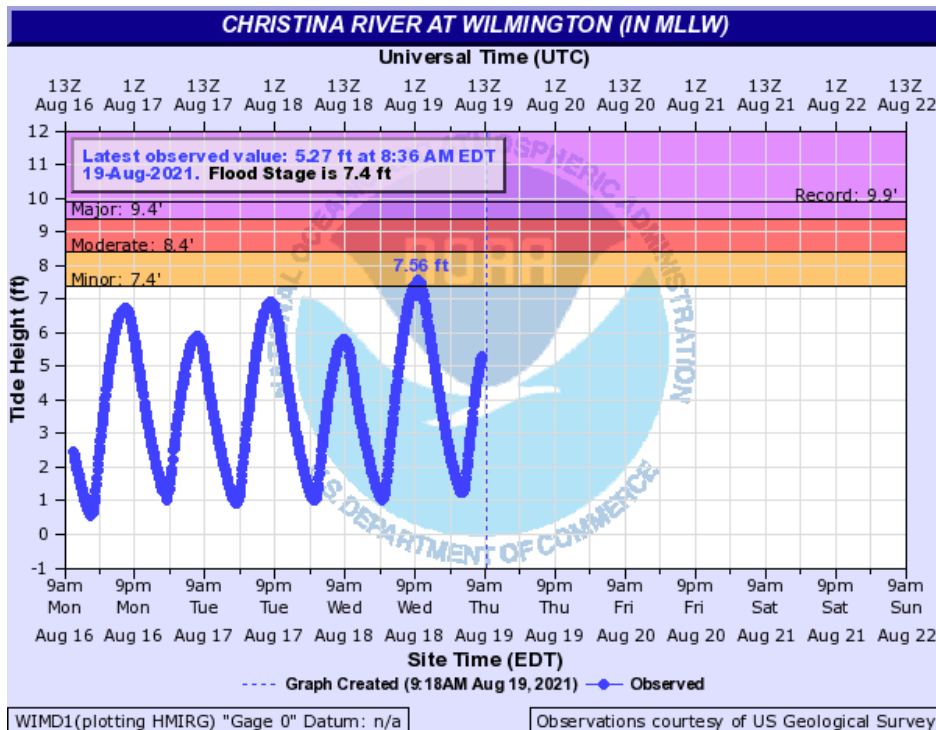


Schuylkill River near Philadelphia's 30th Street, Action Stage, Peak 5.25 feet.

Annual Hydrologic Conditions Report



Christina River Newport Del., Minor Flood Stage , Peak 7.32 feet.



Christina River at Wilmington, Del., Minor Flood Stage, Peak 7.56 feet

Annual Hydrologic Conditions Report

For official information on the storm, please visit the National Hurricane Center at www.nhc.noaa.gov.

For official information on impacts to the Delaware River Basin, please visit the National Weather Service Mt. Holly website at <https://www.weather.gov/phi/> and the Mid-Atlantic River Forecast Center website at <https://www.weather.gov/marfc/>

APPENDIX C: HENRI

Hurricane Henri passed through the Delaware River Basin (DRB or Basin) from Saturday, August 21, 2021, to Monday, August 23, 2021. Isolated areas of up to eight inches of precipitation occurred in portions of the upper-middle Basin. As a result, minor flooding¹³ occurred in Pennsylvania on the Bush Kill, Lehigh River, the Perkiomen and Brodhead creeks. Minor flooding also occurred in New Jersey on the Paulins Kill and the North Branch Rancocas Creek. Action Stage was reached on portions of the main stem Delaware River, on the Assunpink Creek and the Musconetcong River in New Jersey and on the West Branch Delaware River at Walton, N.Y.. Minor flooding occurred along the tidal portion of the Delaware River, and the tidal portion of the Schuylkill River reached Action Stage.

Hurricane Henri – Characteristics

Henri was classified as a Category 1 Hurricane as of 11 AM on Saturday, August 21, 2021. The center of the storm was located approximately 200 miles southeast of the mouth of the Delaware Bay, shown in the first row of radar imagery below. The annotated purple arrows show the motion of the individual bands of storms within the larger system. The storm progressed north, and precipitation associated with the storm began in the Delaware River Basin at approximately 8:00 PM on Saturday, August 21, 2021. Through the overnight hours, a band of heavy precipitation was located over the middle-upper region of the Basin, with storms moving from west to east, as seen in the second radar image in the first row. On the morning of Sunday, August 22, 2021, Henri made landfall in Rhode Island, shown in the first image of the second row in the radar imagery below. The storm was downgraded to a tropical storm as of 8 AM on August 22, 2021. The same band of heavy precipitation was still located over the middle-upper region of the Basin at this time. As the storm moved further inland, the track shifted west at 6:30 PM on August 22, 2021, when several heavy bands of precipitation moved over the upper Basin. At 8 PM on August 22, 2021, the storm was then a tropical depression. On the morning of August 23, 2021, the center of the storm was located over the upper Basin with heavy precipitation occurring over much of the Basin as shown in the final row of radar imagery below. The storm began to shift eastward by the afternoon hours, and only one band of scattered storms remained in the Basin. By the evening of Monday, August 23, 2021, the storm was no longer over the Basin.

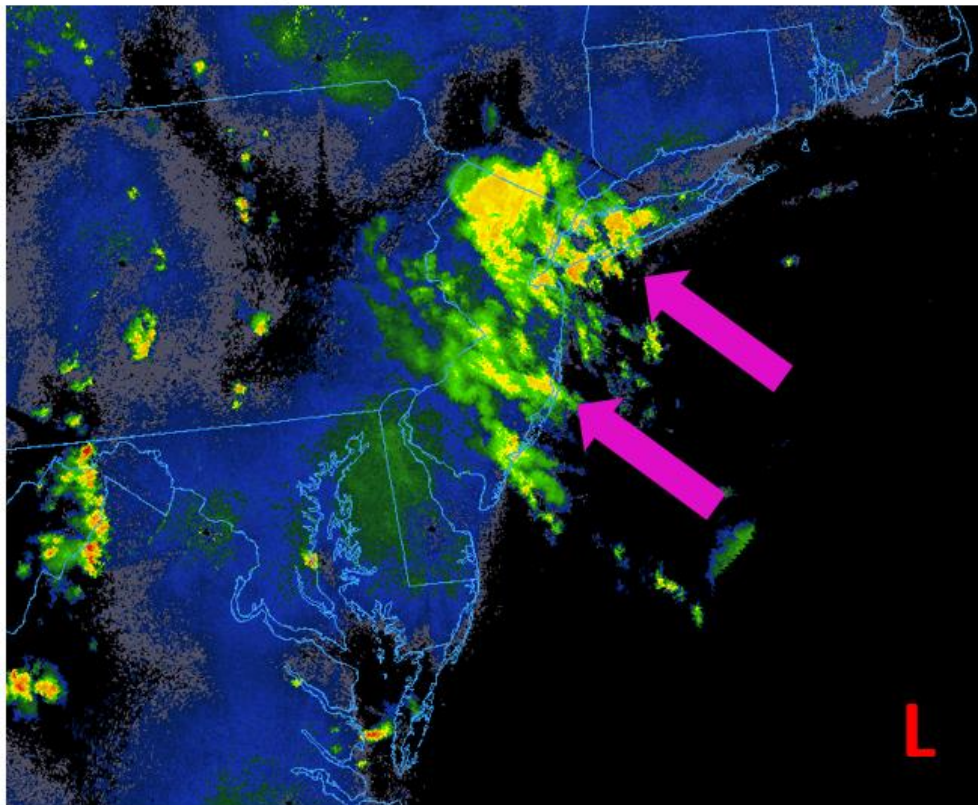
Precipitation

Precipitation was highest in the upper-middle Basin, where a widespread area in northeastern Pennsylvania and northwestern New Jersey received approximately five inches, with isolated area of up to eight inches.¹⁴). The total precipitation is shown in Figure 1. The accumulated precipitation at stations in Pennsylvania and New Jersey/New York are shown in Figures 2 and 3, respectively.

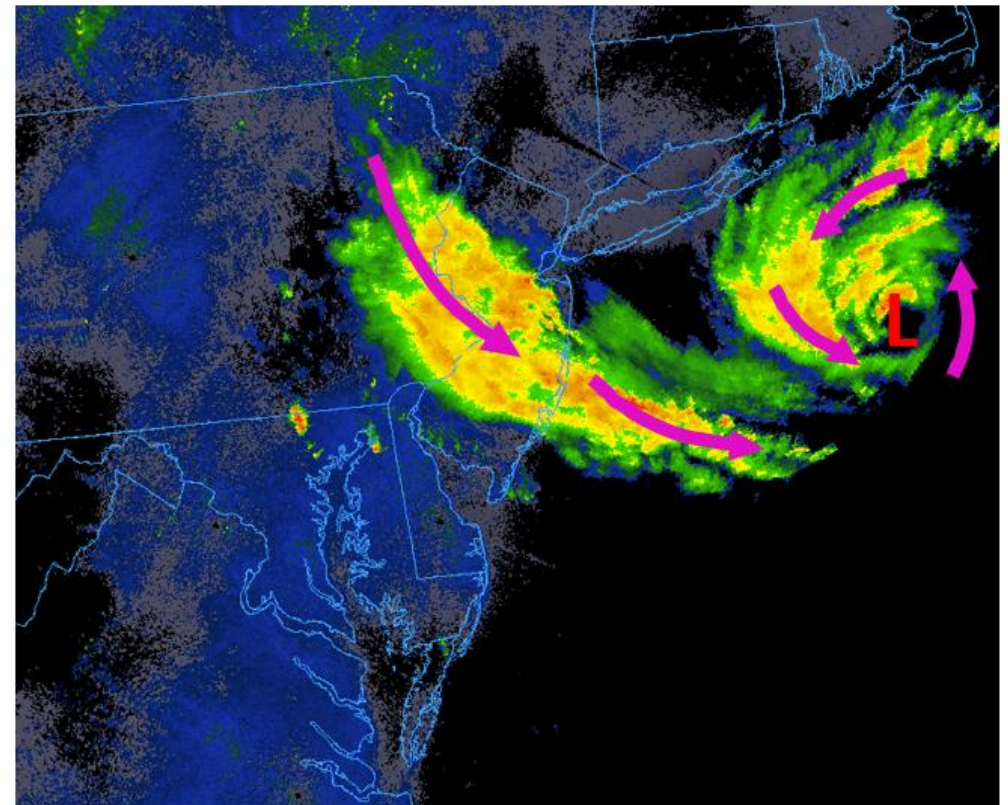
¹³ Definitions for flood stages are provided in the 'Definitions' section of the 2021 Annual Report.

¹⁴ Advanced Hydrologic Prediction Service

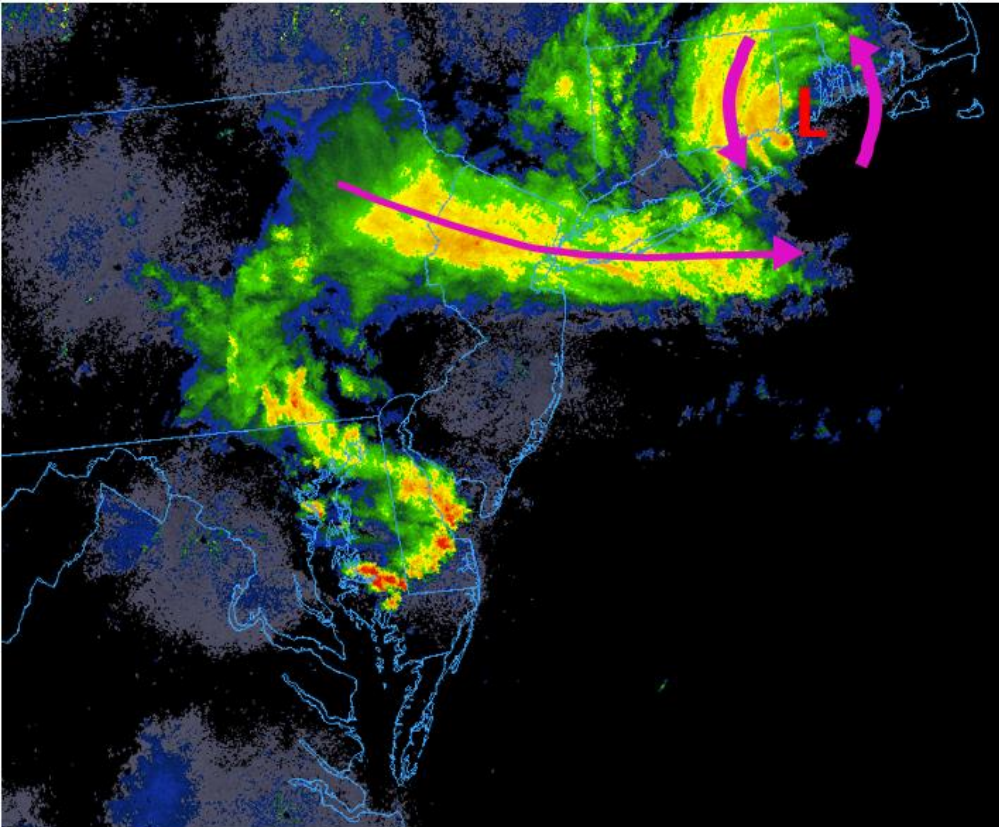
August 21, 2021 - 9:05 PM EDT



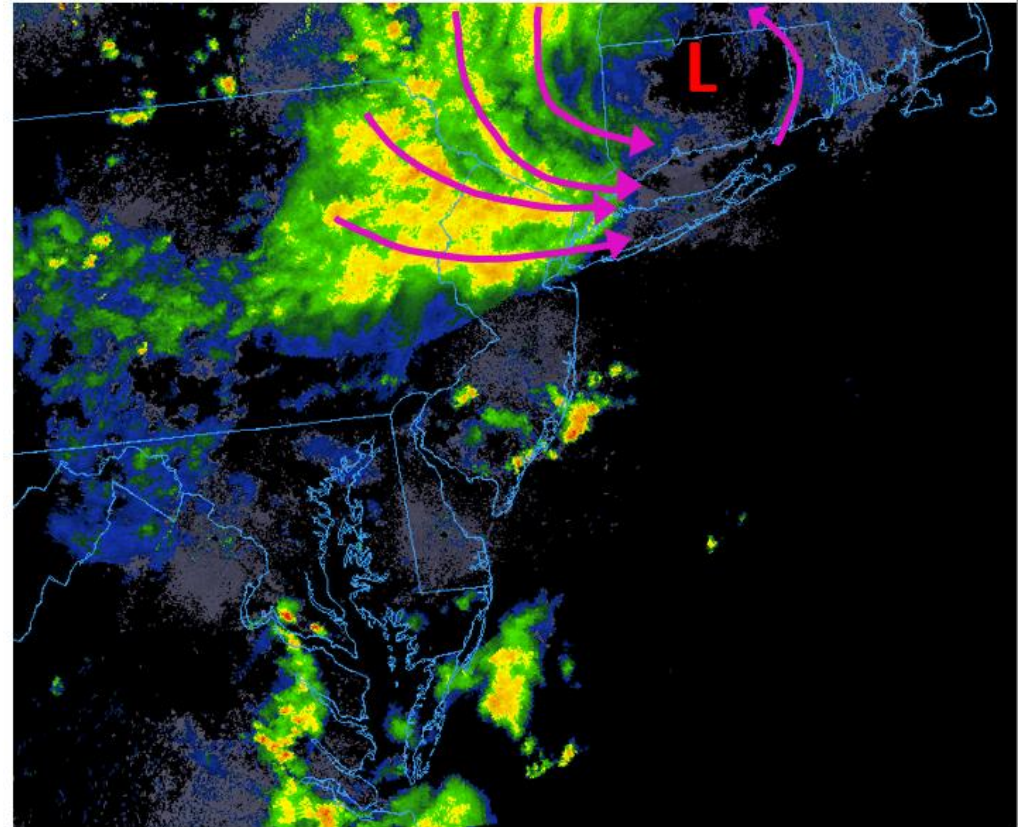
August 22, 2021 - 3:45 AM EDT



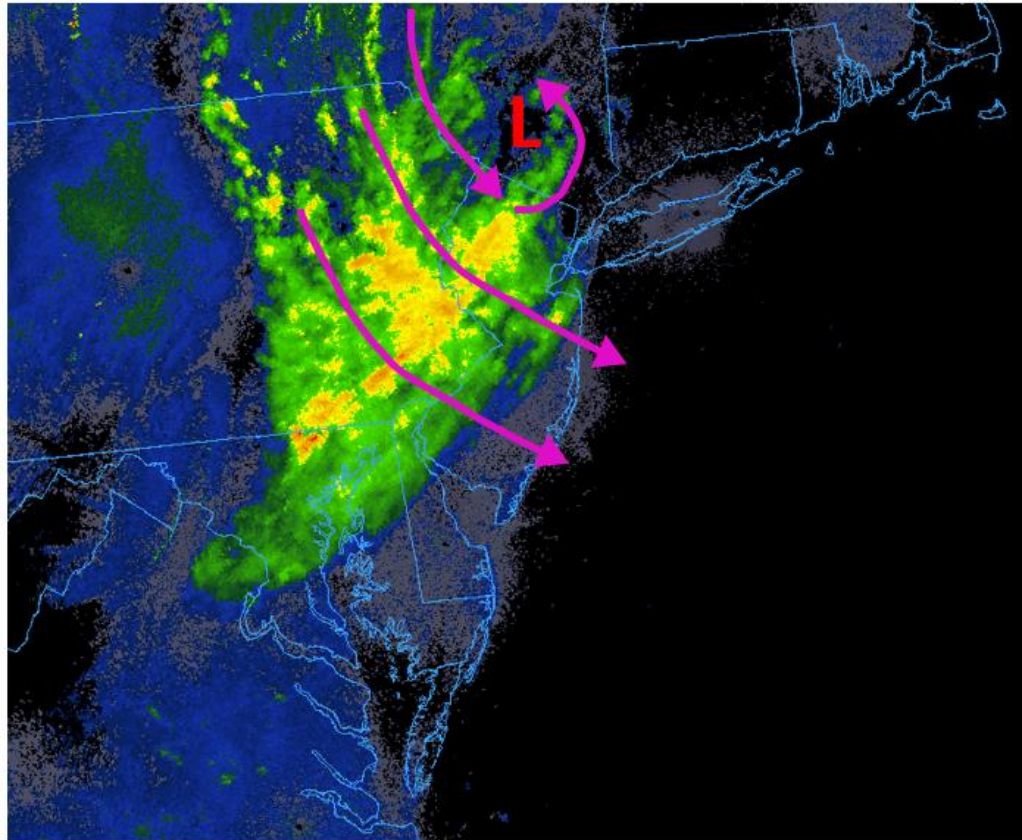
August 22, 2021 - 11:05 AM EDT



August 22, 2021 - 6:25 PM EDT



August 23, 2021 - 1:45 AM EDT



August 23, 2021 – 3:35 PM EDT

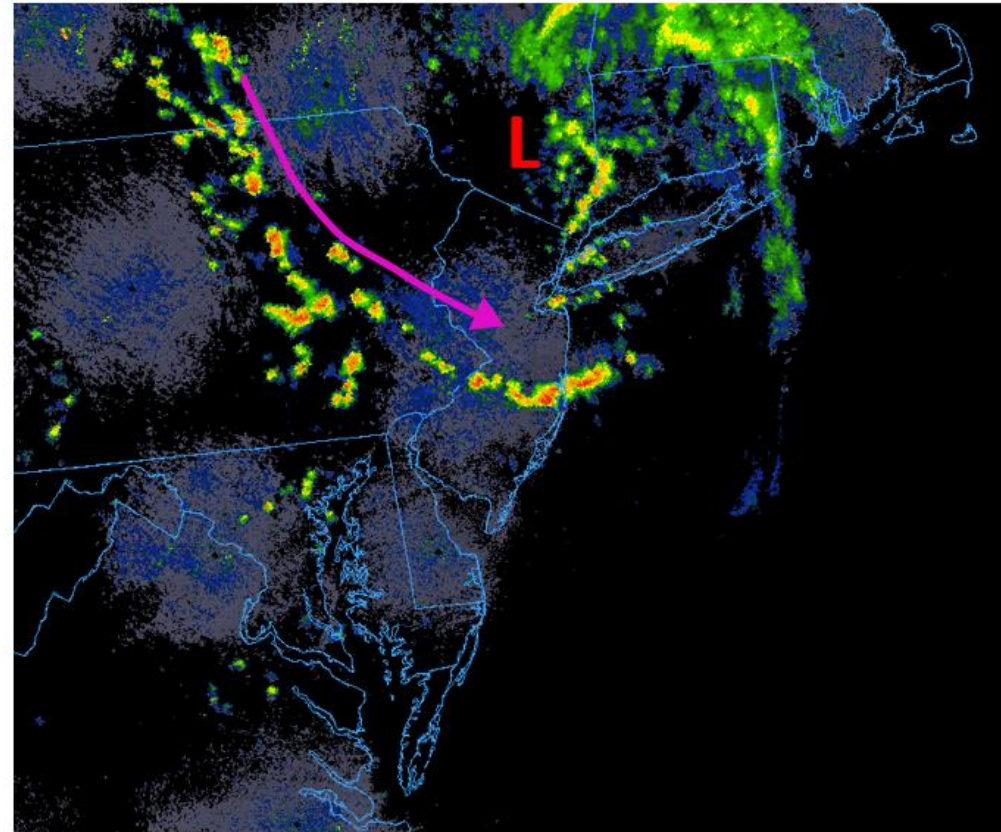


Figure 1. Total Precipitation from Hurricane Henri

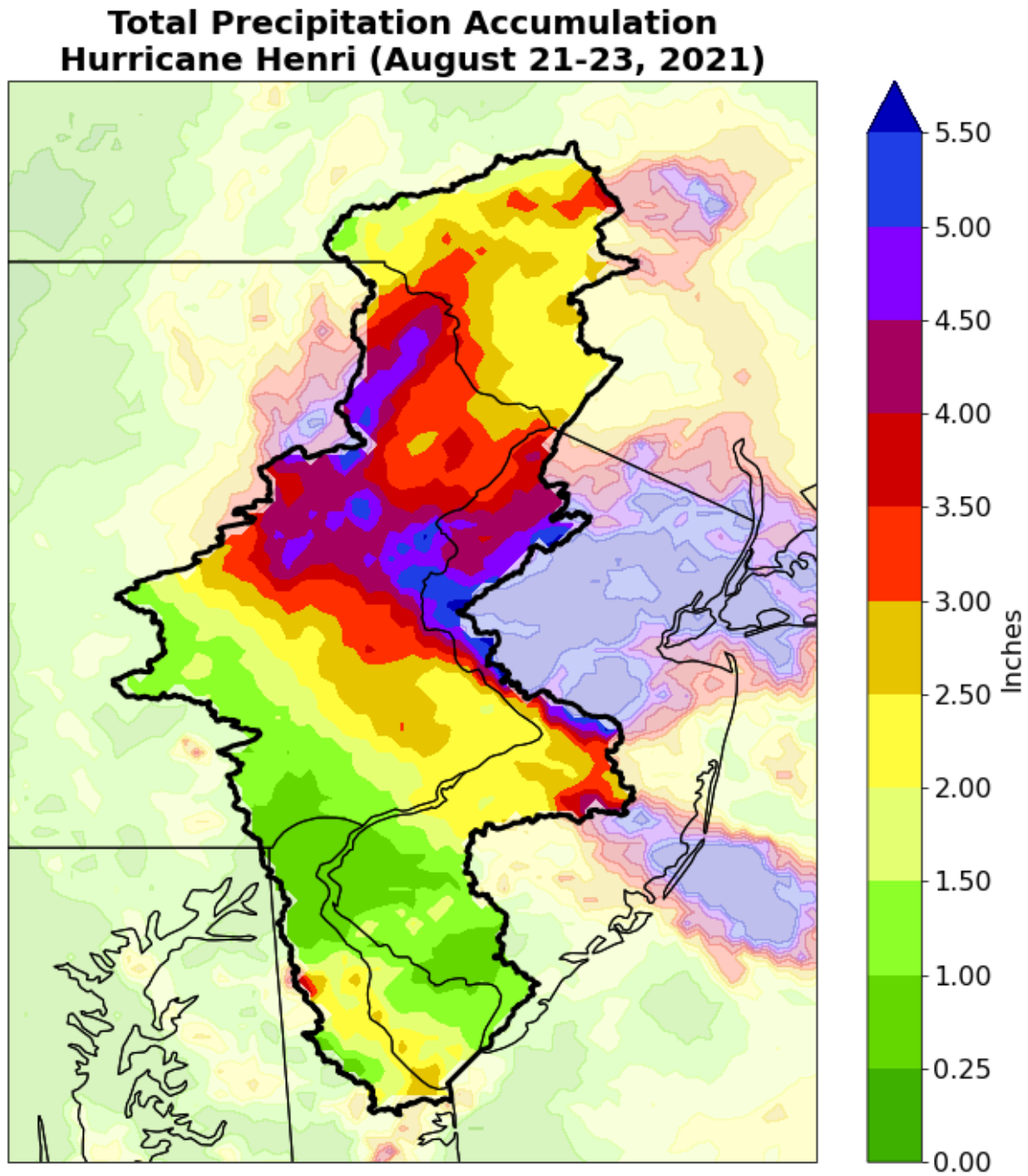


Figure 2. Accumulated Precipitation at Pennsylvania Locations

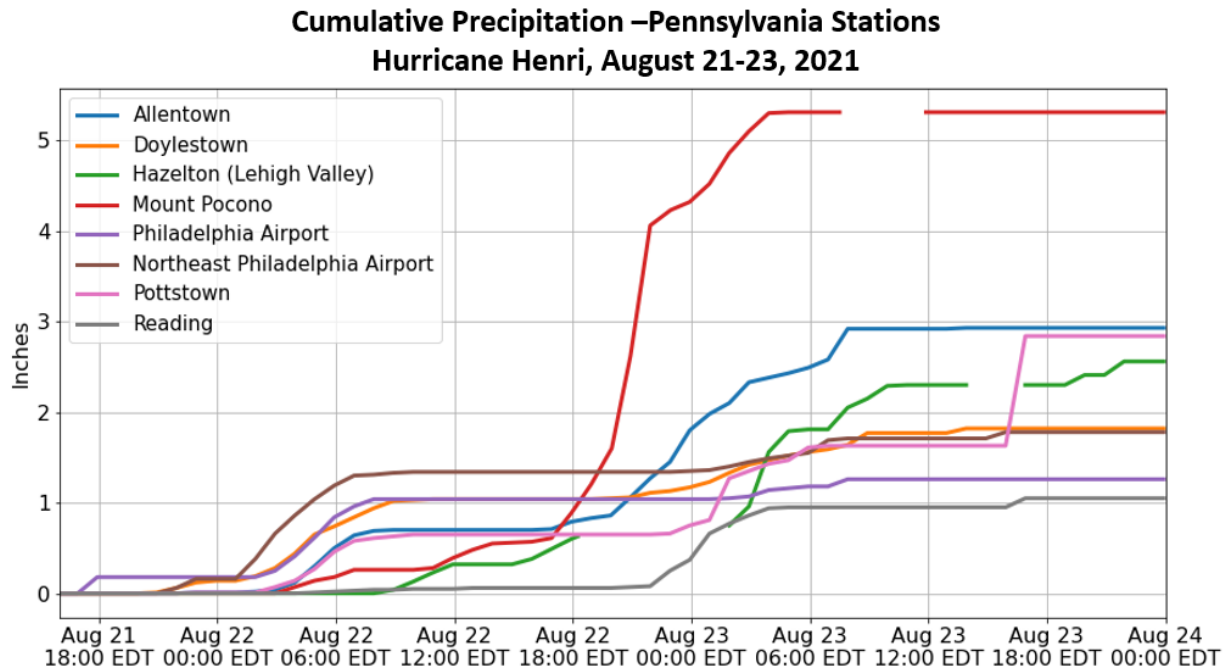
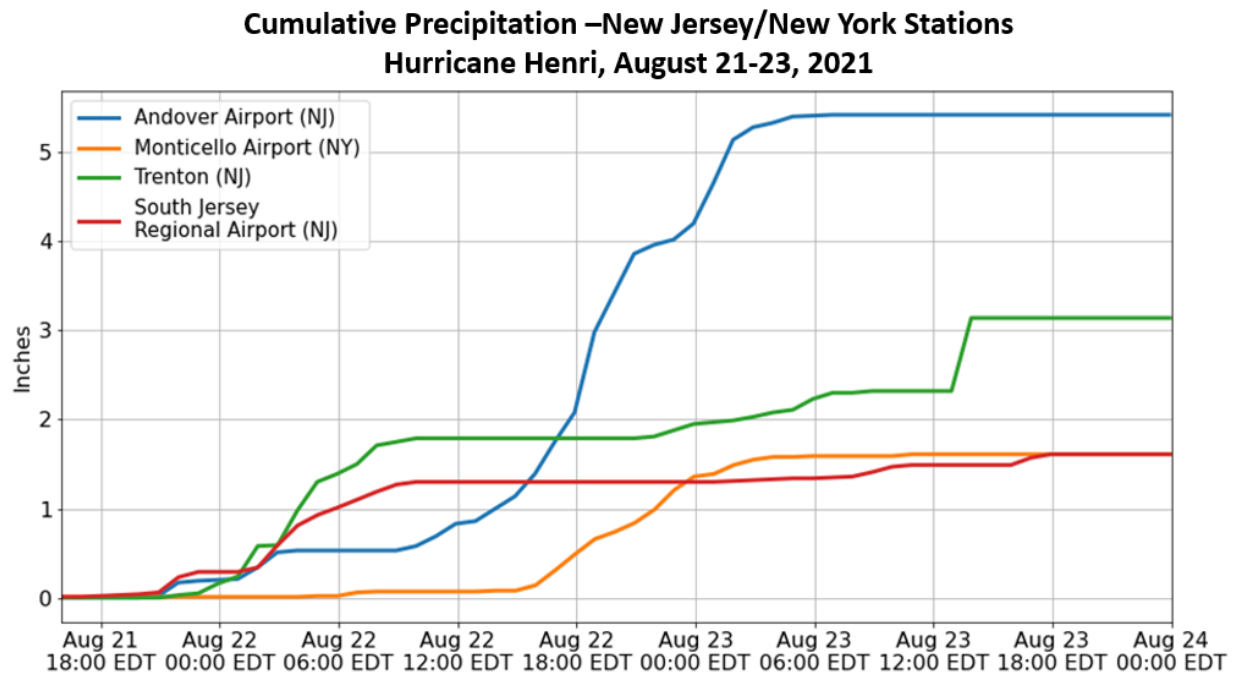


Figure 3. Accumulated Precipitation at New Jersey and New York Stations



Flooding

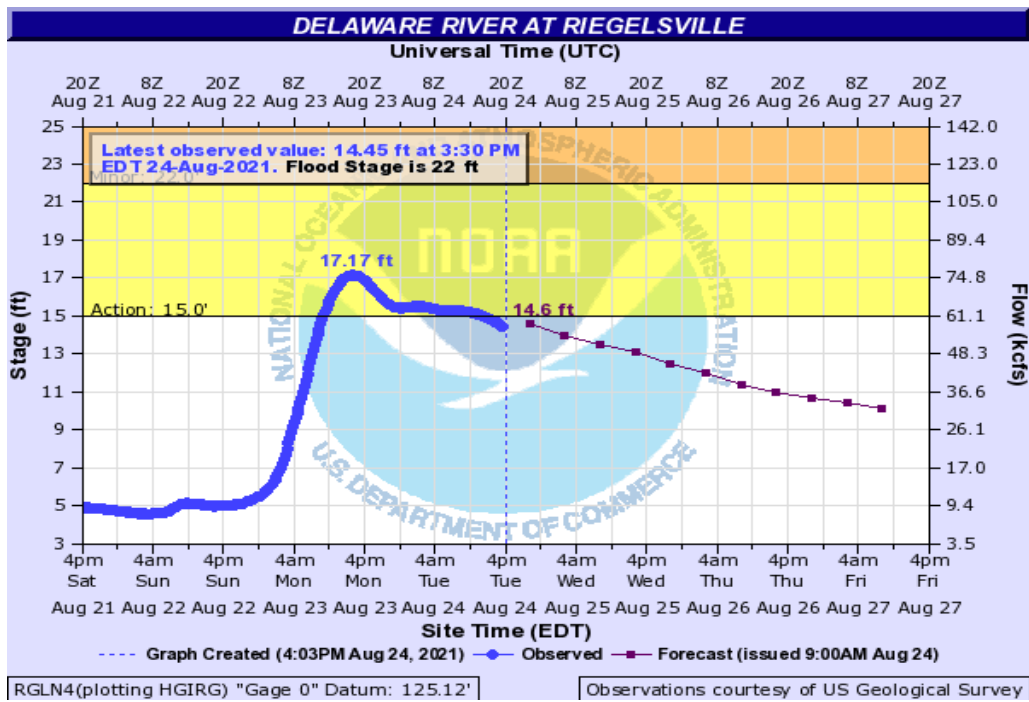
Flooding occurred at 18 locations in the Basin. It began on Sunday morning – where, most locations began flooding by Monday morning and finished by Tuesday morning. On the main stem of the Delaware River, action stage was reached at Riegelsville for approximately 26 hours beginning on Monday, August 23, 2021. The west branch of the Delaware River above Cannonsville at Walton, N.Y. also reached Action Stage flooding. In total, there were 18 gages that experienced flooding. Four gages were in the tidal section of the Delaware River, one gage was in the tidal section of the Schuylkill River, twelve gages were in tributaries and one gage on the main stem non-tidal Delaware River. Eight gages (seven of which were on tributaries) reached Action Stage, and 10 reached Minor Flood Stage (six of which were on tributaries).

<u>National Weather Service Flood Forecast and Observation Location</u>	Waterbody Type	Peak Stage	Flood Type
Delaware River at Riegelsville	Main Stem	17.17 feet	Action
West Branch Delaware River at Walton	Stream	7.71 feet	Action
Bush Kill at Shoemakers	Stream	6.26 feet	Minor
Brodhead Creek at Minisink Hills	Stream	11.12 feet	Minor
Paulins Kill at Blirstown	Stream	6.1 feet	Minor
Lehigh River below FE Walter near White Haven	Stream	8.01 feet	Minor
Lehigh River at Lehighon	Stream	9.68 feet	Action
Lehigh River at Walnutport	Stream	9.18 feet	Minor
Lehigh River at Glendon	Stream	17.94 feet	Action
Musconetcong River at Bloomsbury	Stream	5.6 feet	Action
Assunpink Creek at Trenton	Stream	7.79 feet	Action
North Branch Rancocas Creek at Pemberton	Stream	2.52 feet	Minor
Perkiomen Creek at East Greenville	Stream	3.73 feet	Action
Schuylkill River near Philadelphia Near 30th Street	Tidal	5.27 feet	Action
Delaware River at Newbold Island	Tidal	>10 feet*	Minor
Delaware River at Burlington	Tidal	10.07 feet	Minor
Delaware River at USCG Station Washington Street	Tidal	8.58 feet	Minor
Delaware River at Marcus Hook	Tidal	7.73 feet	Minor
* The gage at Newbold Island likely experienced an error which caused a false crest of 11.16 feet to be reported. During the flooding due to Henri, the stage was between 10 and 11 feet, which is minor flooding.			

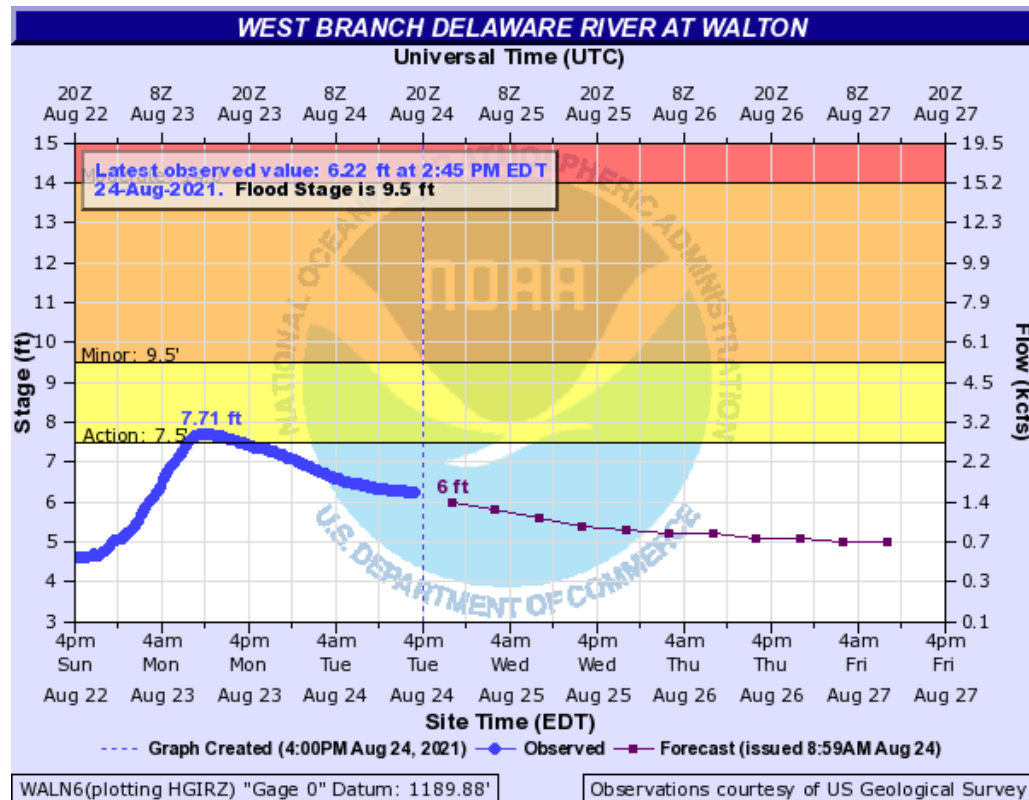
Flooding Locations and Hydrographs

The locations that experienced flooding from Tropical Storm Henri are below. A hydrograph, which is a plot of water level or stage over time, for each location is provided.

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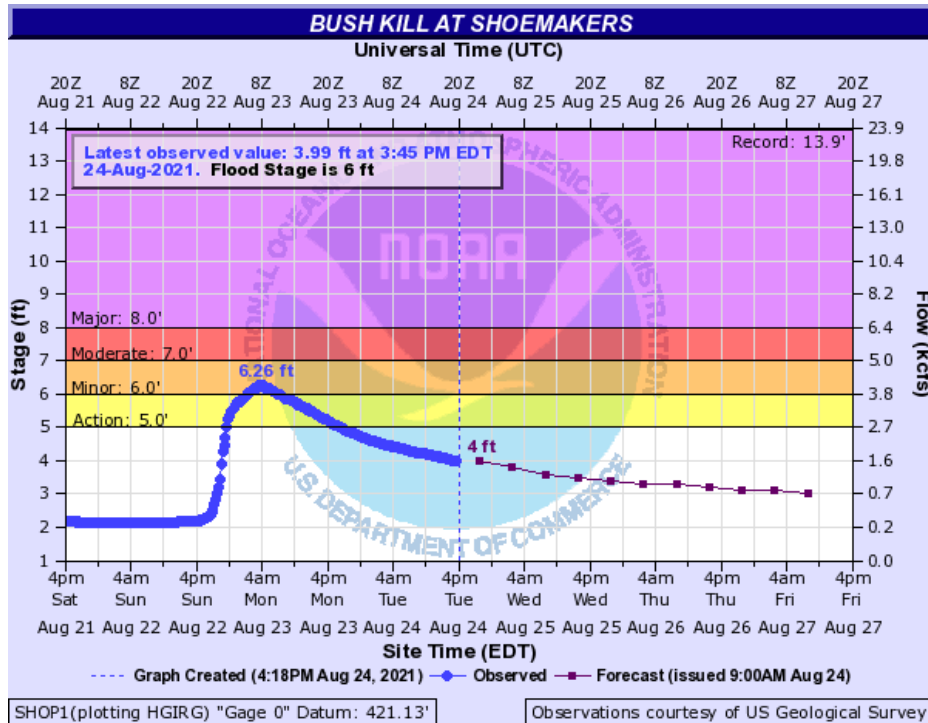


Delaware River at Riegelsville, Action Stage, Peak 17.17 feet.

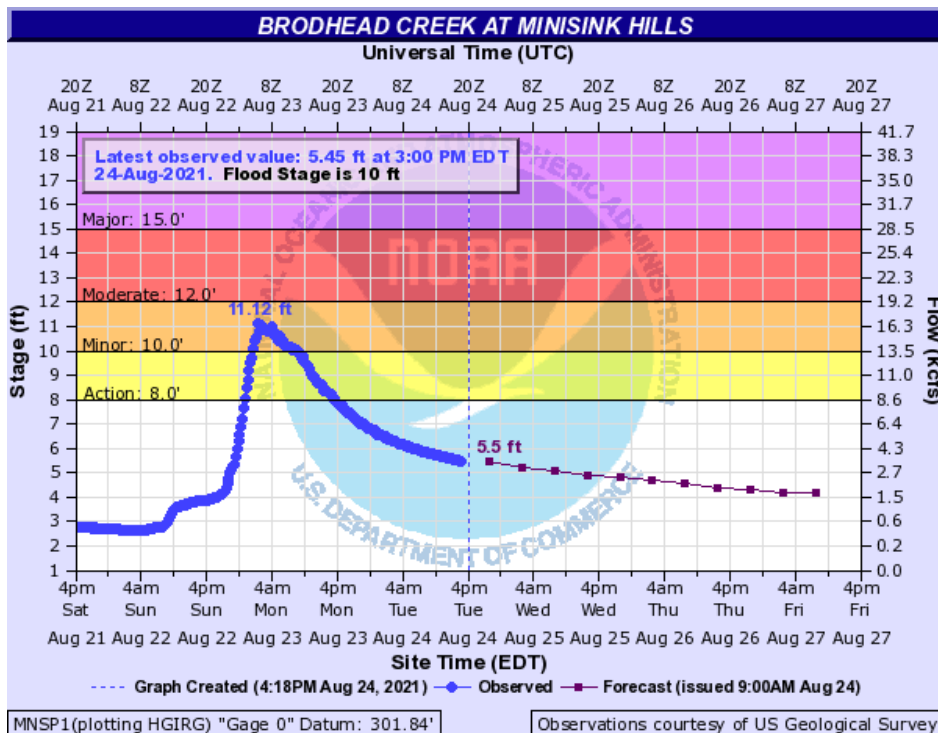


West Branch Delaware River at Walton, Action Stage, Peak 7.71 feet.

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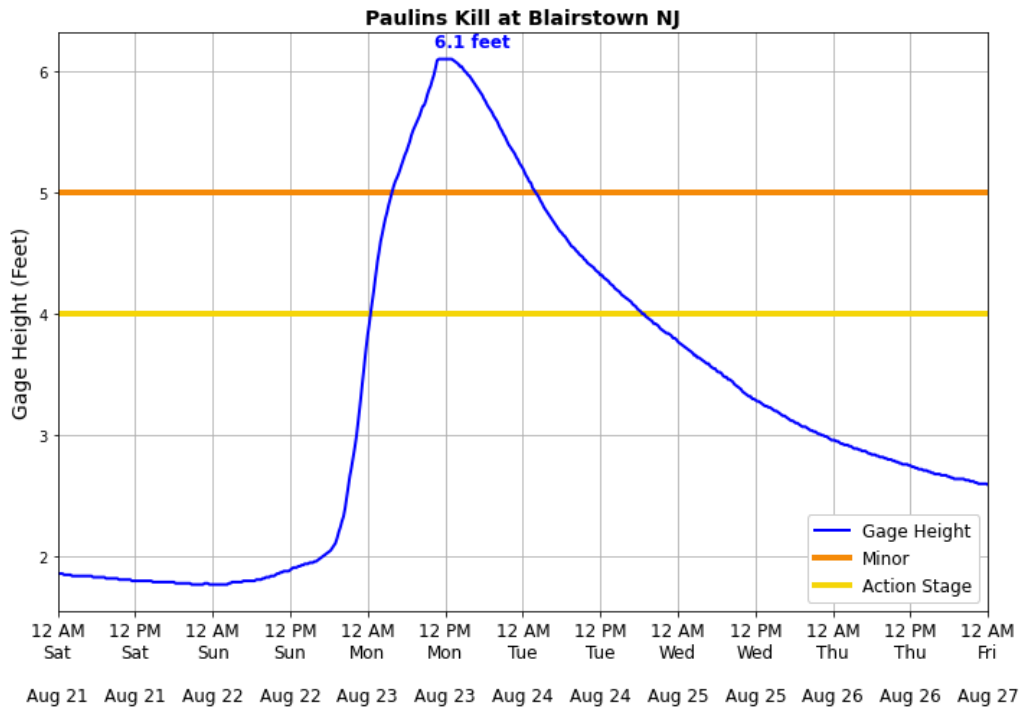


Bush Kill at Shoemakers, Minor Flood Stage, Peak 6.26 feet.

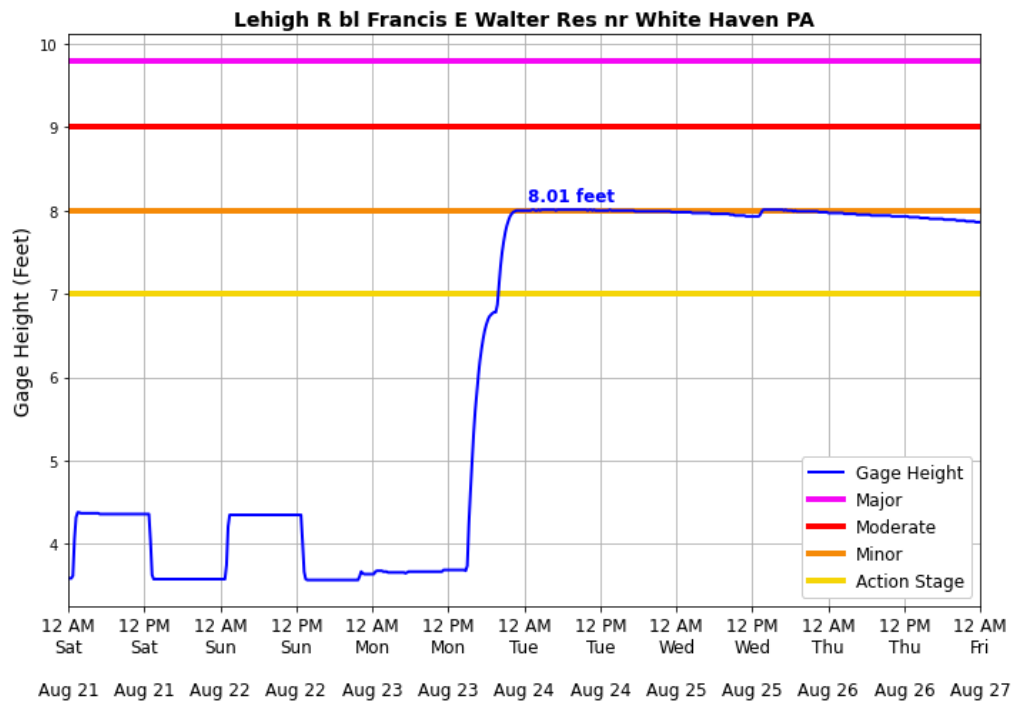


Brodhead Creek at Minisink Hills, Minor Flood Stage, Peak 11.12 feet.

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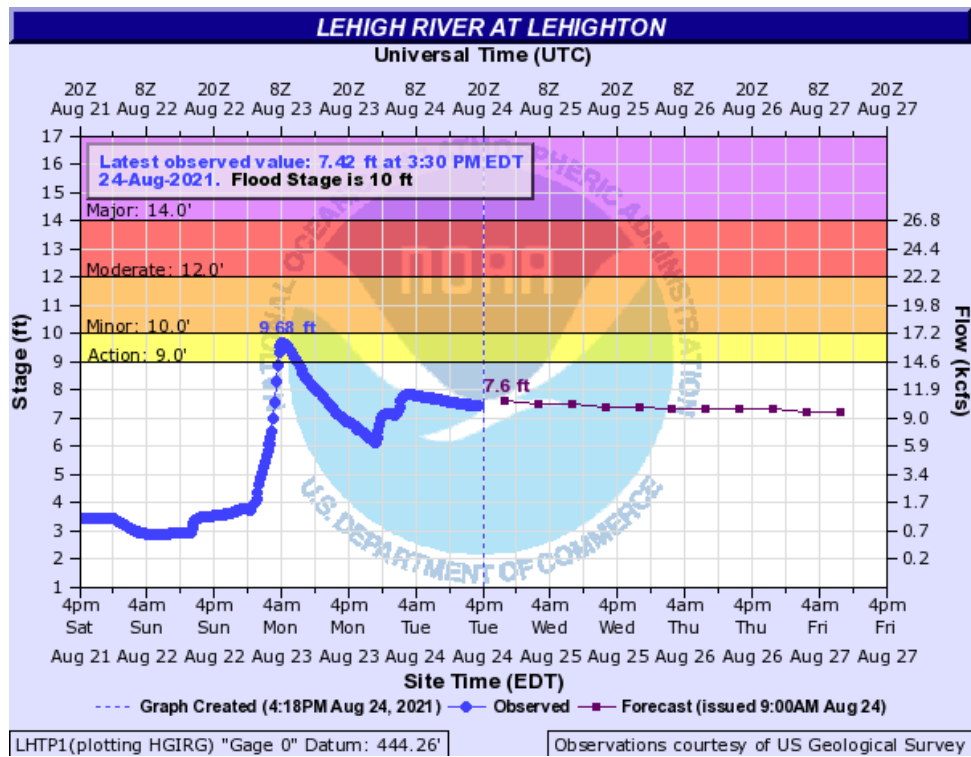


Paulins Kill at Blairstown, Minor Flood Stage, Peak 6.1 feet.

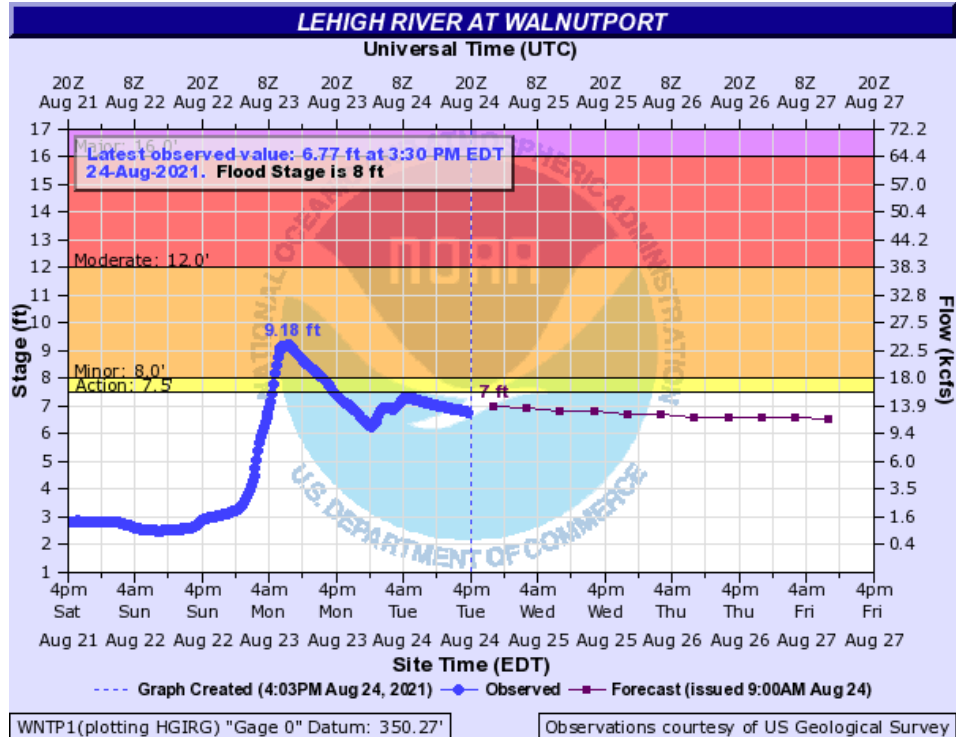


Lehigh River below the Francis E. Walter Reservoir near White Haven, Minor Flood Stage, Peak 8.01 feet.

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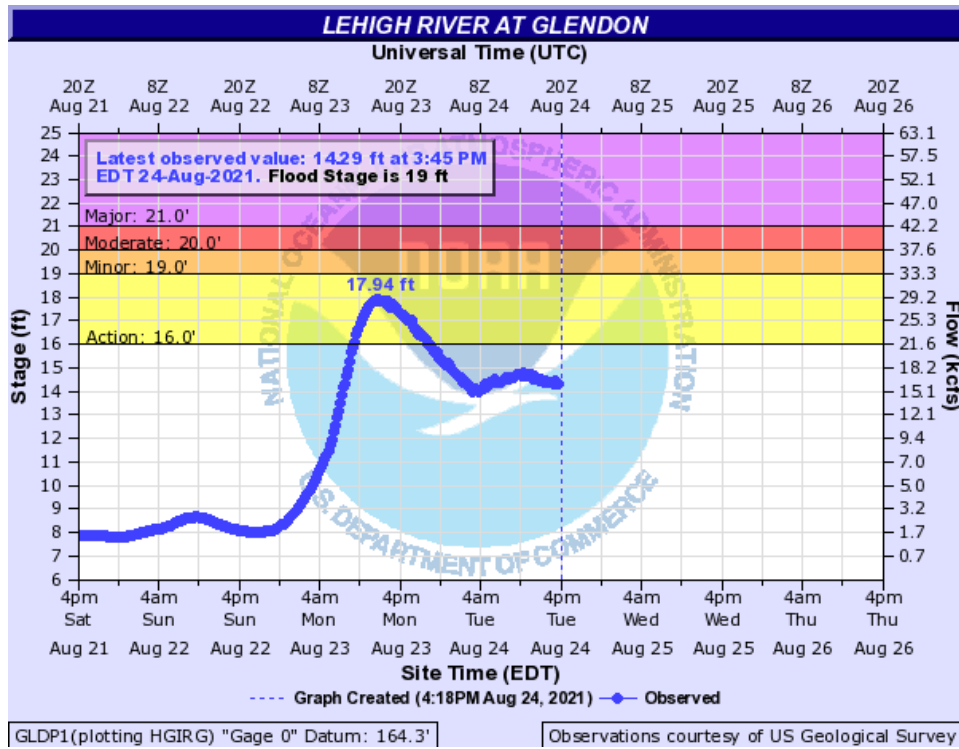


Lehigh River at Lehighon, Action Stage, Peak 9.68 feet.

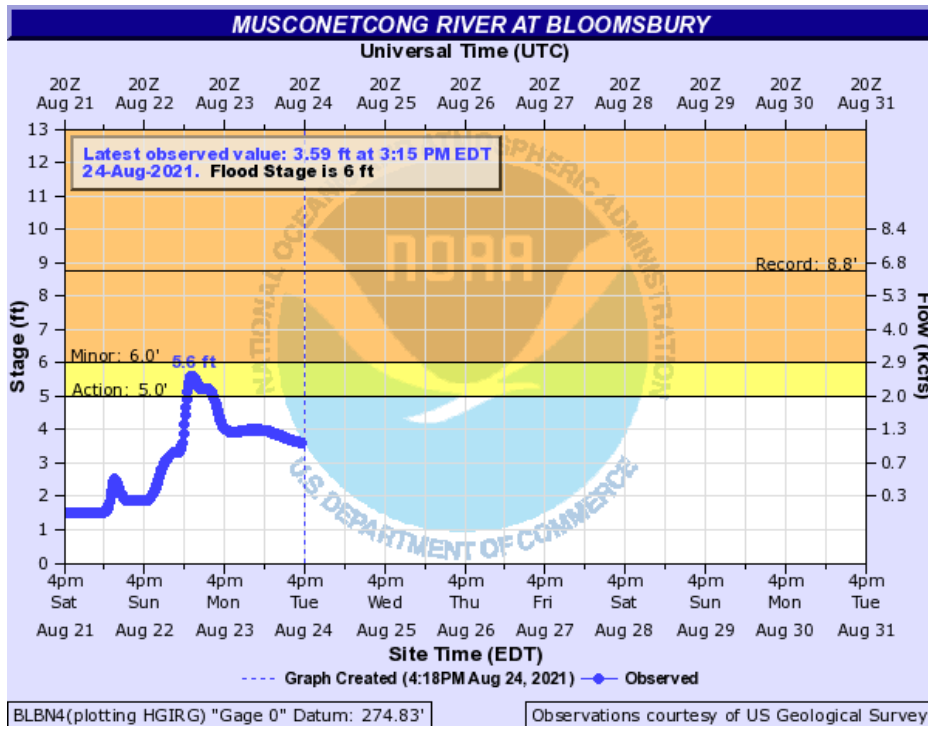


Lehigh River at Walnutport, Minor Flood Stage, Peak 9.18 feet.

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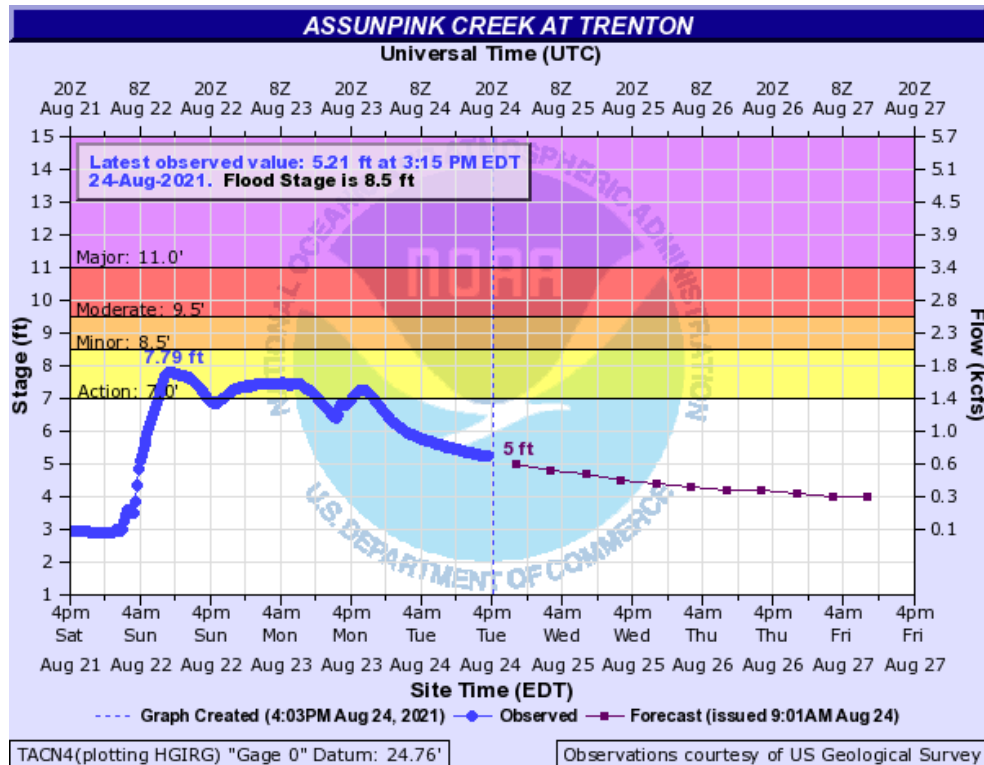


Lehigh River at Glendon, Action Stage, Peak 17.94 feet.

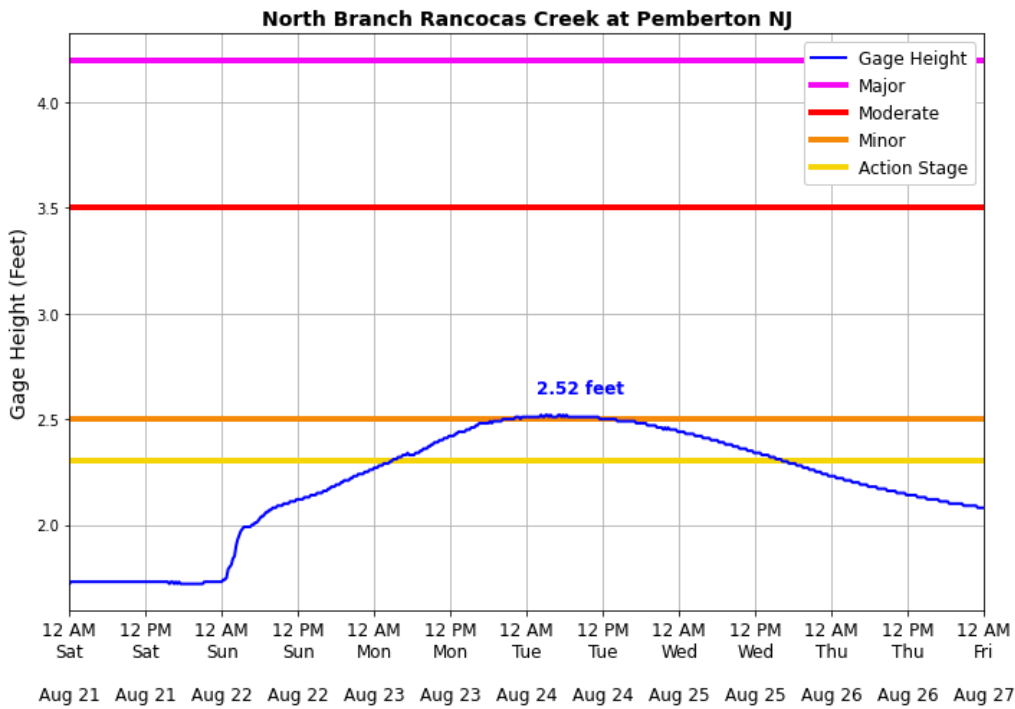


Musconetcong River at Bloomsbury, Action Stage, Peak 5.6 feet.

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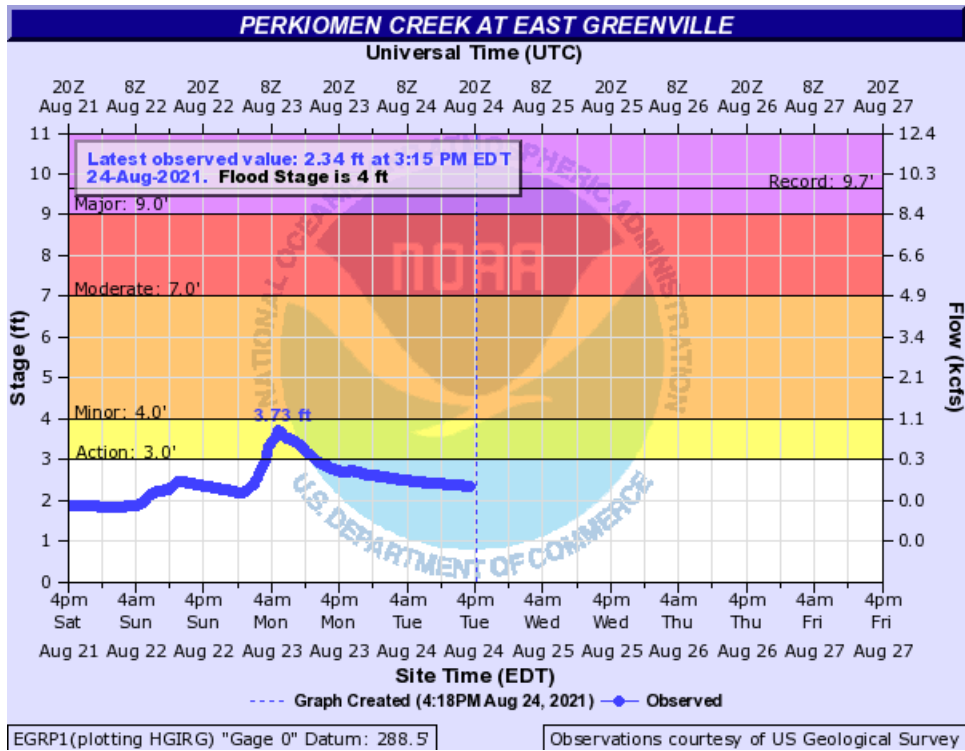


Assunpink Creek at Trenton, Action Stage, Peak 7.79 feet.

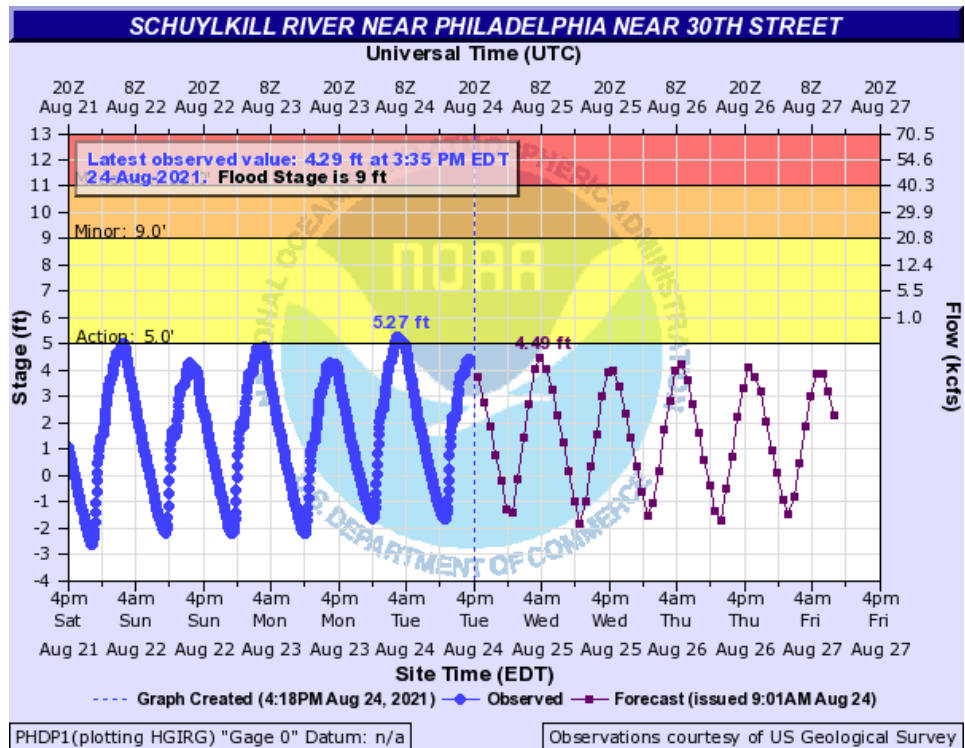


North Branch Rancocas Creek at Pemberton, Minor Flood Stage, Peak 2.52 feet.

Annual Hydrologic Conditions Report

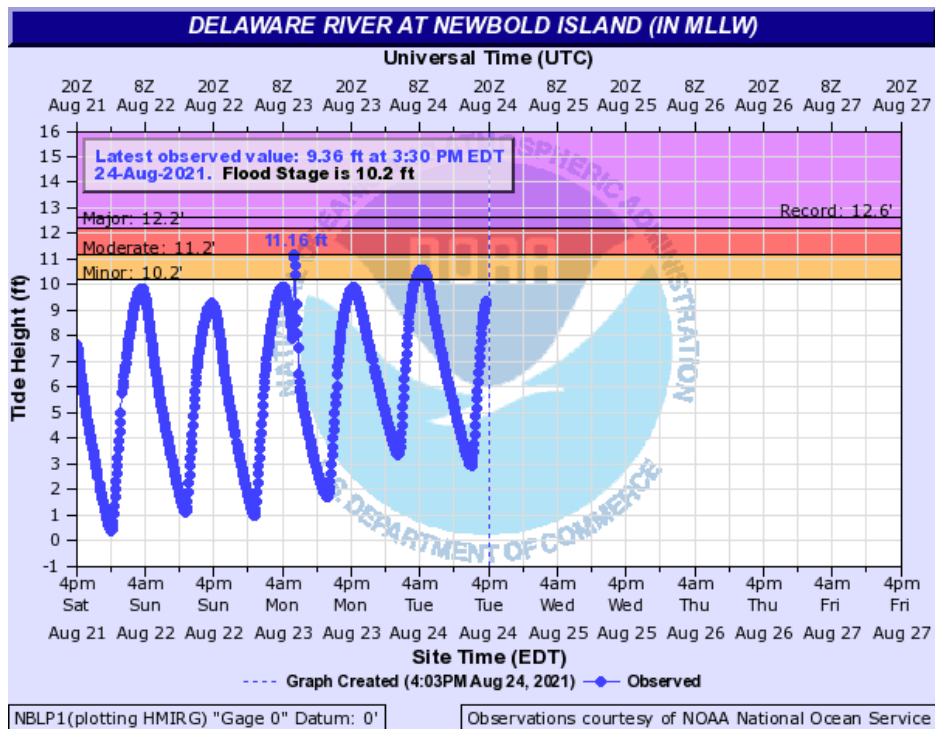


Perkiomen Creek at East Greensville, Action Stage, Peak 3.73 feet.

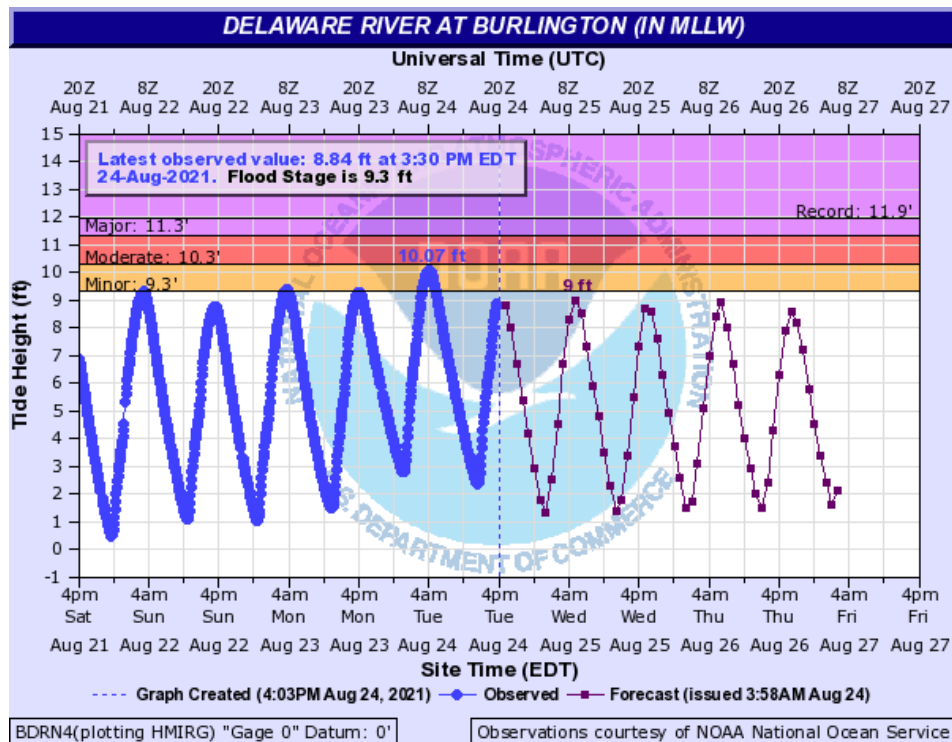


Schuylkill River near Philadelphia near 30th street, Action Stage, Peak 5.27 feet.

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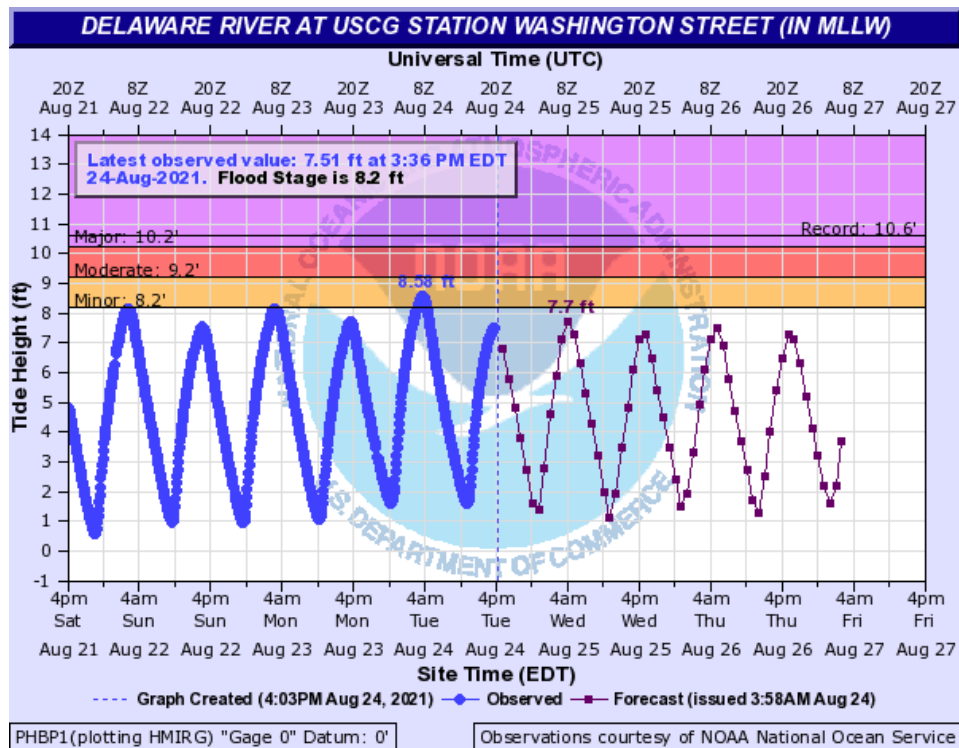


Delaware River at Newbold Island, Minor Flood Stage. The peak tide is approximate due to an error at the tide gage.

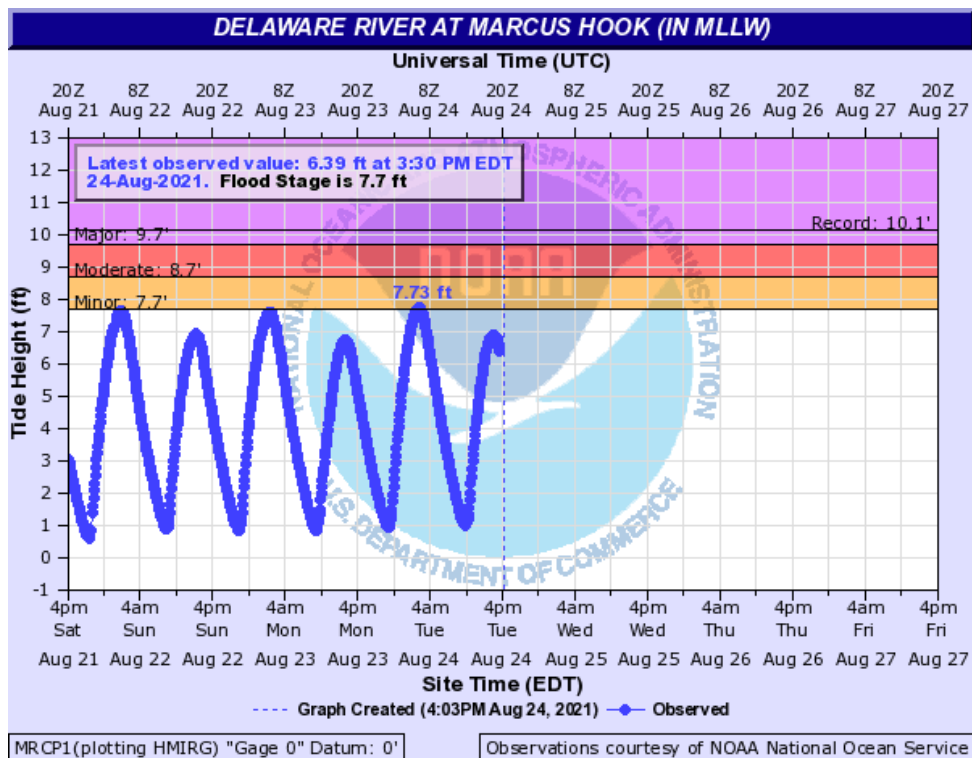


Delaware River at Burlington, Minor Flood Stage, Peak 10.07 feet.

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Delaware River at USCG station Washington Street, Minor Flood Stage, peak 8.58 feet.



Delaware River at Marcus Hook, Minor Flood Stage, Peak 7.73 feet

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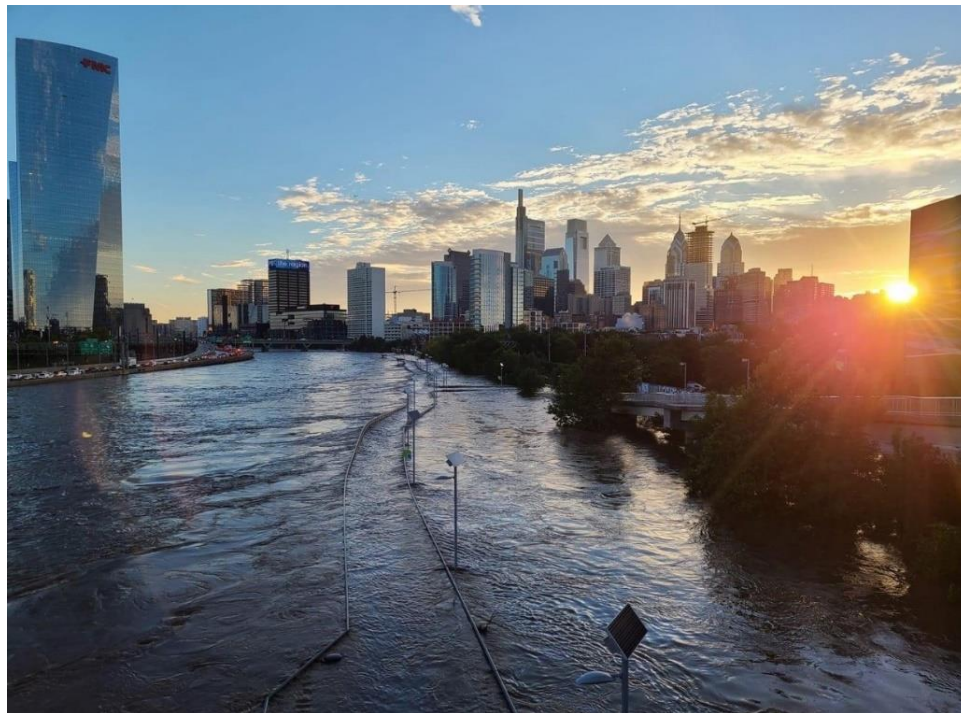
For official information on the storm, please visit the National Hurricane Center at www.nhc.noaa.gov.

For official information on impacts to the Delaware River Basin, please visit the National Weather Service Mt. Holly website at <https://www.weather.gov/phi/> and the Mid-Atlantic River Forecast Center website at <https://www.weather.gov/marfc/>

APPENDIX D: IDA

From Wednesday, September 1, through Thursday, September 2, 2021, the remnants of Hurricane Ida passed through the Delaware River Basin (DRB or Basin). Widespread rainfall amounts of up to five inches of precipitation occurred in the central region of the Basin and localized amounts greater than 10 inches occurred in Bucks, Berks, and Montgomery Counties in PA, and Mercer and Hunterdon counties in NJ. Major, record-breaking flooding occurred on the Schuylkill River (pictured below) and on the Perkiomen, Neshaminy and Brandywine creeks in Pennsylvania. Major flooding¹⁵ also occurred on Frankford and Pennypack creeks and the Lehigh River in Pennsylvania, the Assunpink Creek, in New Jersey, and the White Clay Creek in Pa. and Delaware. Moderate flooding occurred in Delaware on the Christina River and Red Clay Creek in Delaware. In Pennsylvania, moderate flooding occurred on Chester Creek, along the Little Lehigh River and Jordan Creek, and along Brodhead Creek and the Lackawaxen river.

Minor flooding occurred along the main stem of the Delaware River, the Bush Kill in Pennsylvania and the Pequest River and Paulins Kill in New Jersey. Action Stage was reached along the Neversink River and Beaver Kill in New York and the Beaver Brook in New Jersey. Minor to major tidal flooding also occurred along the tidal Delaware River, the tidal Schuylkill River, and the tidal Christina River. Records were broken at Newbold Island and Bridesburg, Pennsylvania along the tidal Delaware.



Flooding along the Schuylkill River Trail on September 2, 2021. Credit: Philadelphia Water Department

¹⁵ Definitions for flood stages are provided in the 'Definitions' section.

Remnants of Ida – Characteristics

Hurricane Ida was classified as a Category 4 hurricane when landfall occurred in Louisiana on August 30, 2021. The storm weakened as it moved 1000 miles northeast and lost tropical characteristics when precipitation arrived in the Basin on the morning of September 1, 2021. A separate weather system approached the DRB from the west, and the combined storm system resulted in a large area of precipitation to develop over the region and remain in place for several hours. Moderate to heavy rain fell continuously over much of the Basin on September 1, 2021, and the storm was out of the Basin by 10:00 PM EDT.

The onset of the rain began early on the morning of September 1, 2021, where heavy rain impacted parts of the lower Basin near Wilmington, Del. (shown in radar image 1 below). At this time, lighter but steady rain expanded north through Pennsylvania and into southern New York but remained mostly west of the Delaware River Basin. The central low pressure of the storm was located near northern Virginia by late afternoon (shown in radar image 2). The precipitation had increased intensity in Pennsylvania at this time. Through the evening, the storm slowly moved northeast through the DRB. This is when the heaviest precipitation fell over the lower-central portion of the Basin, where storm motion led to the same area receiving the heaviest rain for several hours (shown in radar image 3). Later in the evening, the storm developed a second low pressure center north of the original low pressure (shown in radar image 4). This increased the amount of moisture that was transported into the storm. By the early morning hours on Thursday, September 2, the last few lines of showers and storms had moved out of the area.

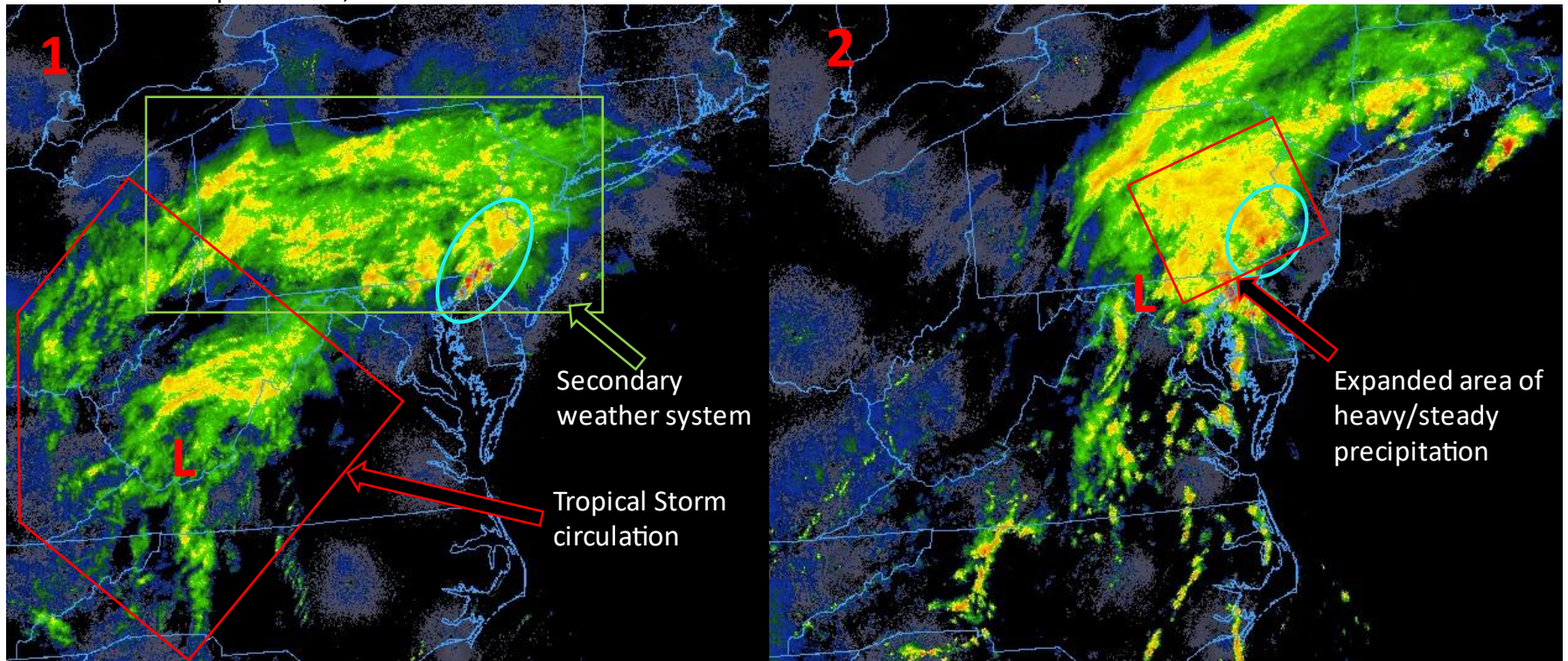
Precipitation

The highest amounts of precipitation occurred in the middle-lower portion of the Basin with the largest amounts in Chester, Montgomery, and Bucks counties in Pennsylvania and Mercer County and Hunterdon Counties in New Jersey. These counties received approximately eight to 10 inches from the storm¹⁶. The total a precipitation in the Basin is shown in Figure 1. The timing and accumulation of precipitation at individual stations during the remnants of Ida are shown in Figure 2. The most precipitation was reported in Quakertown, Bucks County, Pa. Locations farther south and north received between one and three inches, while widespread areas in the central region of the Basin received four to six inches of rain over the two days (Data Source: Iowa Environmental Mesonet).

¹⁶ Data Source: Advanced Hydrologic Prediction Service

September 1, 2021 – 6:15 AM EDT

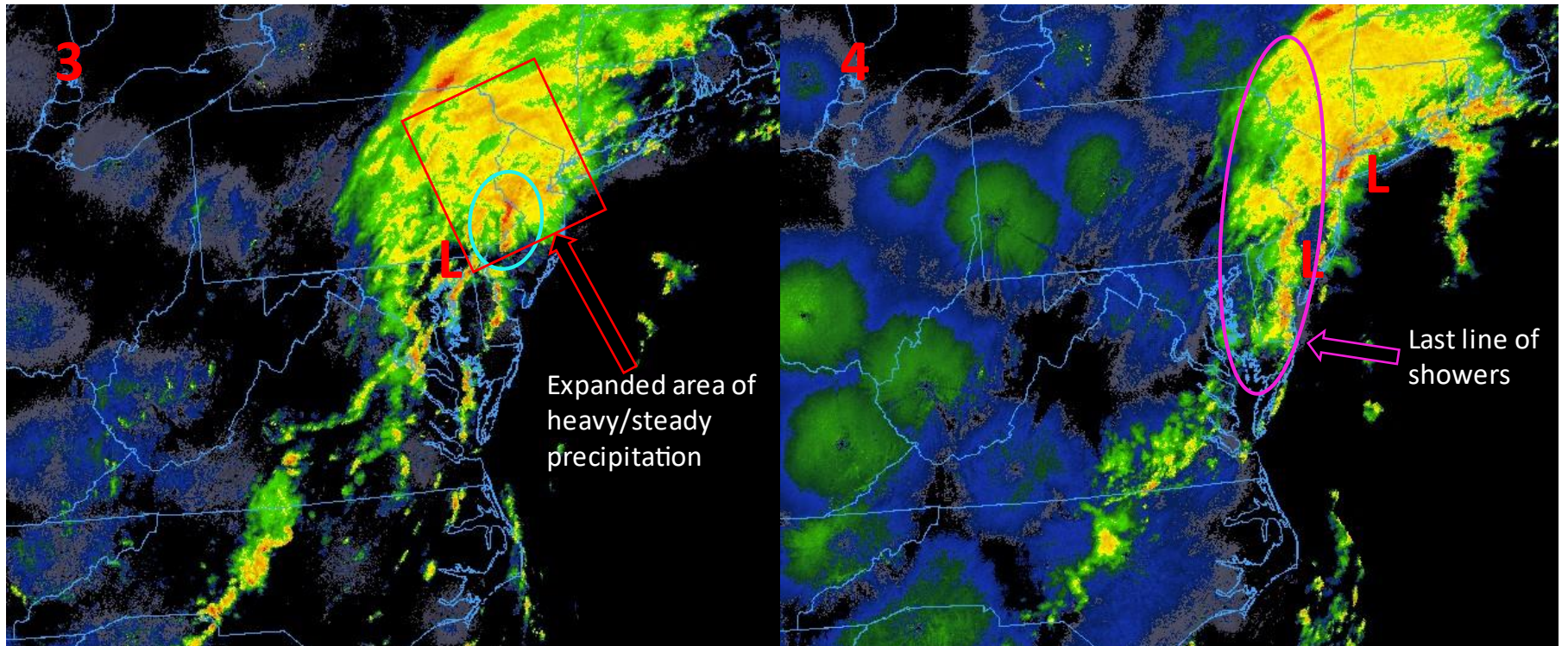
September 1, 2021 – 4:00 PM EDT



Note: The area where the highest rainfall is occurring is circled in teal. The radar images are labeled in the top left corner of each image.

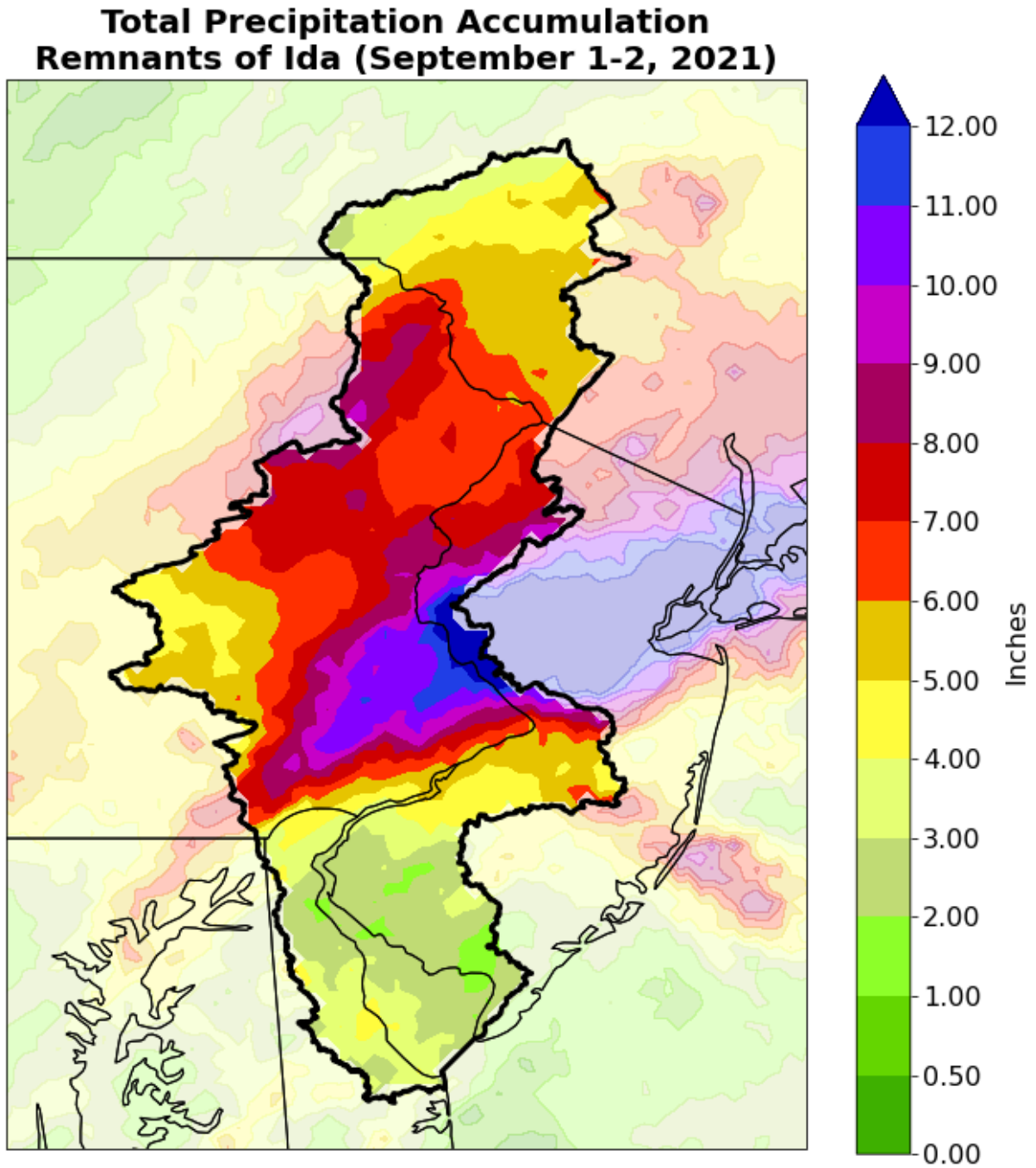
September 1, 2021 – 6:25 PM EDT

September 1, 2021 – 9:55 PM EDT



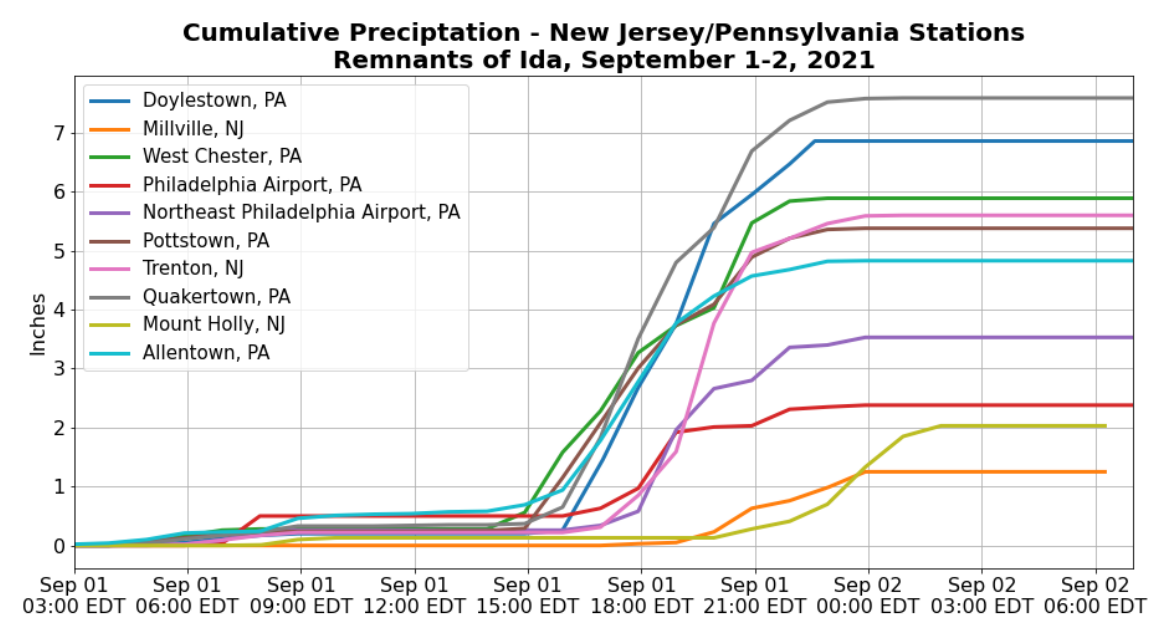
Note: The area where the highest rainfall is occurring is circled in teal. The radar images are labeled in the top left corner of each image.

Figure 1. Total Precipitation from the Remnants of Ida.



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Figure 2. Accumulated Precipitation at New Jersey and Pennsylvania Locations



Flooding

Flooding in the Basin began on Thursday in the tributaries and continued overnight into Friday morning. By Friday afternoon, the main stem of the Delaware River was flooding. On the main stem Delaware River, minor flooding occurred at Easton, Pa. and at all National Weather Service flood forecast locations, downstream of Easton to Trenton, N.J. Flooding occurred at 63 locations. Of those, 46 were on tributaries and eight were on the non-tidal Delaware River. Tidal flooding occurred at nine tidal locations; six on the Delaware River, one on the Schuylkill River and two on the Christina River. The record high water levels were exceeded at nine locations. Flood Forecast Locations that experienced flooding are listed in Table 1.

Table 1

National Weather Service Flood Forecast and Observation Location	Water Body Type	Peak Stage	Flood Type
Delaware River at Tocks Island	Main Stem	20.69 feet	Action
Delaware River at Easton	Main Stem	25.73 feet	Minor
Delaware River at Riegelsville	Main Stem	24.92 feet	Minor
Delaware River at Frenchtown	Main Stem	16.6 feet	Minor
Delaware River at Stockton	Main Stem	19.32 feet	Minor
Delaware River at New Hope-Lambertville Bridge	Main Stem	13.39 feet	Minor
Delaware River at Washington Crossing	Main Stem	16.91 feet	Minor

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National Weather Service Flood Forecast and Observation Location	Water Body Type	Peak Stage	Flood Type
Delaware River at Trenton	Main Stem	20.76 feet	Minor
Beaver Kill at Cooks Falls	Stream	8.19 feet	Action
West Branch Lackawaxen River near Aldenville	Stream	6.39 feet	Action
Lackawaxen River at Hawley	Stream	14.31 feet	Moderate
Neversink River at Godeffroy	Stream	9.26 feet	Action
Bush Kill at Shoemakers	Stream	6.6 feet	Minor
Brodhead Creek near Analomink	Stream	9.17 feet	Moderate
Brodhead Creek at Minisink Hills	Stream	11.15 feet	Minor
Paulins Kill at Blirstown	Stream	7.02 feet	Minor
Beaver Brook near Belvidere	Stream	4.49 feet	Action
Pequest River at Huntsville	Stream	4.68 feet	Minor
Pohopoco Cr below Beltzville Dam near Parryville	Stream	5.57 feet	Minor
Little Lehigh Creek near Allentown	Stream	9.82 feet	Moderate
Little Lehigh Creek at Allentown	Stream	9.6 feet	Minor
Jordan Creek at Allentown	Stream	10.71 feet	Moderate
Lehigh River at Walnutport	Stream	13.19 feet	Moderate
Lehigh River at Bethlehem	Stream	19.53 feet	Minor
Lehigh River at Glendon	Stream	24.17 feet	Major
Assunpink Creek near Mercerville	Stream	15.82 feet	Major
Assunpink Creek at Trenton	Stream	12.59 feet	Major
Neshaminy Creek near Penns Park	Stream	23.4 feet	Major*
Neshaminy Creek near Langhorne	Stream	20.84 feet	Major
Pennypack Creek at Philadelphia	Stream	14.75 feet	Major
Frankford Creek at Castor Ave, Philadelphia	Stream	11.03 feet	Major
West Branch Perkiomen Creek at Hillegass	Stream	6.42 feet	Moderate

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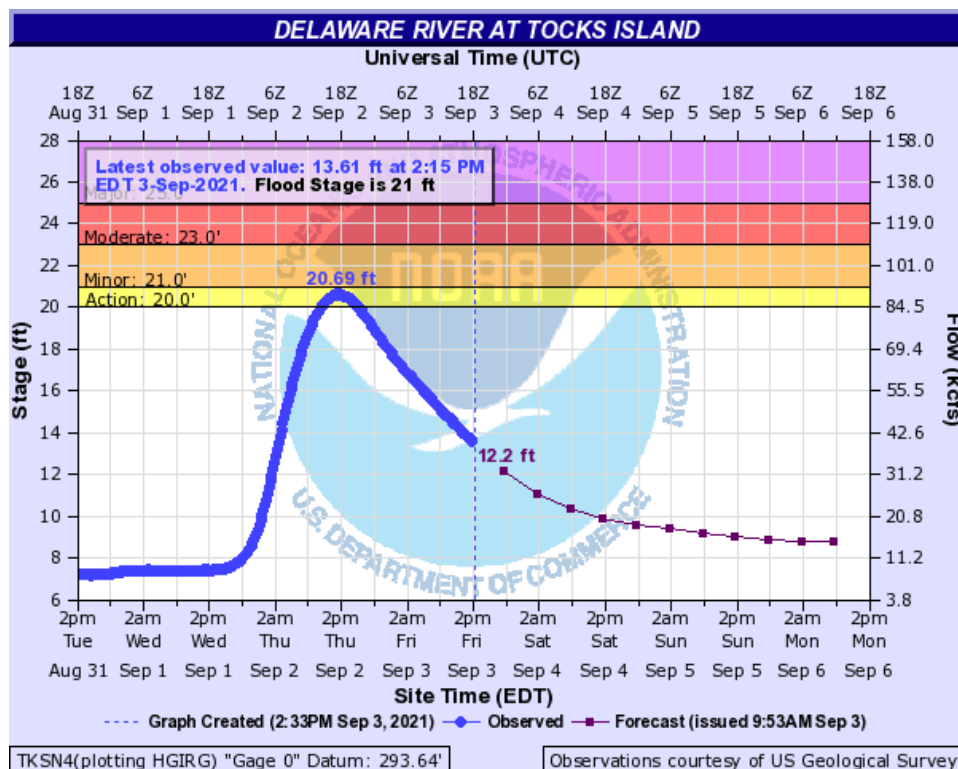
National Weather Service Flood Forecast and Observation Location	Water Body Type	Peak Stage	Flood Type
East Branch Perkiomen Creek at Schwenksville	Stream	16.07 feet	Major*
Perkiomen Creek at East Greenville	Stream	9.24 feet	Major
Perkiomen Creek at Graterford	Stream	20.62 feet	Major*
Schuylkill River at Berne	Stream	15.67 feet	Moderate
Schuylkill River at Reading	Stream	17.02 feet	Minor
Schuylkill River at Pottstown	Stream	16.79 feet	Minor
Schuylkill River at Norristown	Stream	26.85 feet	Major*
Schuylkill River at Philadelphia	Stream	16.35 feet	Major
Chester Creek near Chester	Stream	10.46 feet	Moderate
West Branch Brandywine Creek at Honeybrook	Stream	9.61 feet	Moderate
West Branch Brandywine Creek at Coatesville	Stream	9.62 feet	Moderate
West Branch Brandywine Creek at Modena	Stream	13.38 feet	Major*
East Branch Brandywine Creek below Downingtown	Stream	19.11 feet	Major*
Brandywine Creek at Chadds Ford	Stream	21.04 feet	Major*
Brandywine Creek at Wilmington	Stream	23.14 feet	Major
White Clay Creek near Strickersville	Stream	12.68 feet	Major
White Clay Creek at Newark	Stream	13.08 feet	Minor
White Clay Creek near Newark	Stream	15.77 feet	Moderate
Red Clay Creek near Kennett Square	Stream	8.43 feet	Action
Red Clay Creek at Wooddale	Stream	9.2 feet	Moderate
Red Clay Creek near Stanton	Stream	17.66 feet	Minor
Christina River at Coochs Falls	Stream	12.85 feet	Moderate
Delaware River at Newbold Island	Tidal	13.22 feet	Major*
Delaware River at Burlington	Tidal	10.52 feet	Moderate

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National Weather Service Flood Forecast and Observation Location	Water Body Type	Peak Stage	Flood Type
Delaware River at Bridesburg	Tidal	10.17 feet	Moderate*
Delaware River at USCG Station Washington Street	Tidal	9.72 feet	Moderate
Delaware River at Delaware City	Tidal	8.08 feet	Minor
Delaware River at Marcus Hook	Tidal	8.58 feet	Minor
Schuylkill River near Philadelphia near 30th street	Tidal	16.28 feet	Major
Christina River at Wilmington	Tidal	8.19 feet	Minor
Christina River at Newport	Tidal	8.33 feet	Moderate

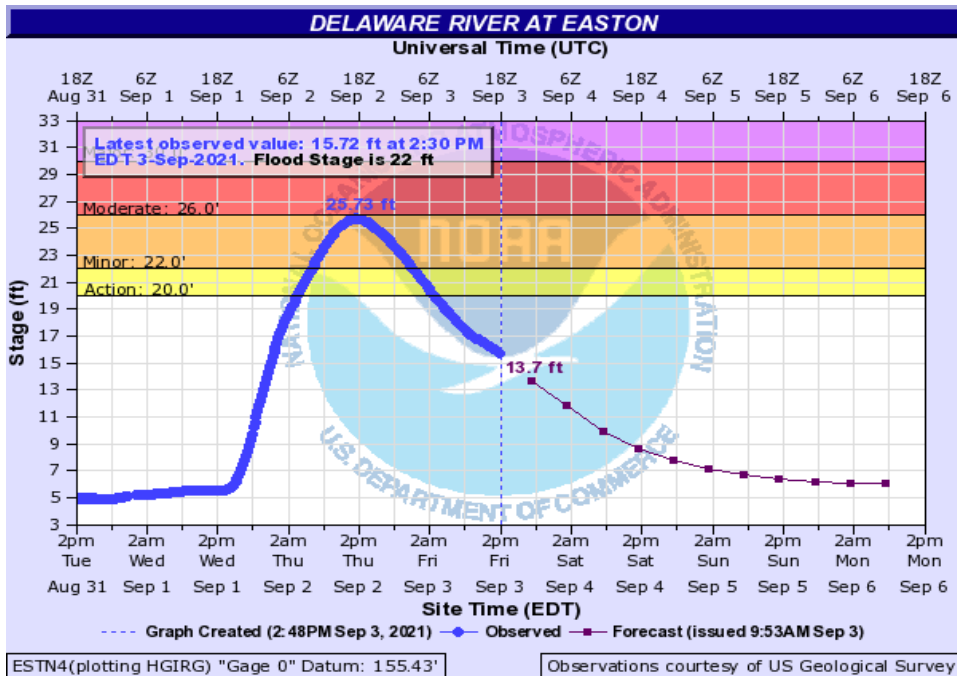
Flooding Locations and Hydrographs

The locations which experienced flooding from the remnants of Ida are below. A hydrograph, which is a plot of water level or stage over time, for each location is provided.

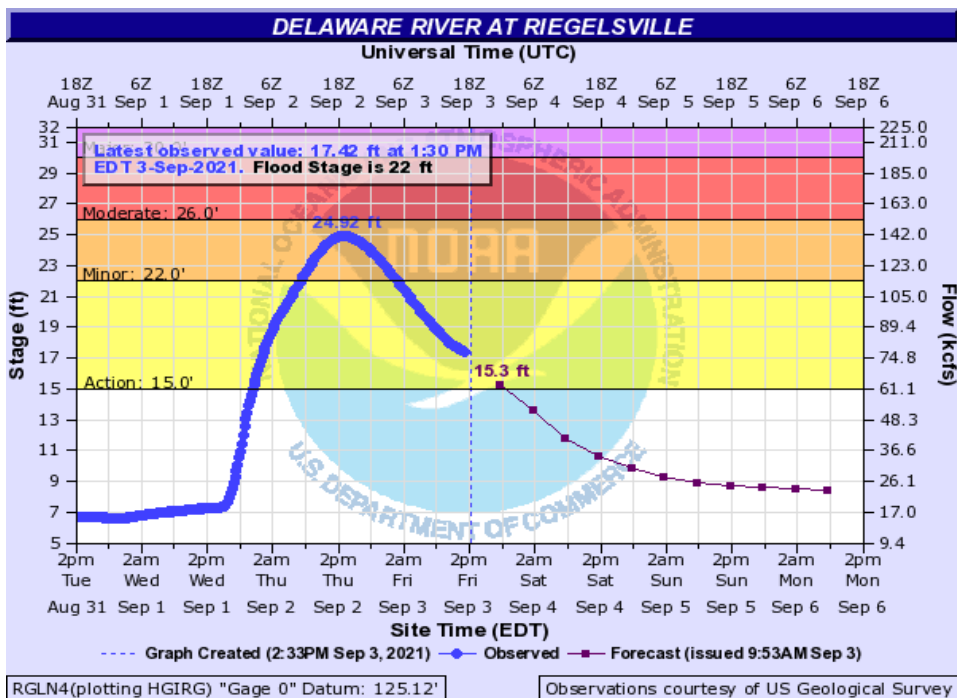


Delaware River at Tocks Island, Action Stage, Peak 20.69 feet

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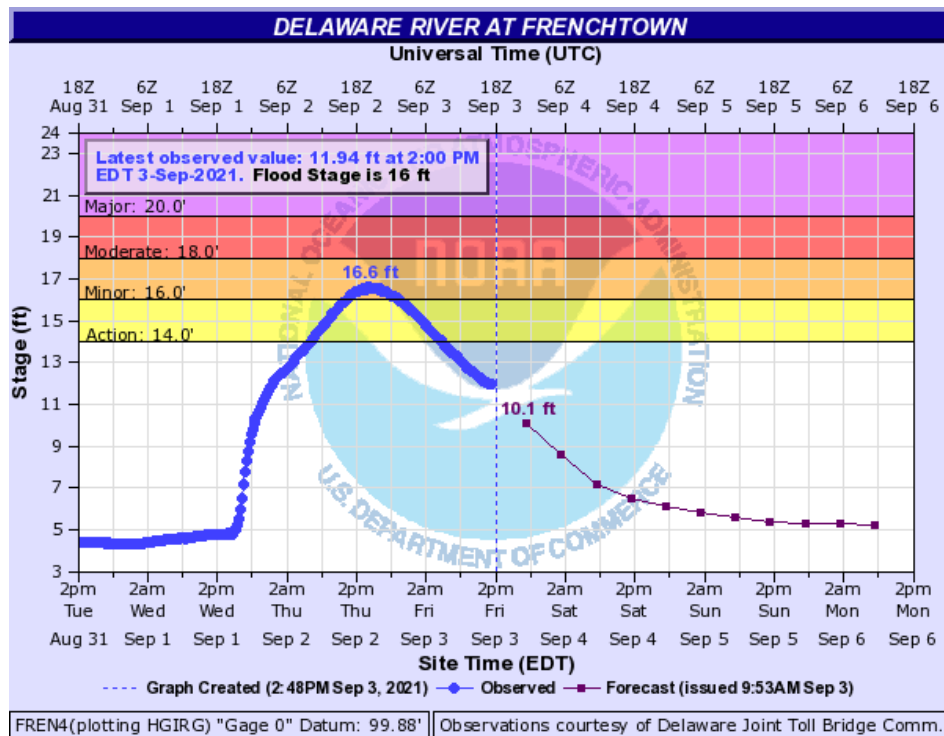


Delaware River at Easton, Minor Flood Stage, Peak 25.73 feet.

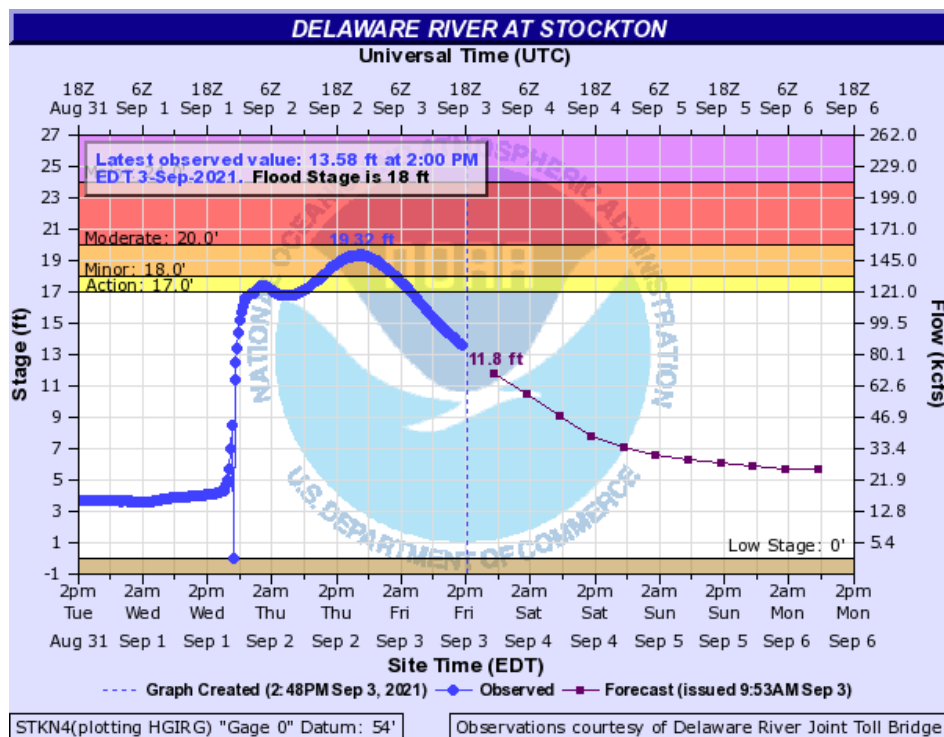


Delaware River at Riegelsville, Minor Flood Stage, Peak 24.92 feet.

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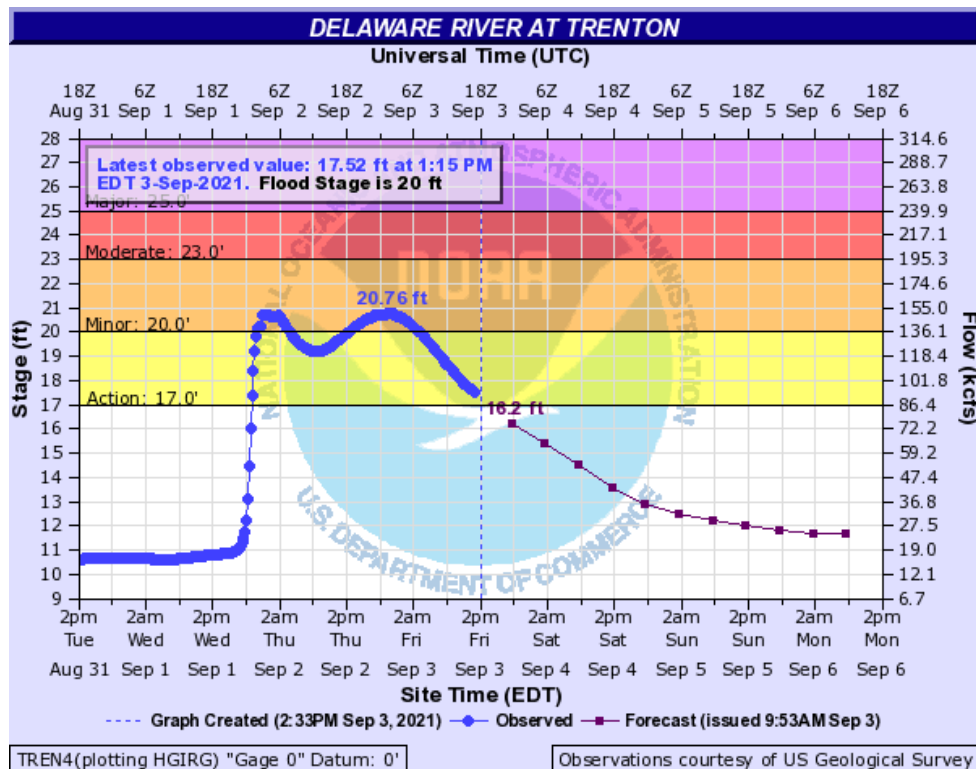


Delaware River at Frenchtown, Minor Flood Stage, Peak 16.6 feet.

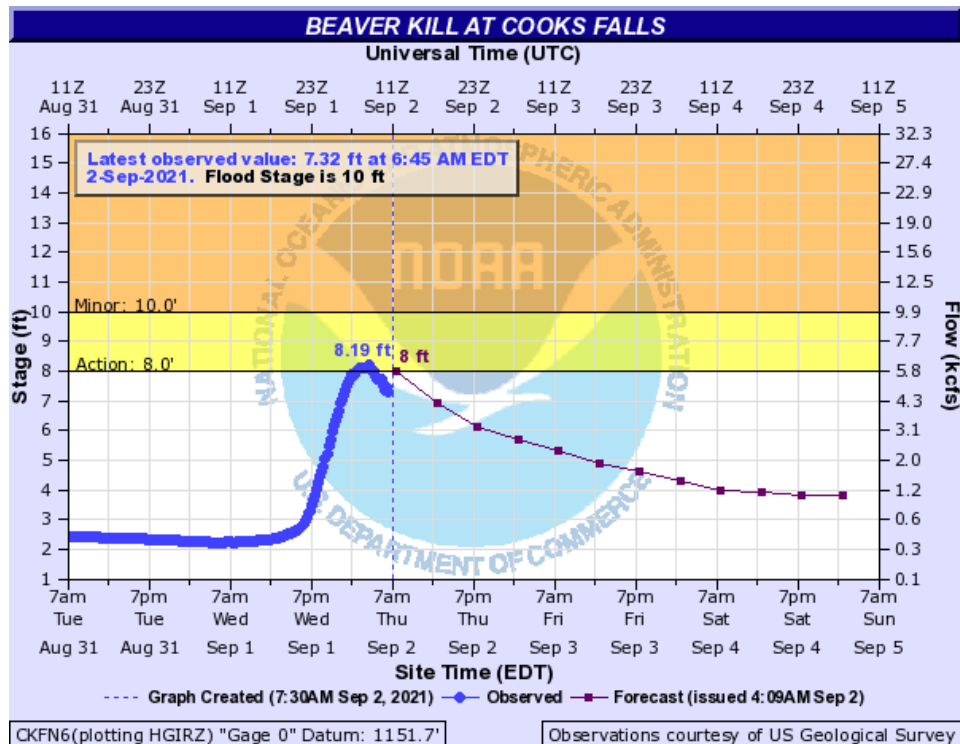


Delaware River at Stockton, Minor Flood Stage, Peak 19.32 feet.

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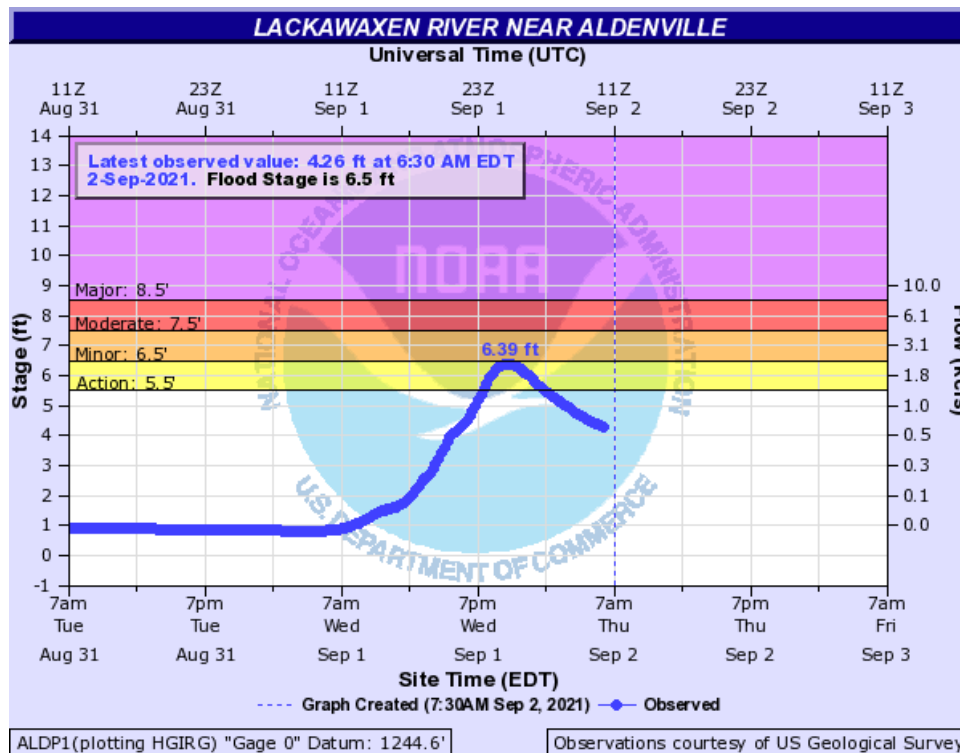


Delaware River at Trenton, Minor Flood Stage, Peak 20.76 feet.

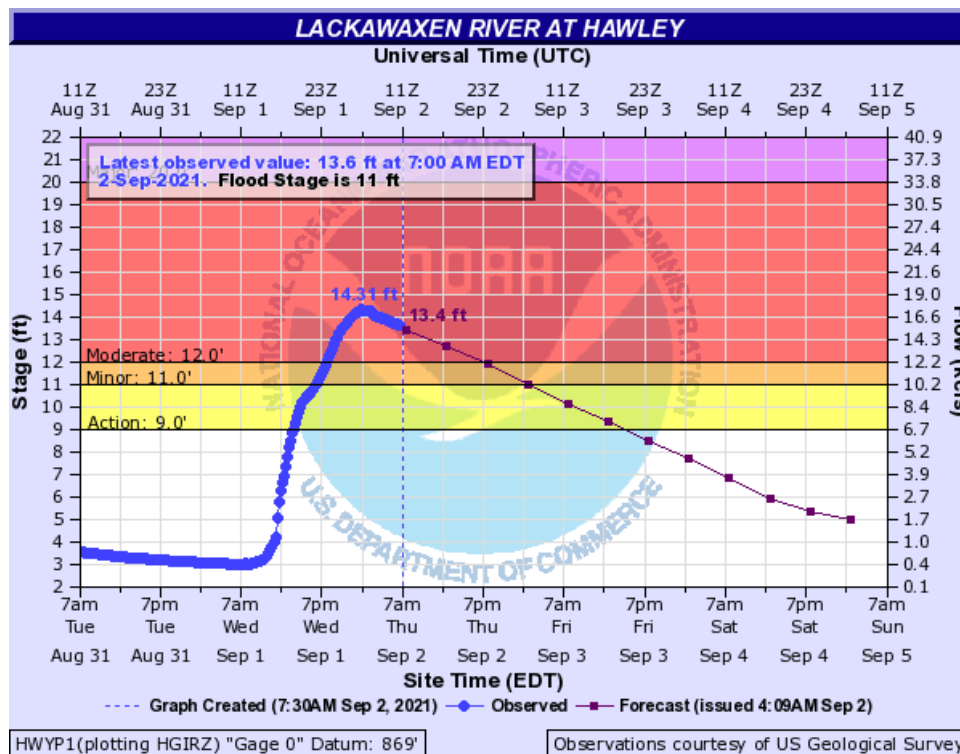


Beaver Kill at Cooks Falls, Action Stage, Peak 8.19 feet.

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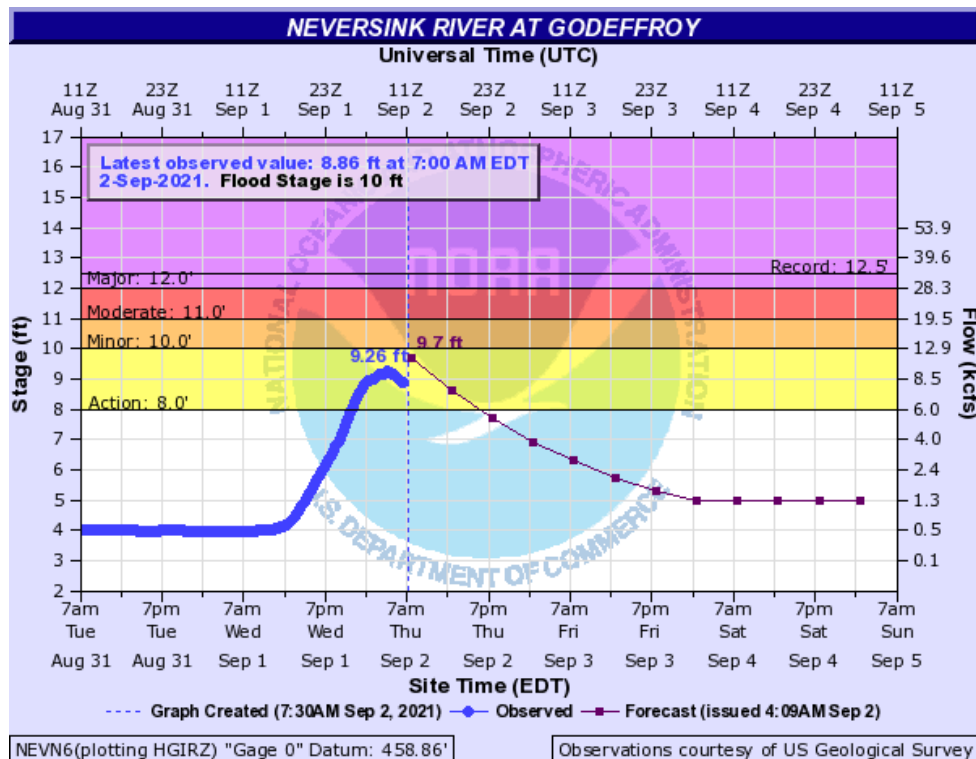


Lackawaxen River near Aldenville, Action Stage, Peak 6.39 feet.

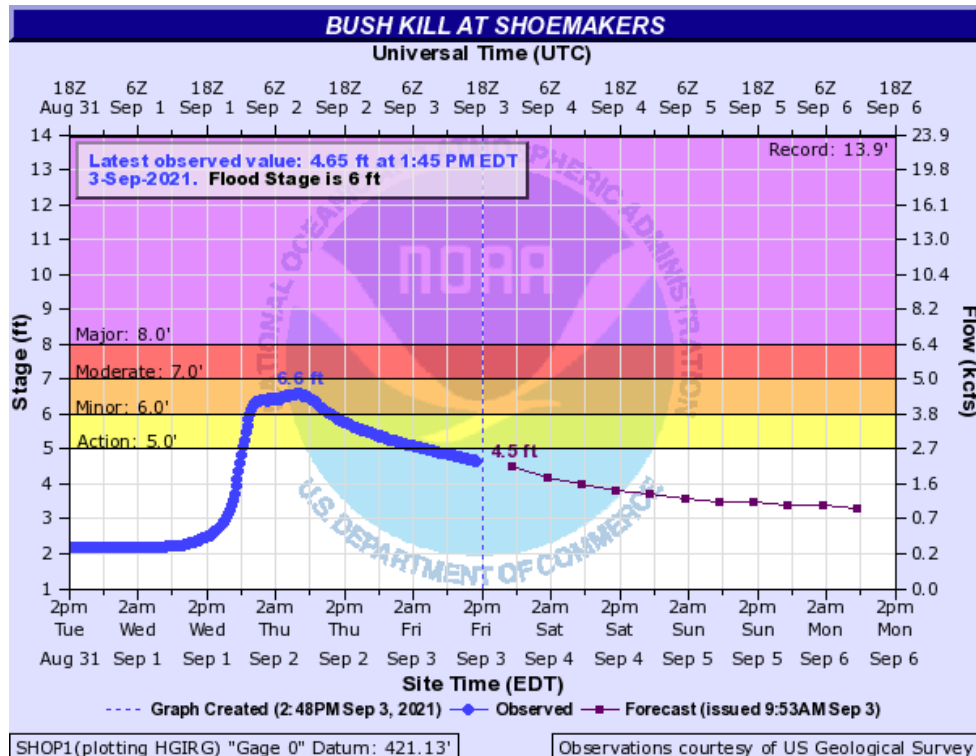


Lackawaxen River at Hawley, Moderate Flood Stage, Peak 14.31 feet.

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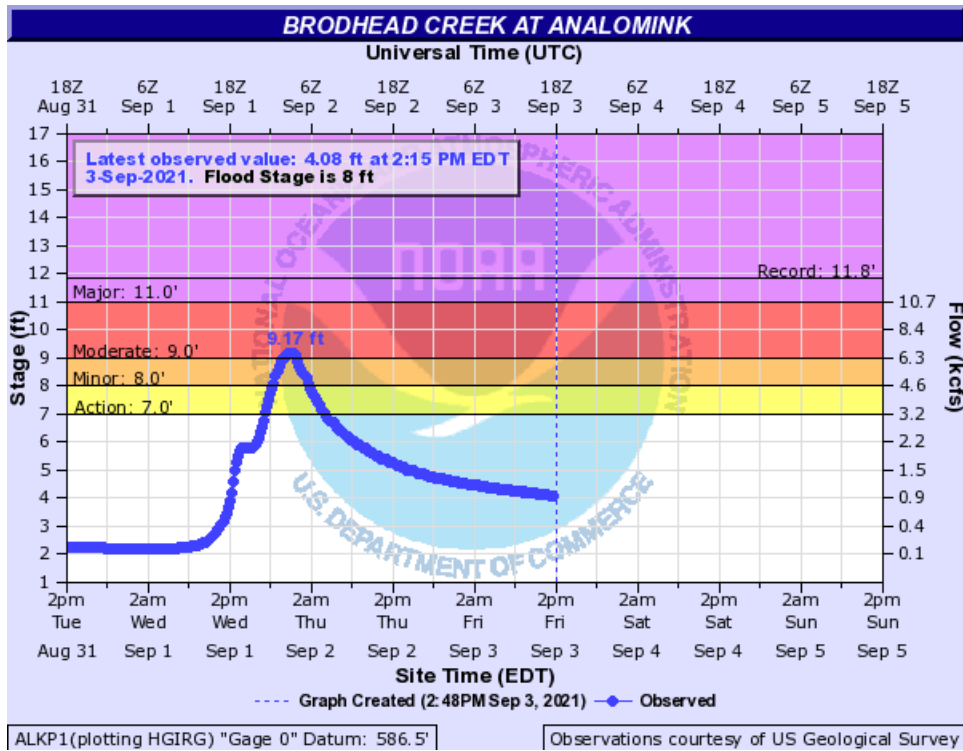


Neversink River at Godeffroy, Action Stage, Peak 9.26 feet.

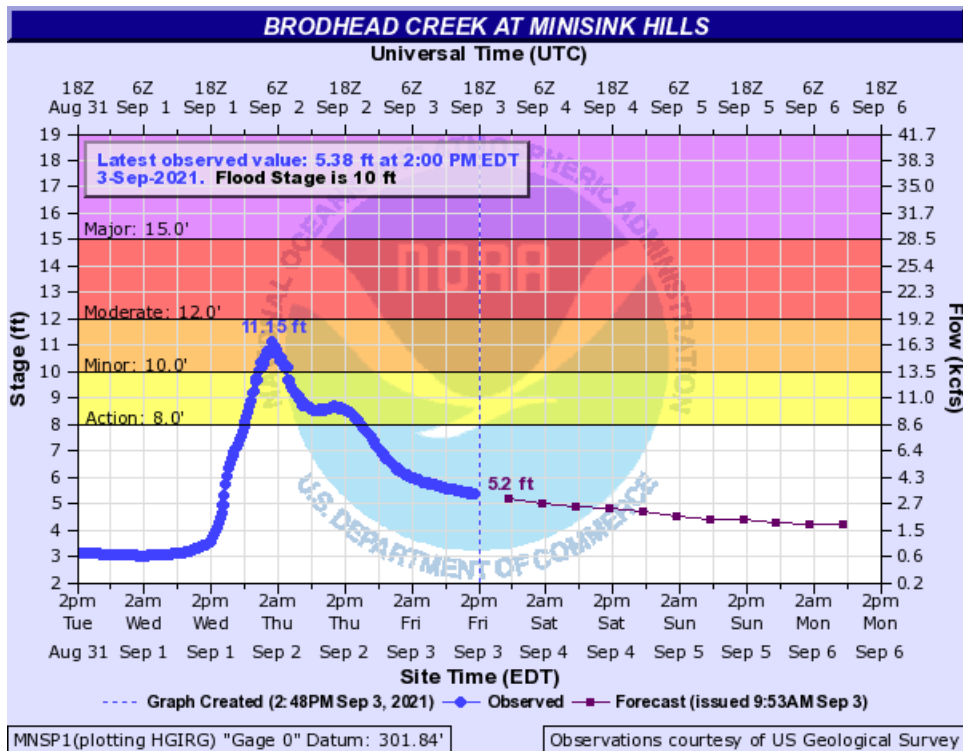


Bush Kill at Shoemakers, Minor Flood Stage, Peak 6.6 feet.

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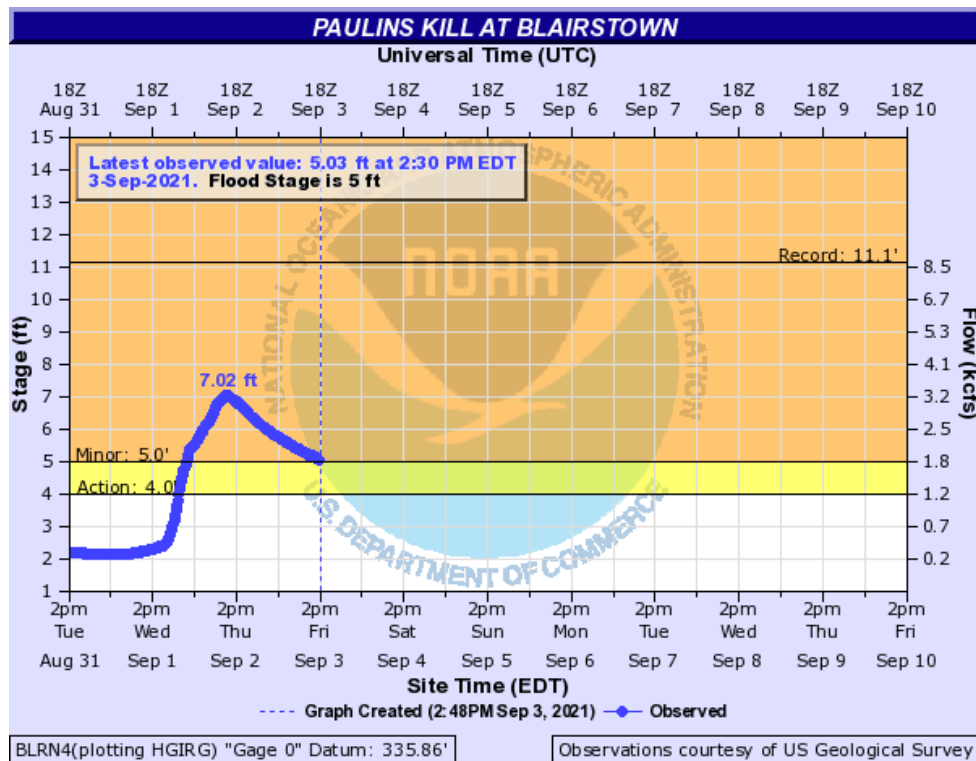


Brodhead at Analomink, Moderate Flood Stage, Peak 9.17 feet.

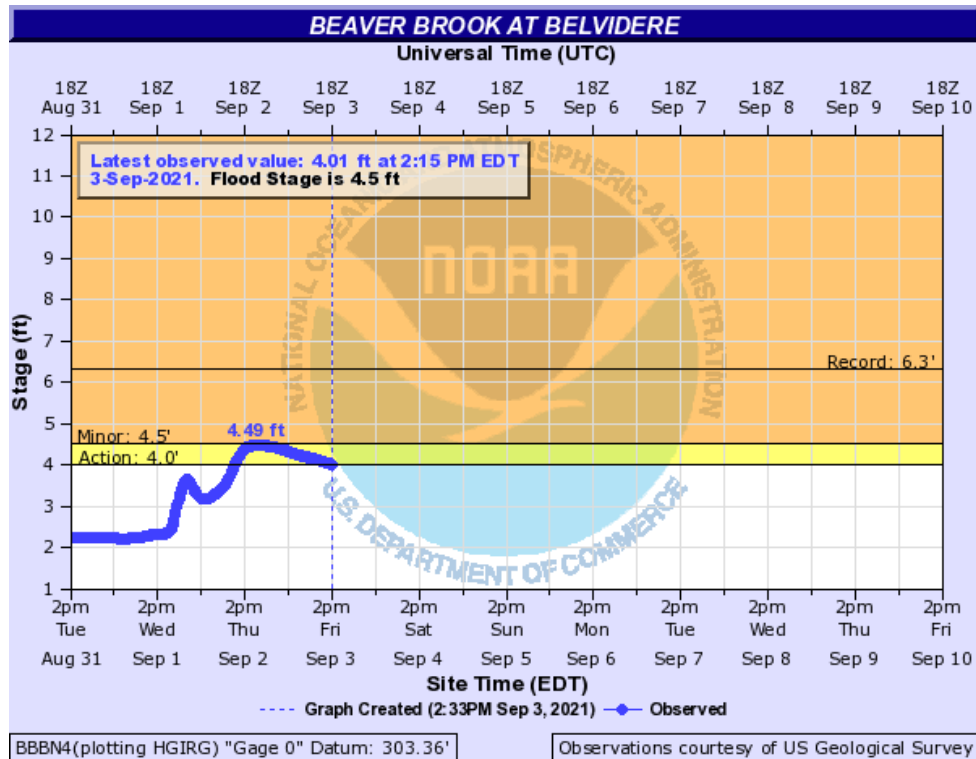


Brodhead Creek at Minisink Hills, Minor Flood Stage, Peak 11.15 feet.

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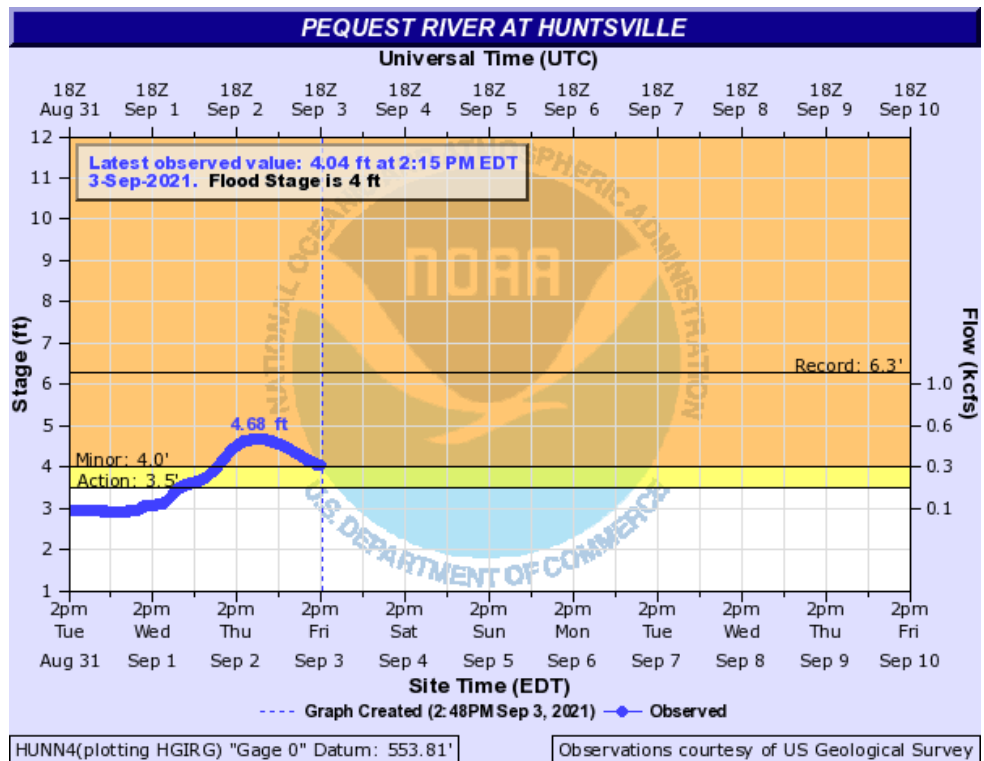


Paulins Kill at Blairstown, Minor Flood Stage, Peak 7.02 feet.

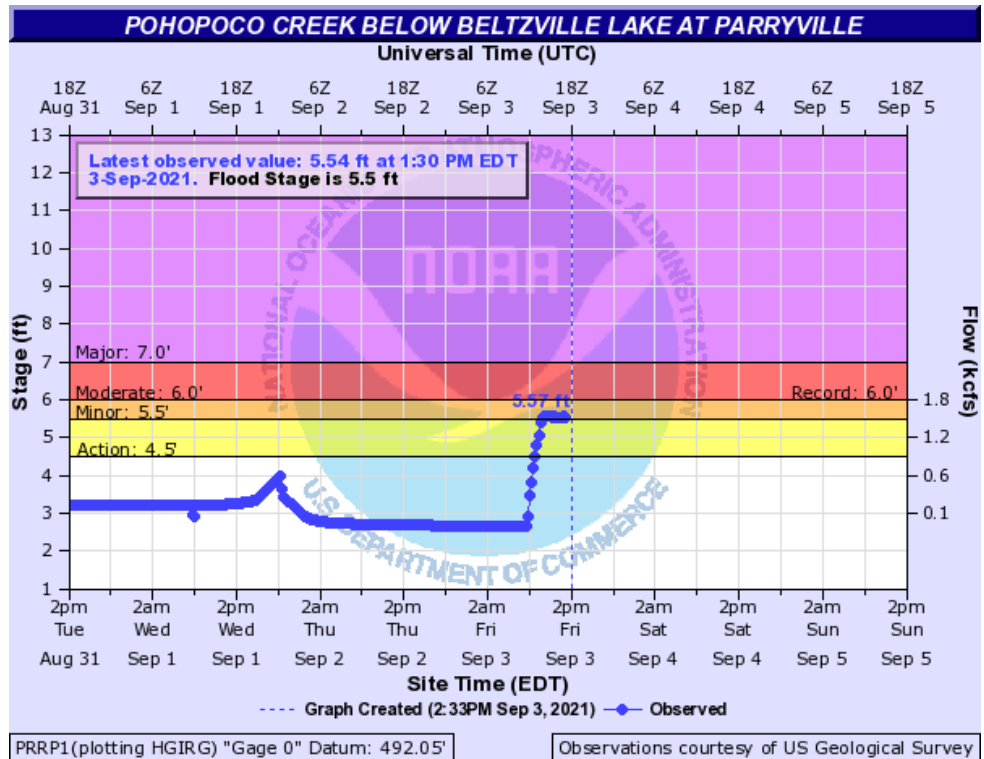


Beaver Brook at Belvidere, Action Stage, Peak 4.49 feet.

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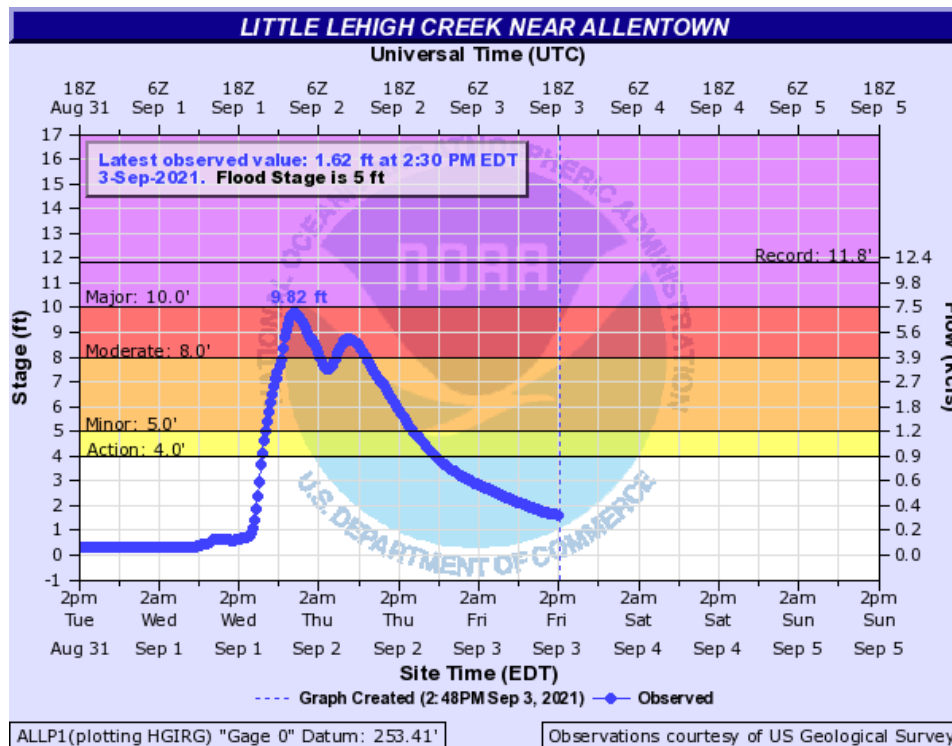


Pequest River at Huntsville, Minor Flood Stage, Peak 4.68 feet.

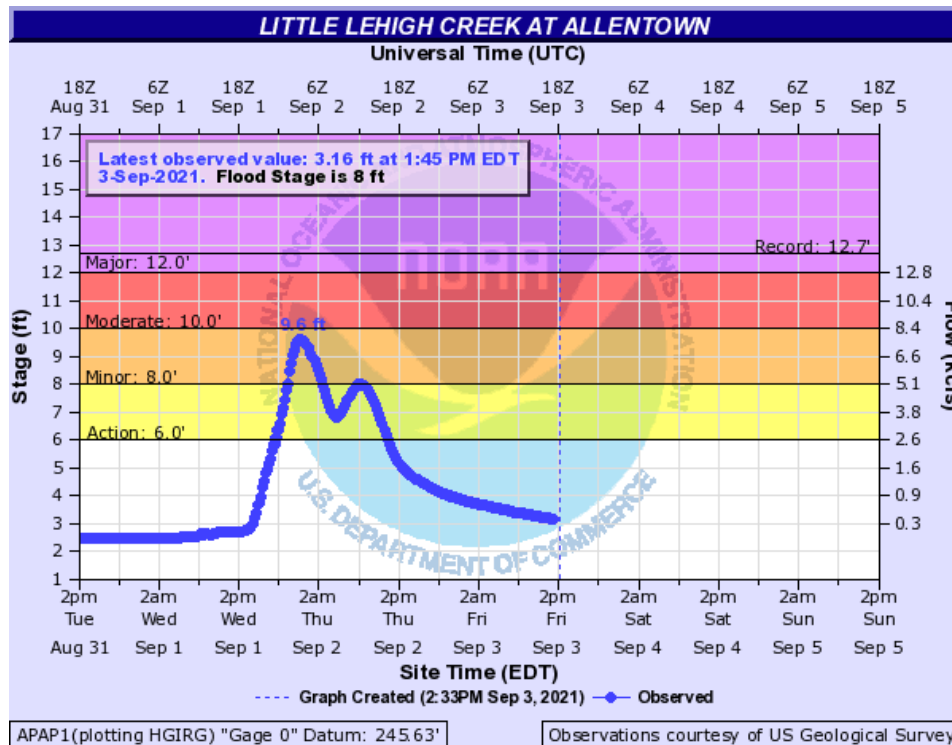


Pohopoco Creek below Beltzville Lake at Parryville, Minor Flood Stage, Peak 5.57 feet.

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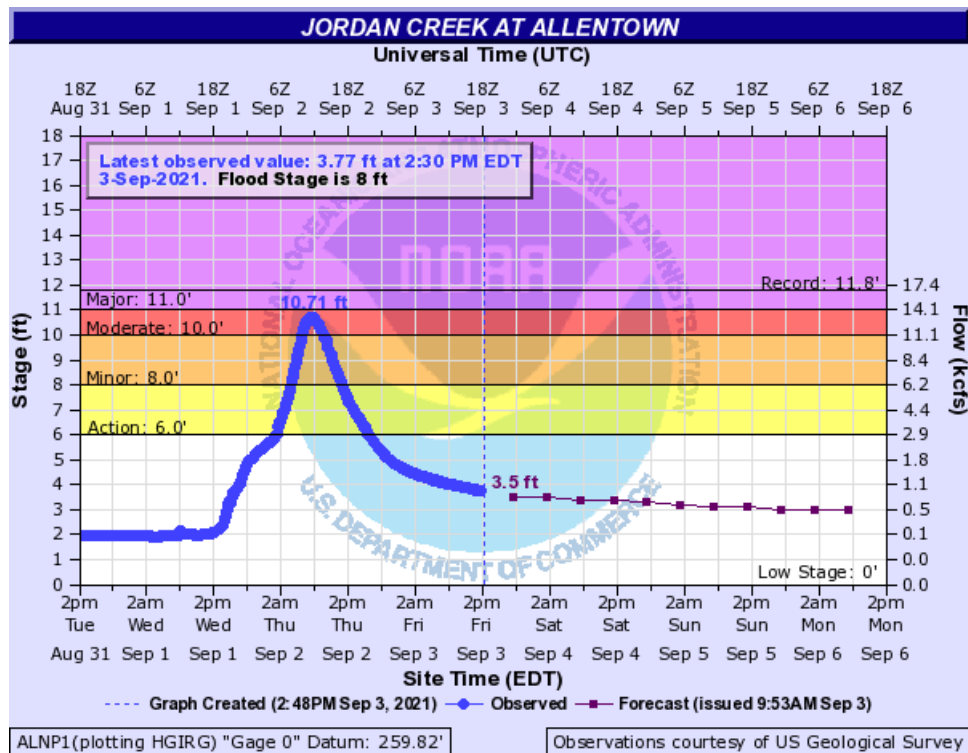


Little Lehigh Creek near Allentown, Moderate Flood Stage, Peak 9.82 feet.

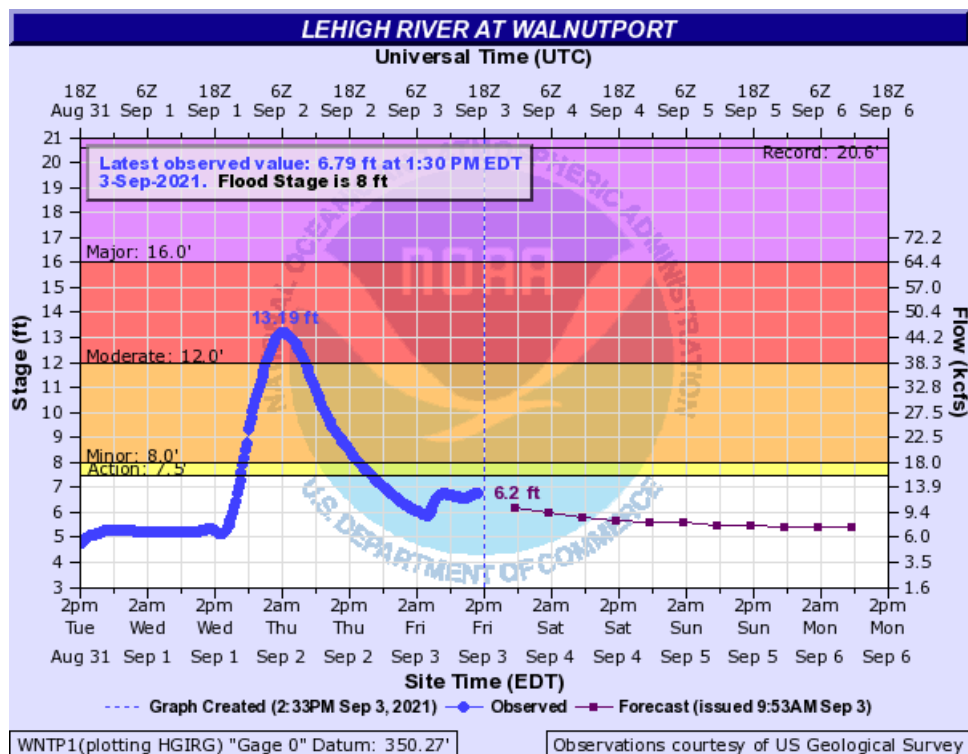


Little Lehigh Creek at Allentown, Minor Flood Stage, Peak 9.6 feet.

Annual Hydrologic Conditions Report

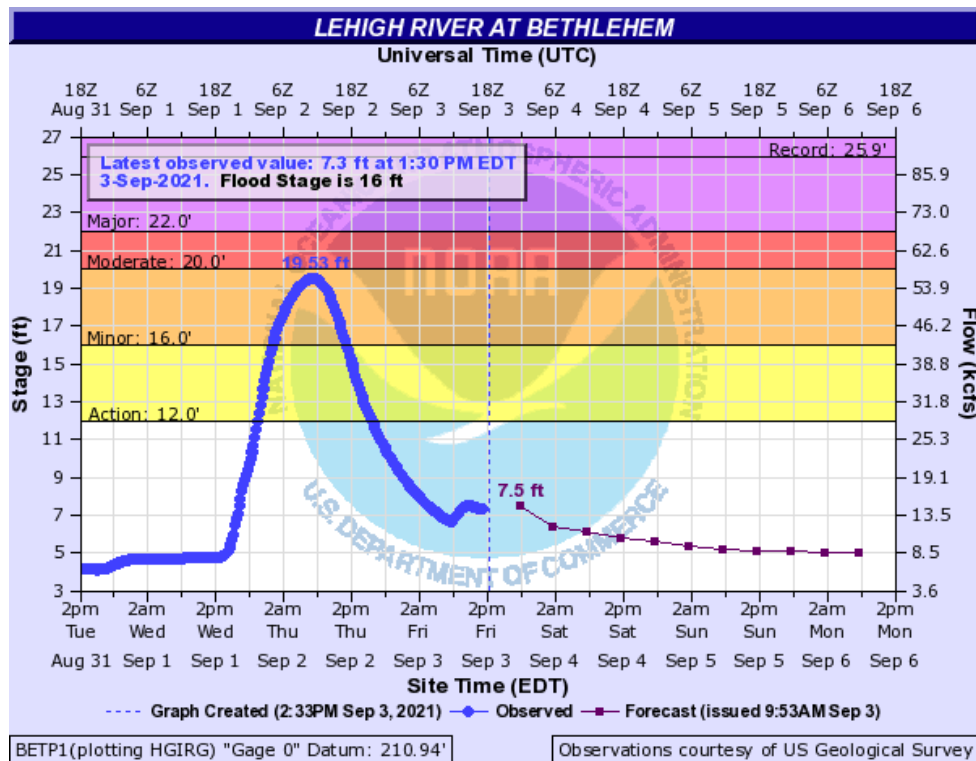


Jordan Creek at Allentown, Moderate Flood Stage, Peak 10.71 feet.

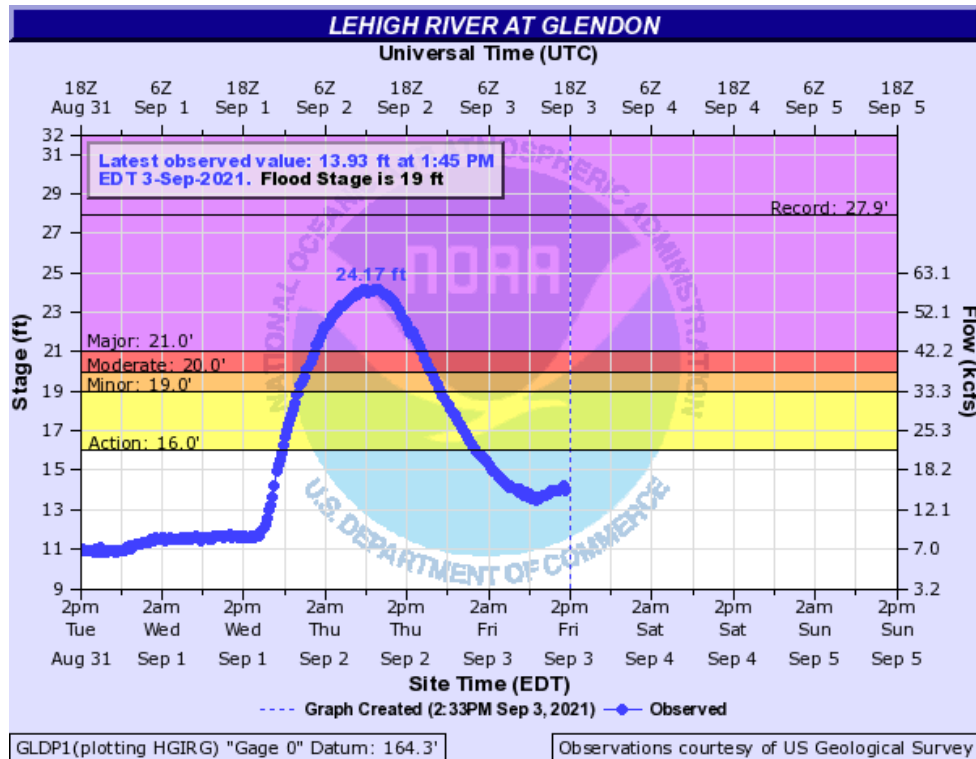


Lehigh River at Walnutport, Moderate Flood Stage, Peak 13.19 feet.

Annual Hydrologic Conditions Report

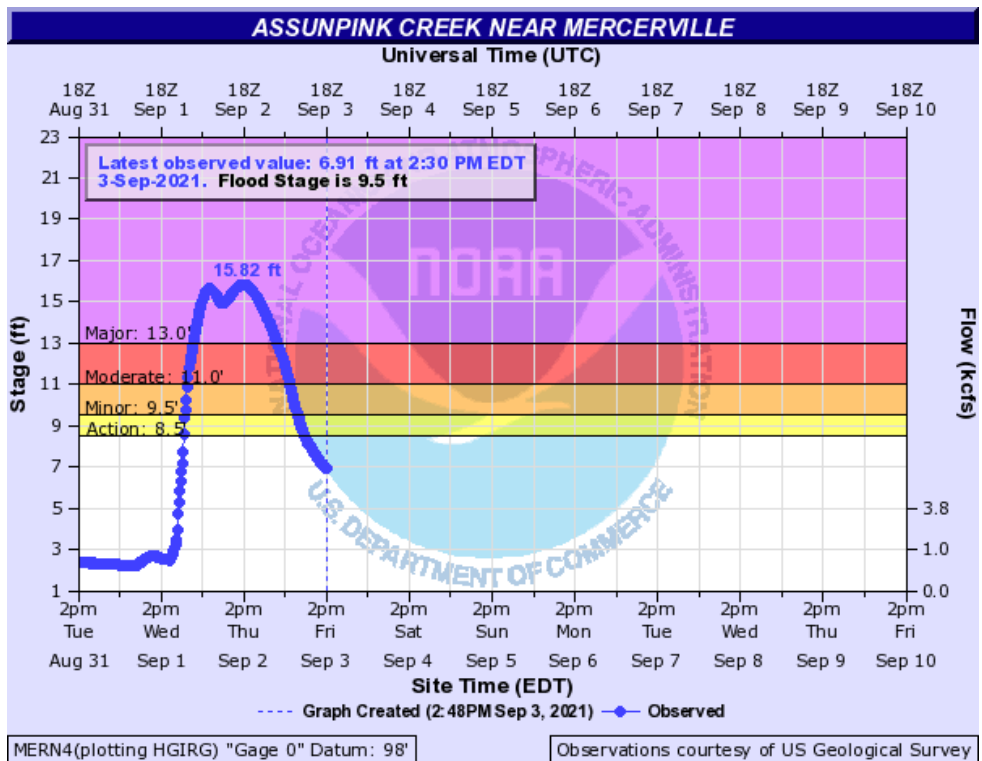


Lehigh River at Bethlehem, Minor Flood Stage, Peak 19.53 feet.

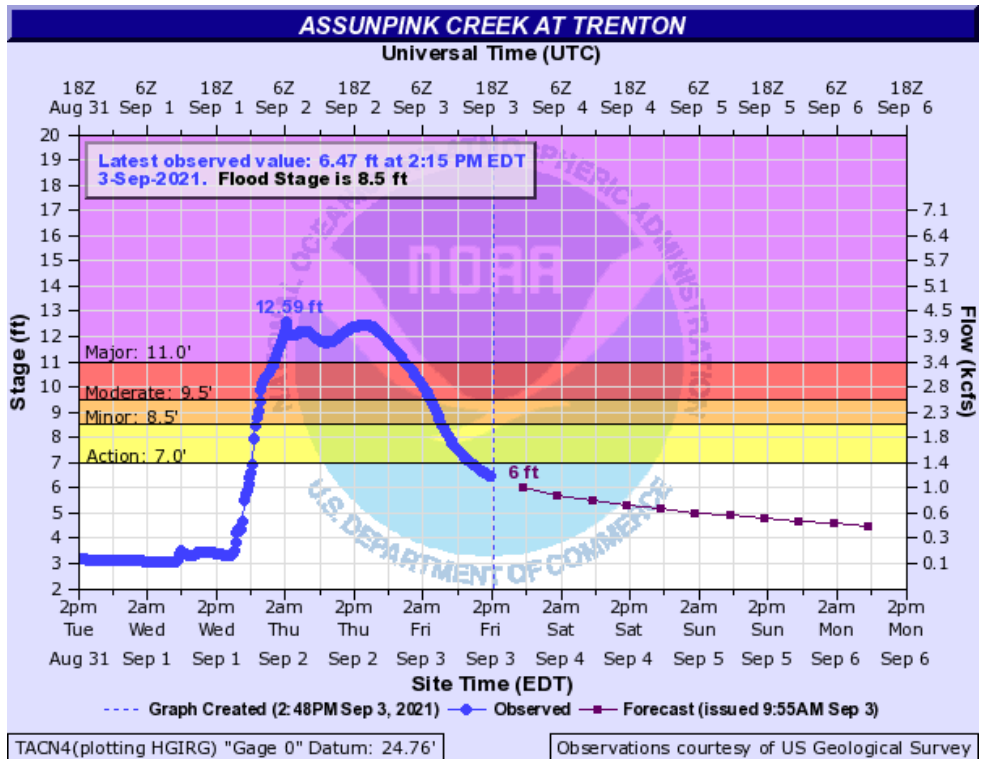


Lehigh River at Glendon, Major Flood Stage, Peak 24.17 feet.

Annual Hydrologic Conditions Report

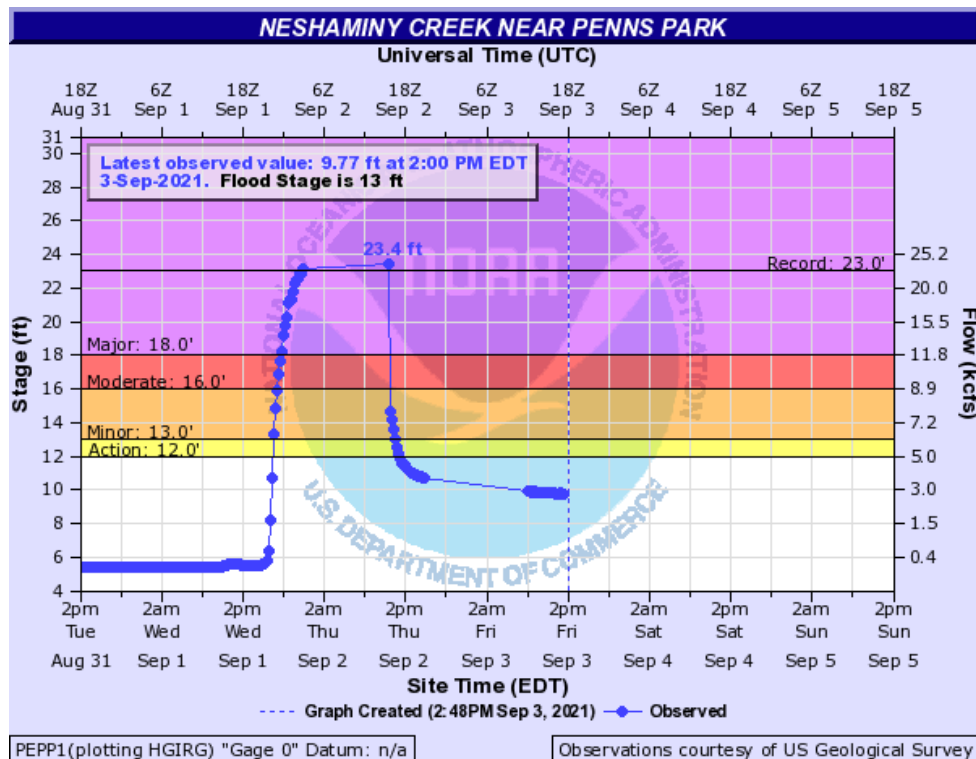


Assunpink Creek near Mercerville, Major Flood Stage, Peak 15.82 feet.

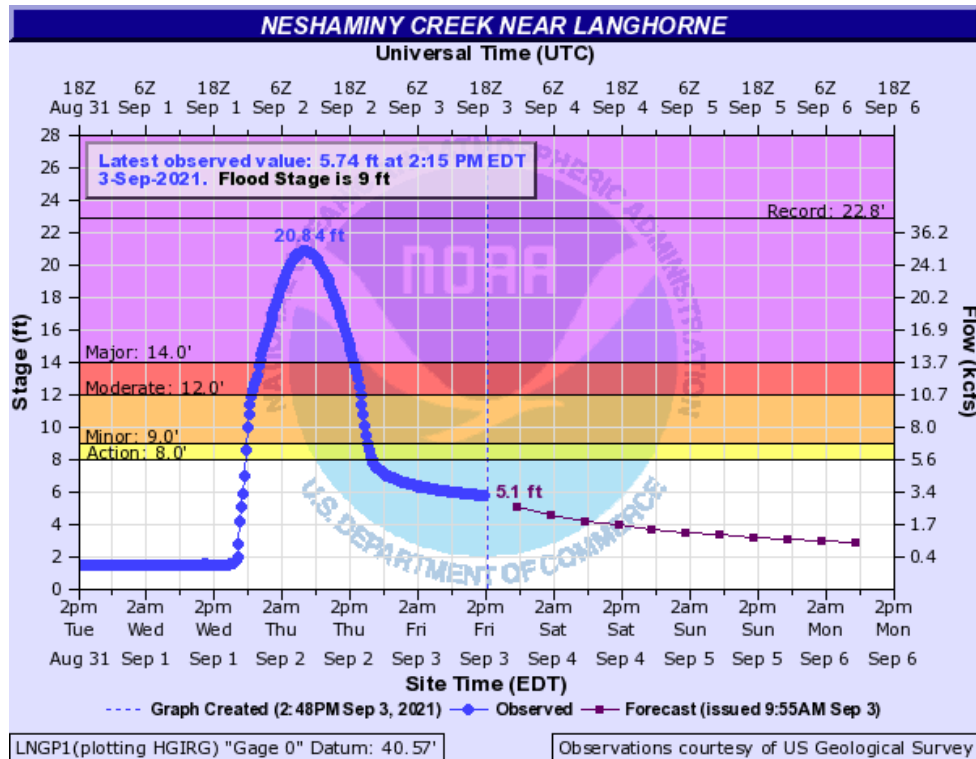


Assunpink Creek at Trenton, Major Flood Stage, Peak 12.59 feet.

Annual Hydrologic Conditions Report

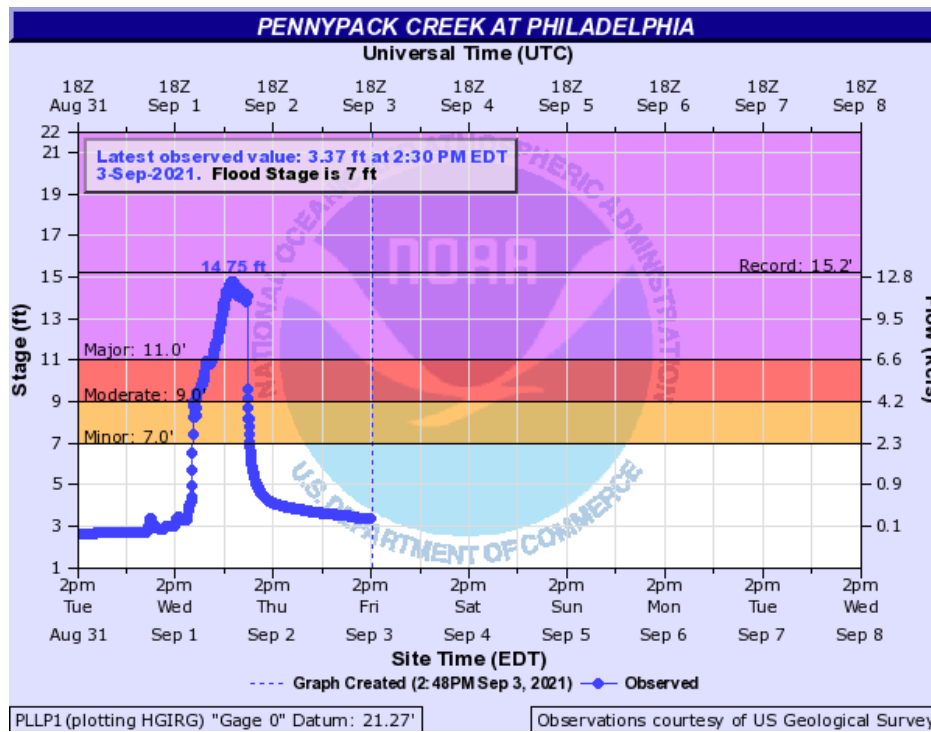


Neshaminy Creek near Penns Park, Major Flooding, Peak 23.4 feet.

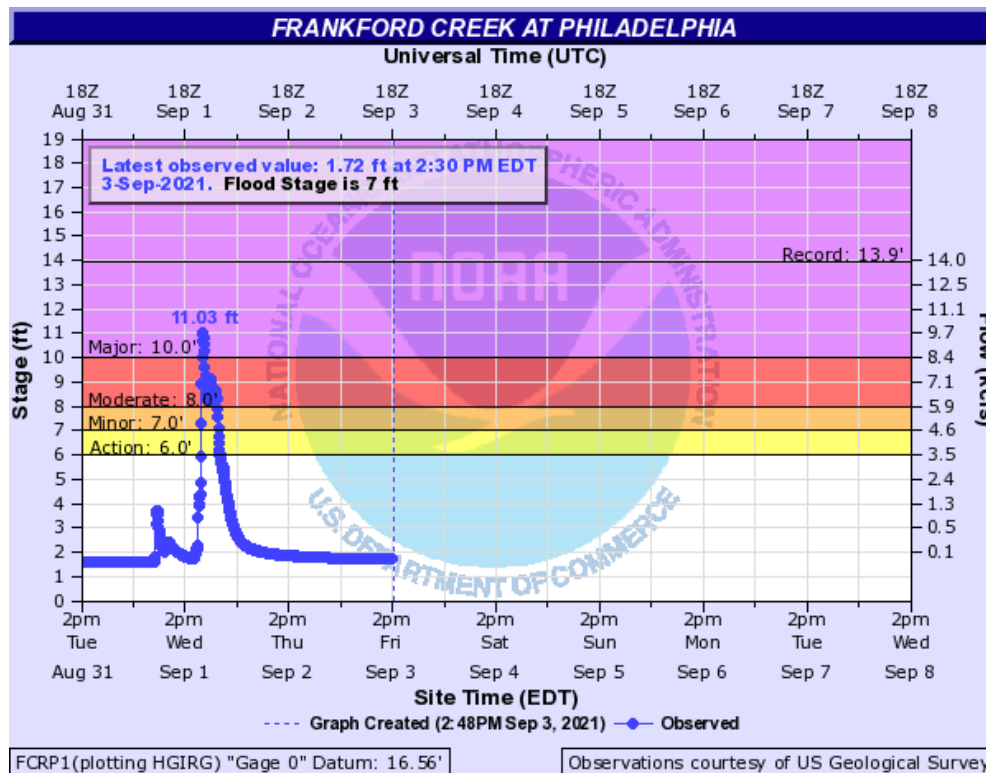


Neshaminy Creek near Langhorne, Major Flood Stage, Peak 20.84 feet.

Annual Hydrologic Conditions Report

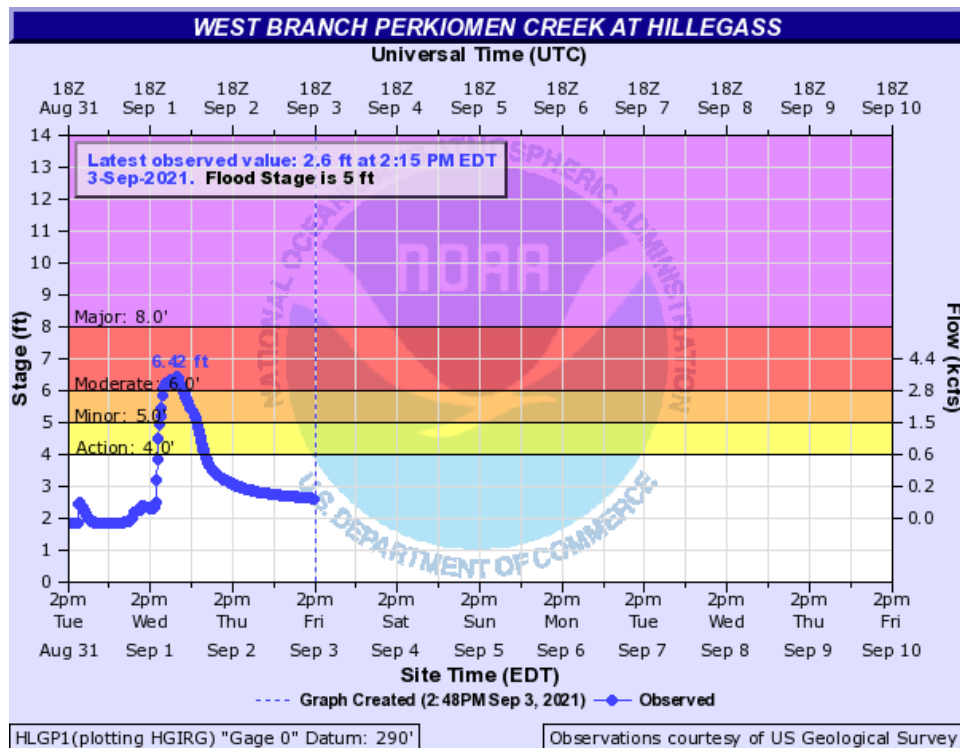


Pennypack Creek at Philadelphia, Major Flood Stage, Peak 14.75 feet.

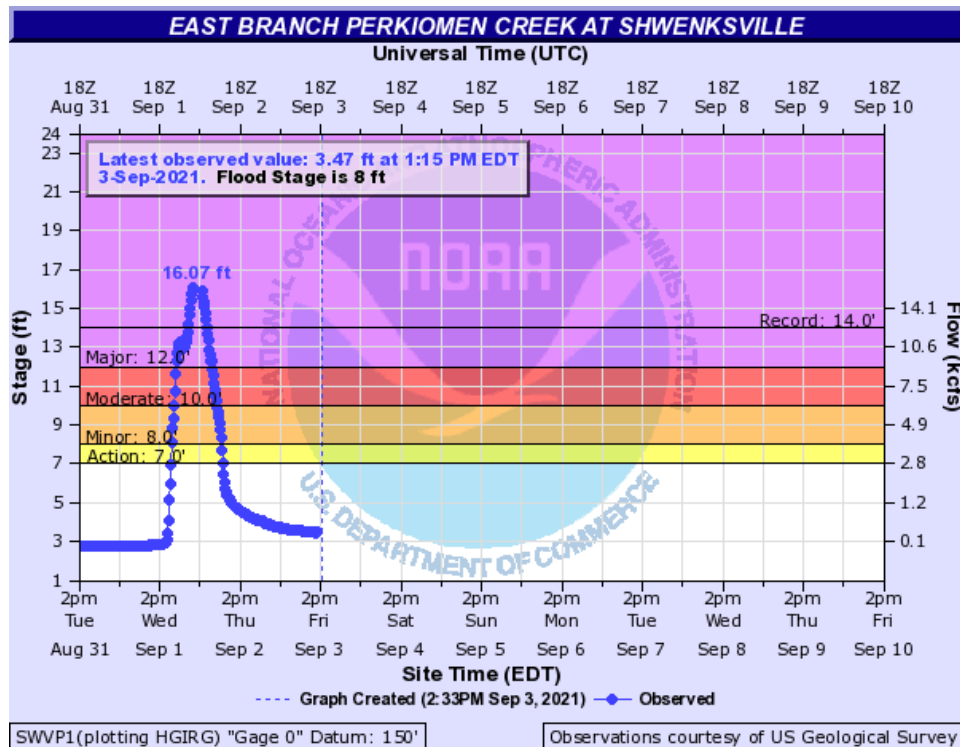


Frankford Creek at Philadelphia, Major Flood Stage, Peak 11.03 feet.

Annual Hydrologic Conditions Report

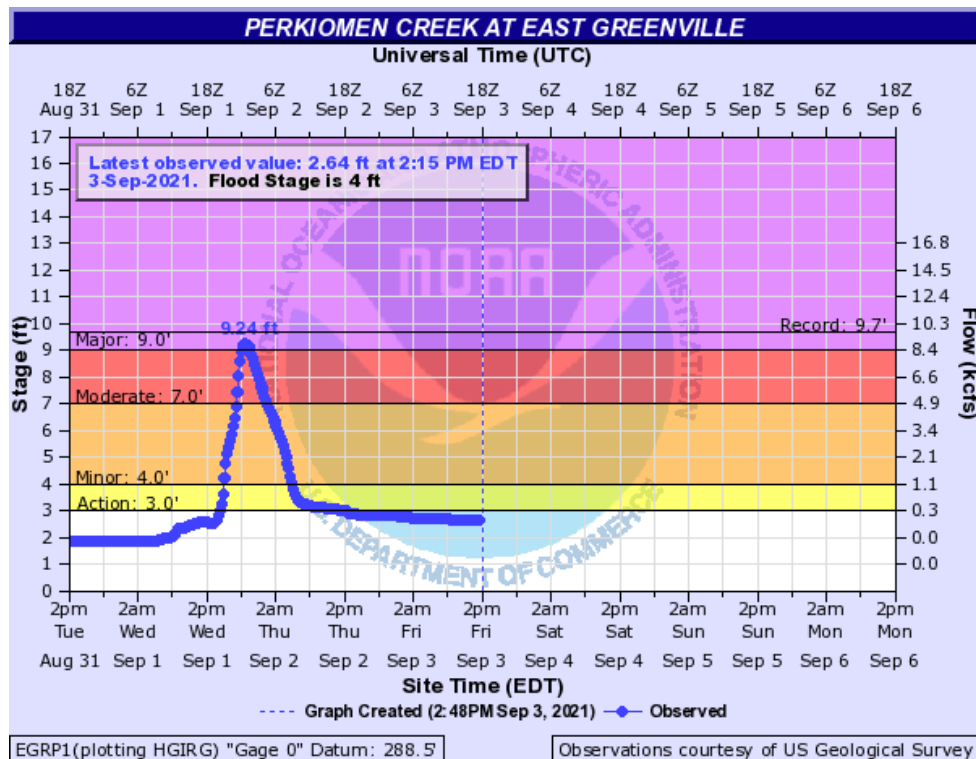


West Branch Perkiomen Creek at Hillegass, Moderate Flood Stage, Peak 6.42 feet.

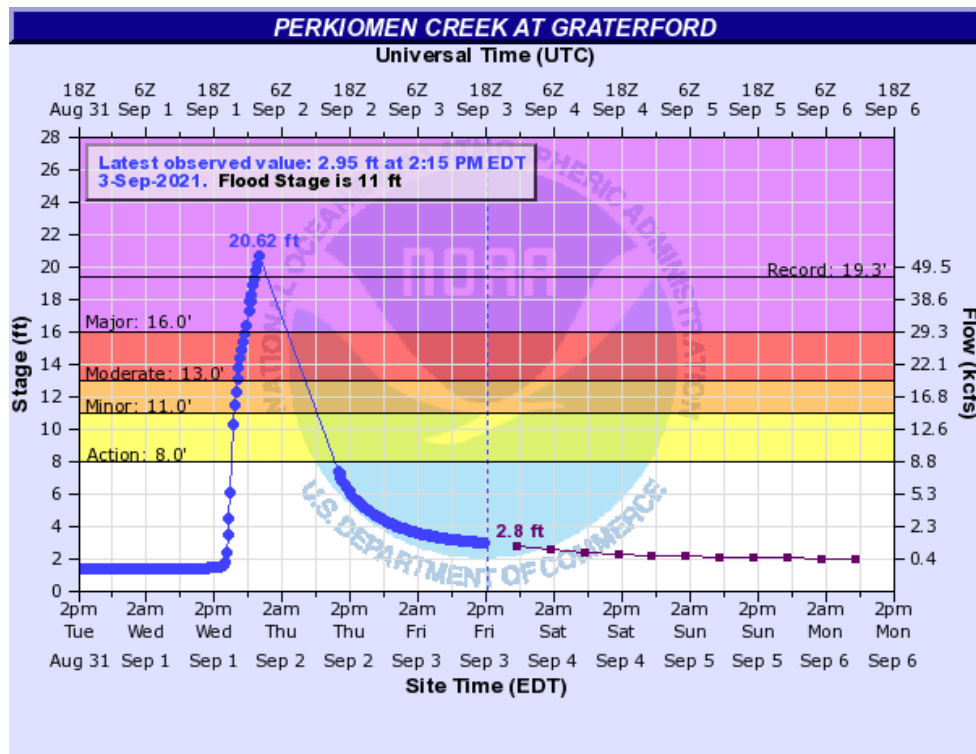


East Branch Perkiomen Creek at Schwenksville, Major Flood Stage, Peak 16.07 feet.

Annual Hydrologic Conditions Report

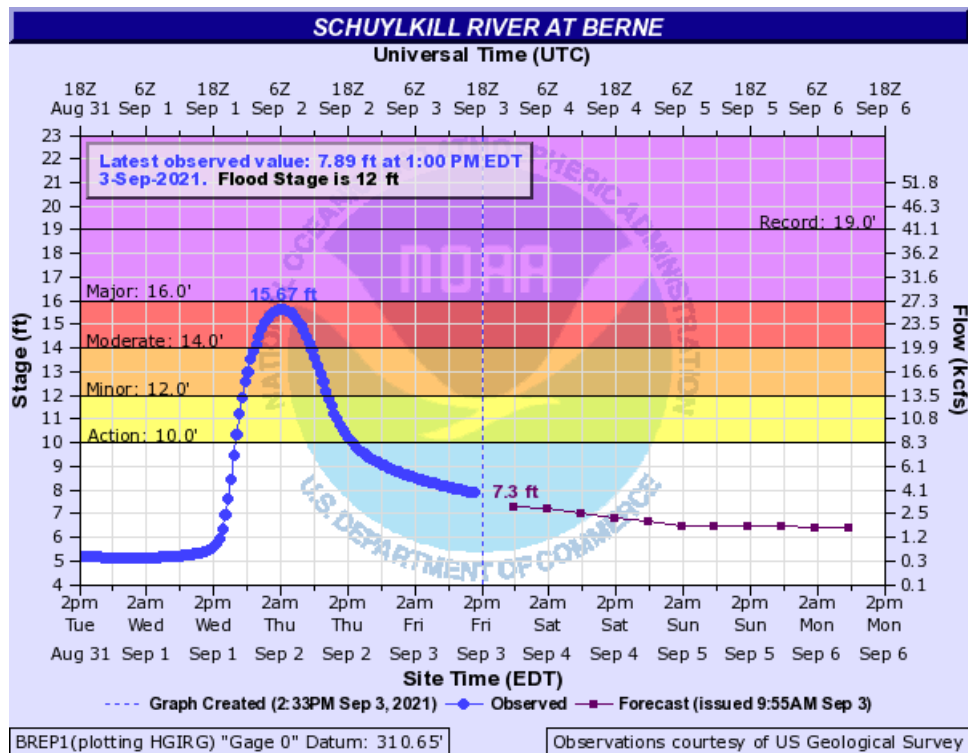


Perkiomen Creek at East Greenville, Major Flood Stage, Peak 9.24 feet.

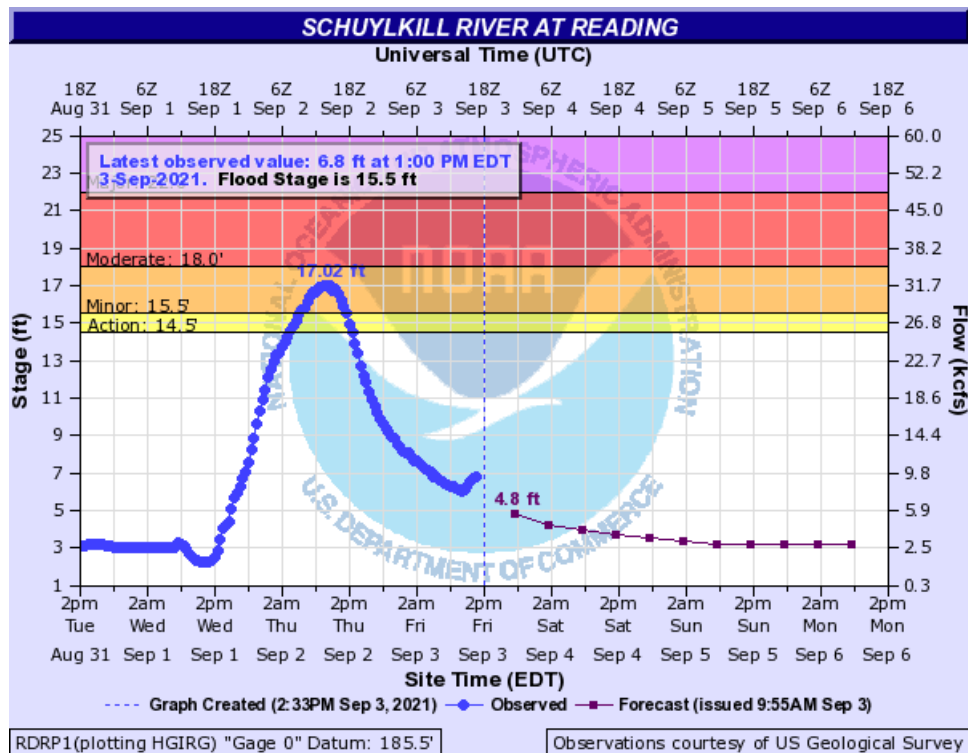


Perkiomen Creek at Graterford, Major Flood Stage, Peak 20.62 feet.

Annual Hydrologic Conditions Report

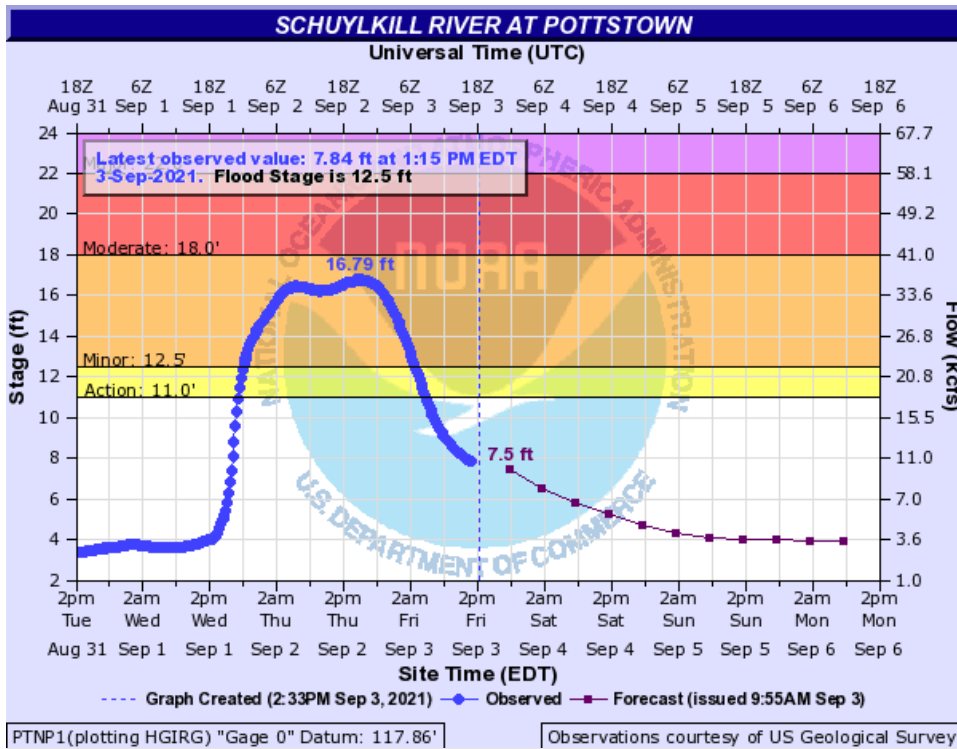


Schuylkill River at Berne, Moderate Flood Stage, Peak 15.67 feet.

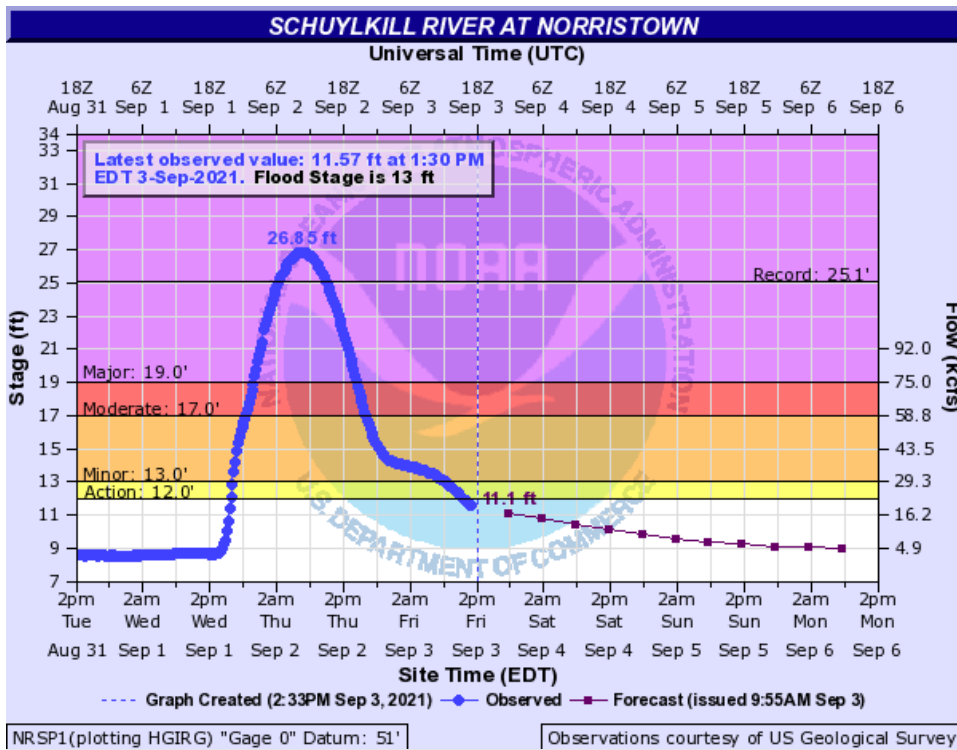


Schuylkill River at Reading, Minor Flood Stage, Peak 17.02 feet.

Annual Hydrologic Conditions Report

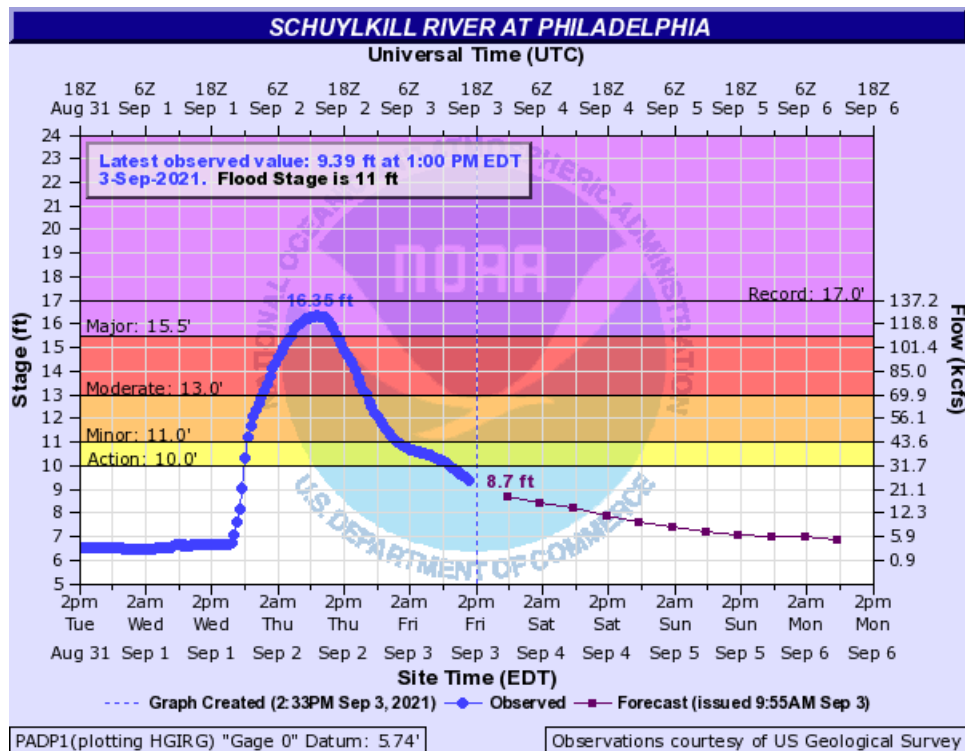


Schuylkill River at Pottstown, Minor Flood Stage, Peak 16.79 feet.

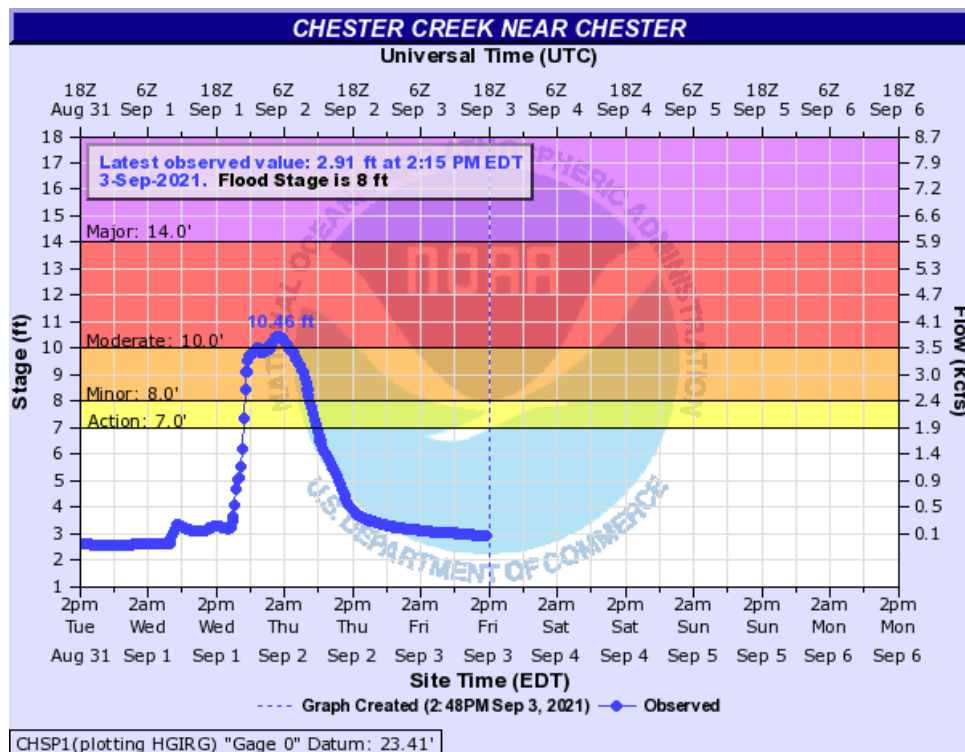


Schuylkill River at Norristown, Major Flood Stage, Peak 26.85 feet.

Annual Hydrologic Conditions Report

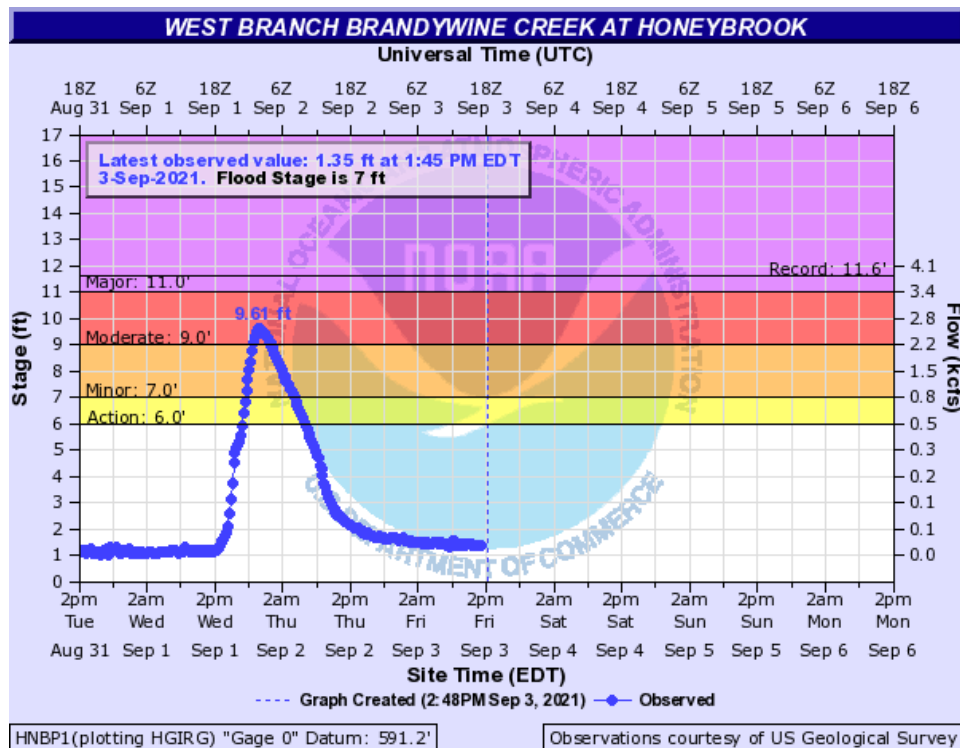


Schuylkill River at Philadelphia, Major Flood Stage, Peak 16.35 feet.

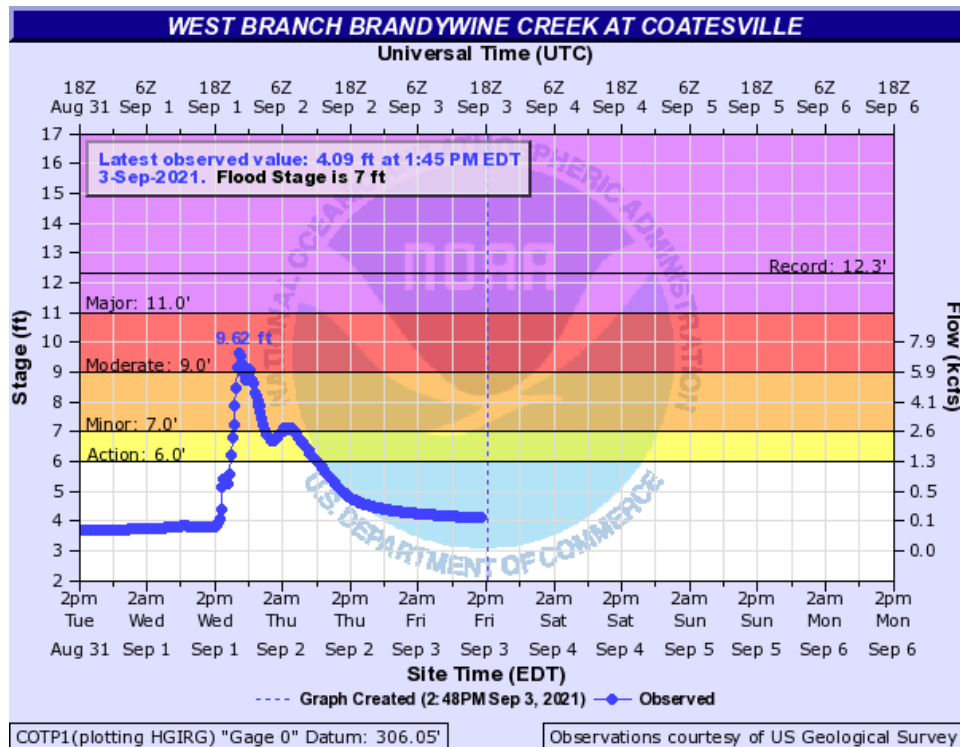


Chester Creek near Chester, Moderate Flood Stage, Peak 10.46 feet.

Annual Hydrologic Conditions Report

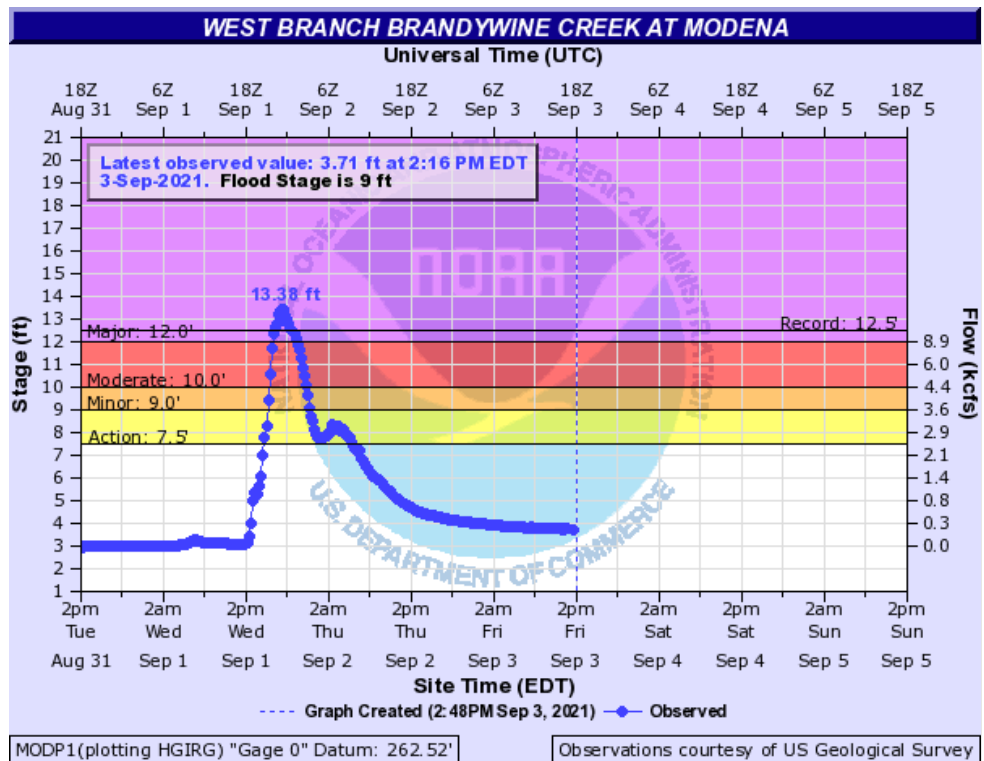


West Branch of the Brandywine Creek at Honeybrook, Moderate Flood Stage, Peak 9.61 feet.

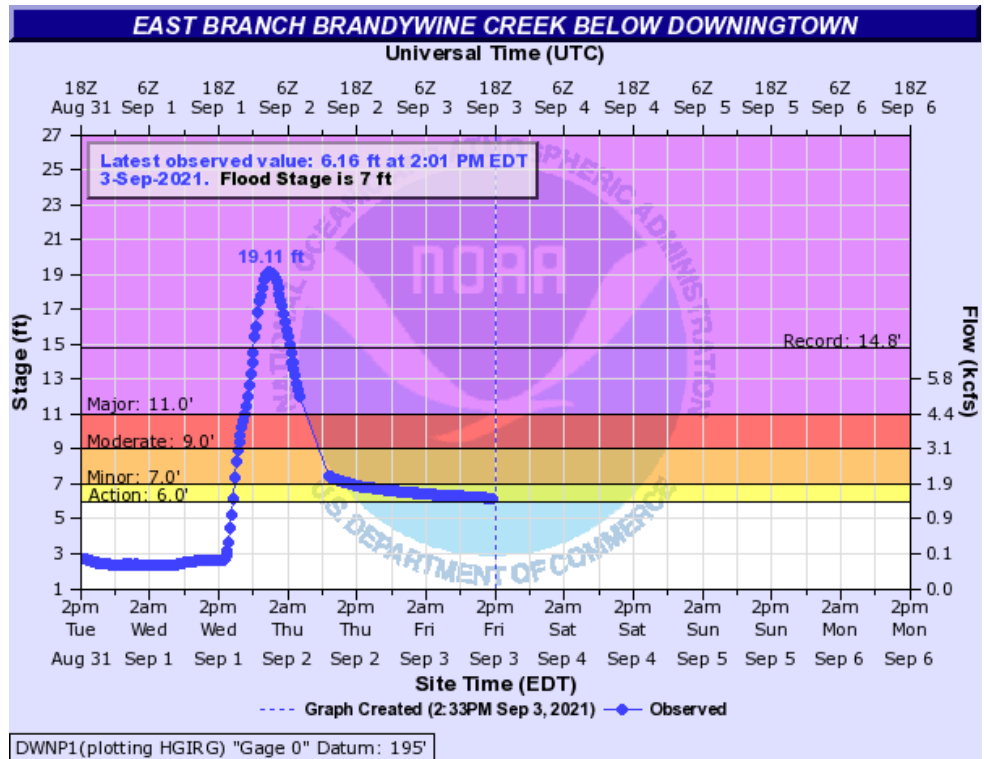


West Branch of the Brandywine at Coatesville, Moderate Flood Stage, Peak 9.62 feet.

Annual Hydrologic Conditions Report

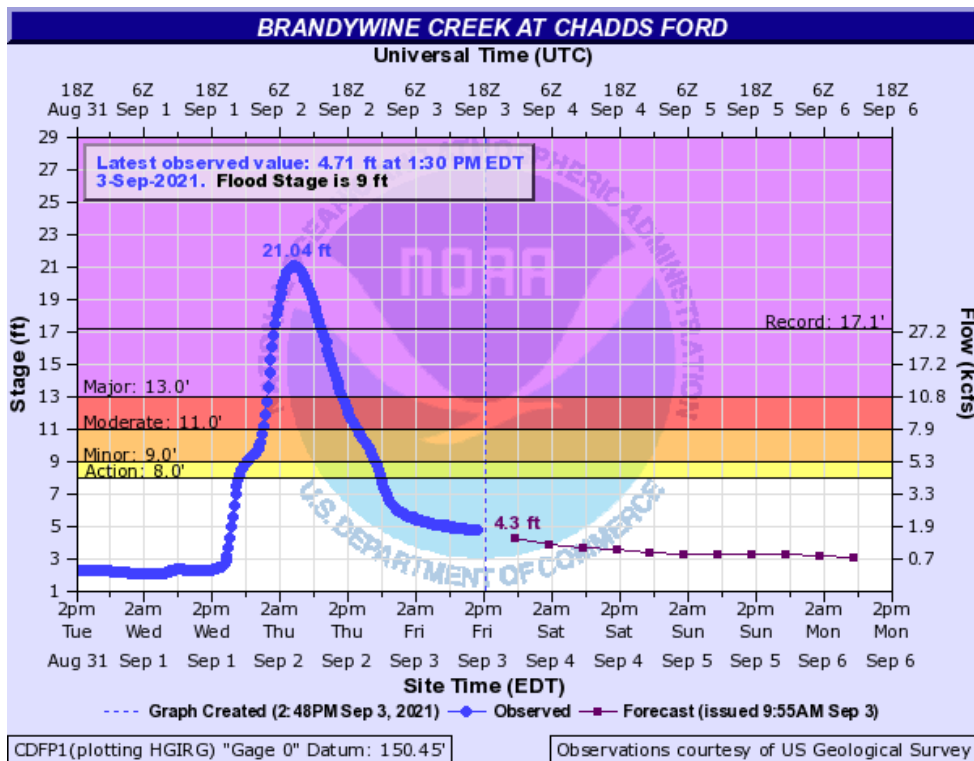


West Branch of the Brandywine Creek at Modena, Major Flood Stage, Peak 13.38 feet.

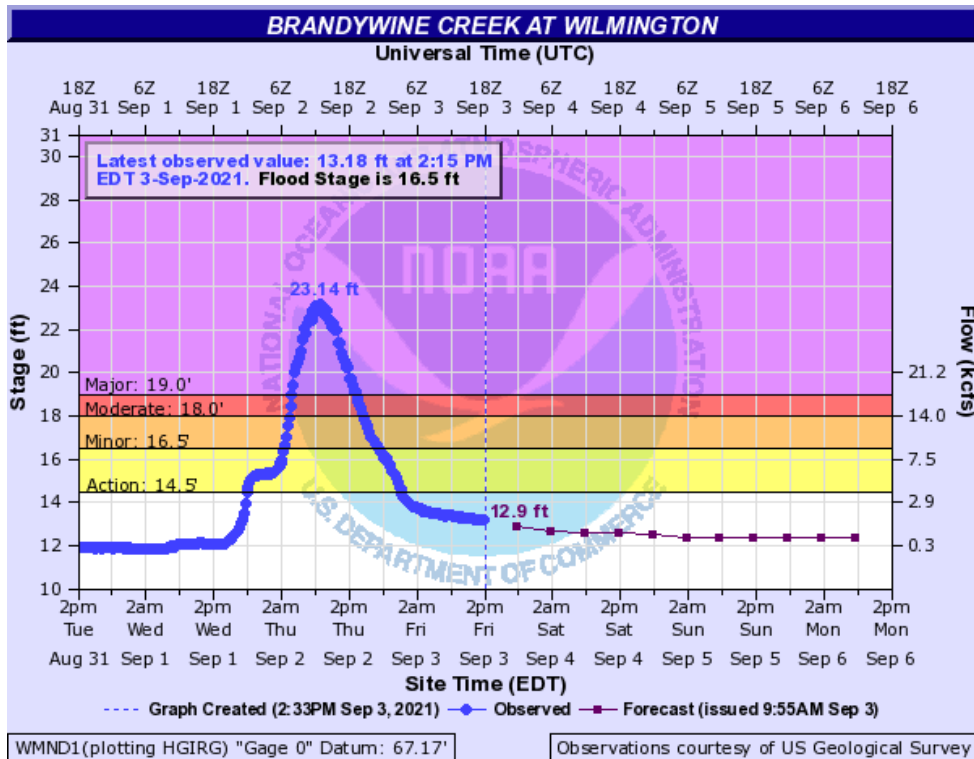


East Branch Brandywine Creek below Downingtown, Major Flood Stage, Peak 19.11 feet.

Annual Hydrologic Conditions Report

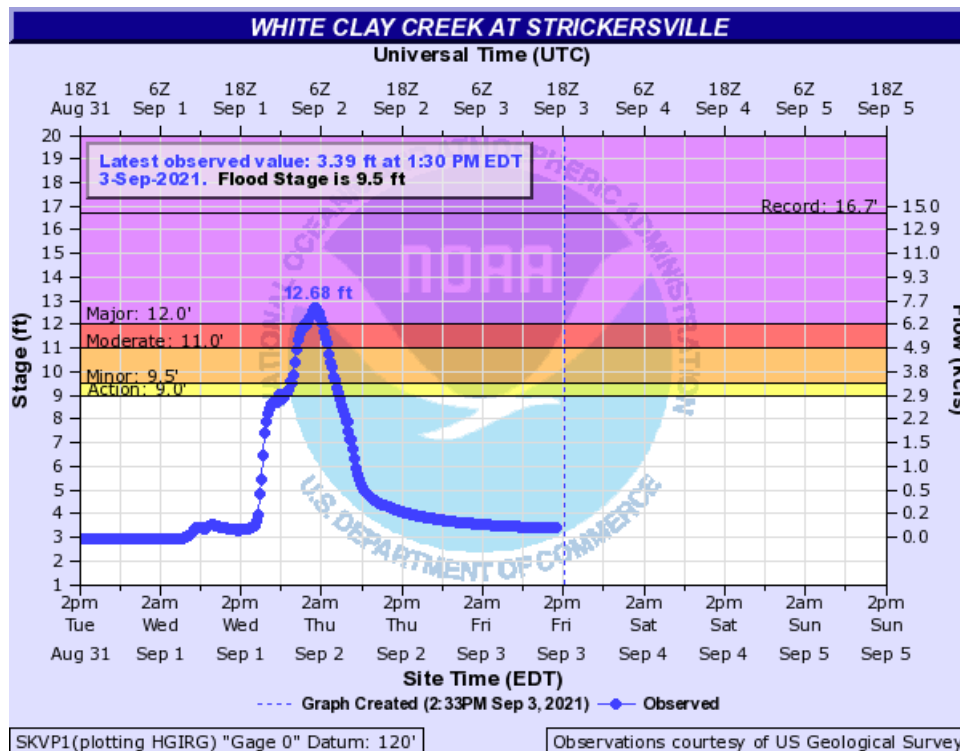


Brandywine Creek at Chadds Ford, Major Flood Stage, Peak 21.04 feet.

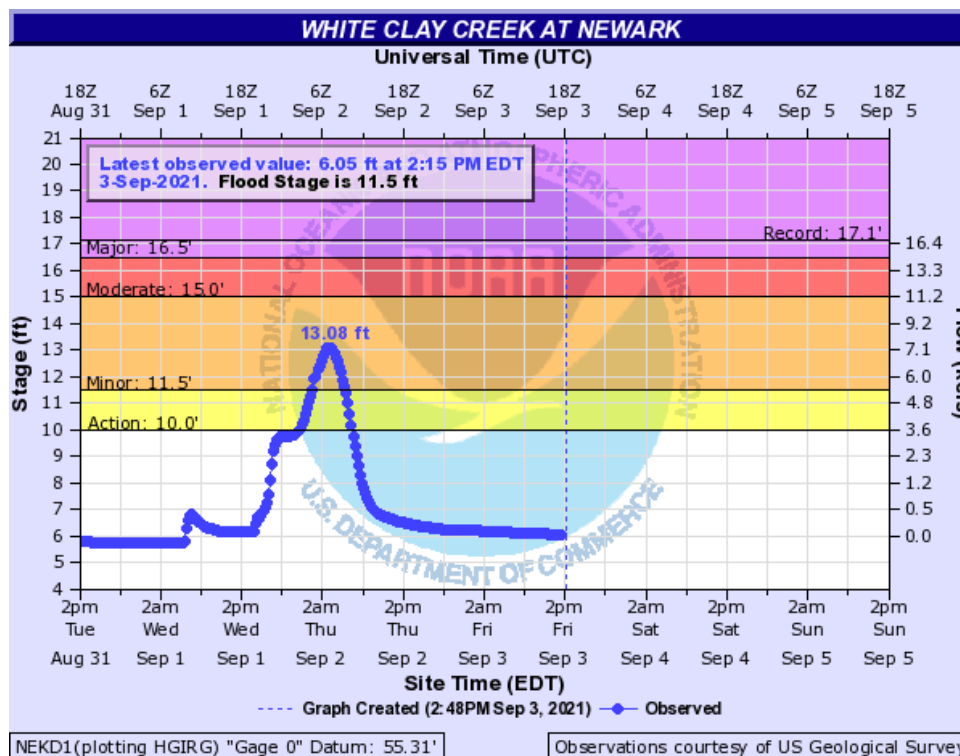


Brandywine Creek at Wilmington, Major Flood Stage, Peak 23.14 feet.

Annual Hydrologic Conditions Report

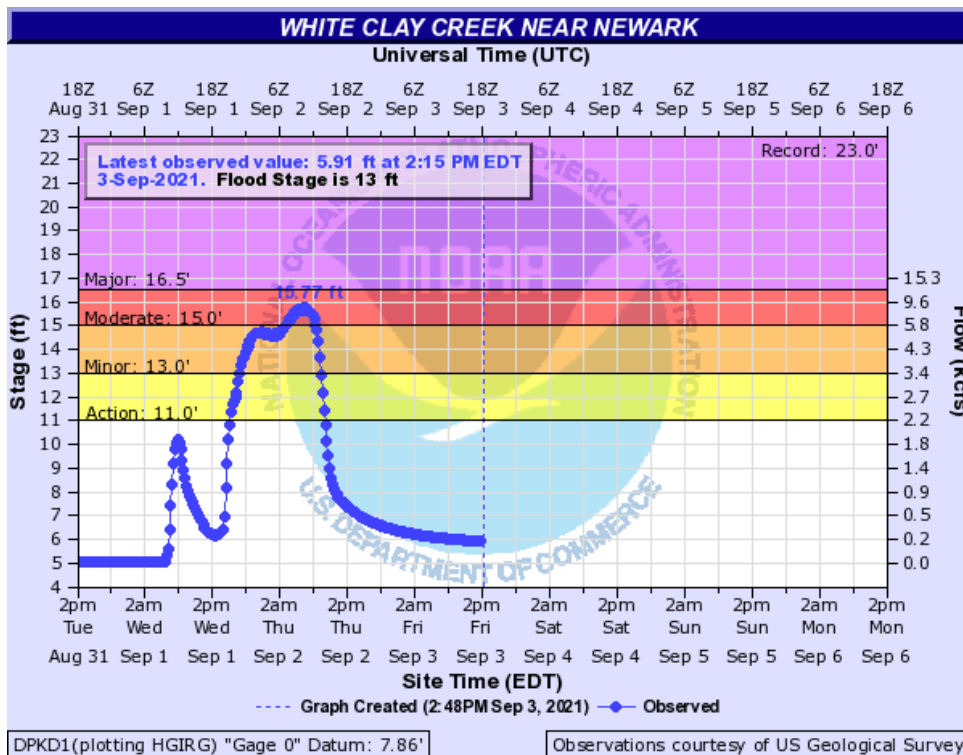


White Clay Creek at Strickersville, Major Flood Stage, Peak 12.68 feet.

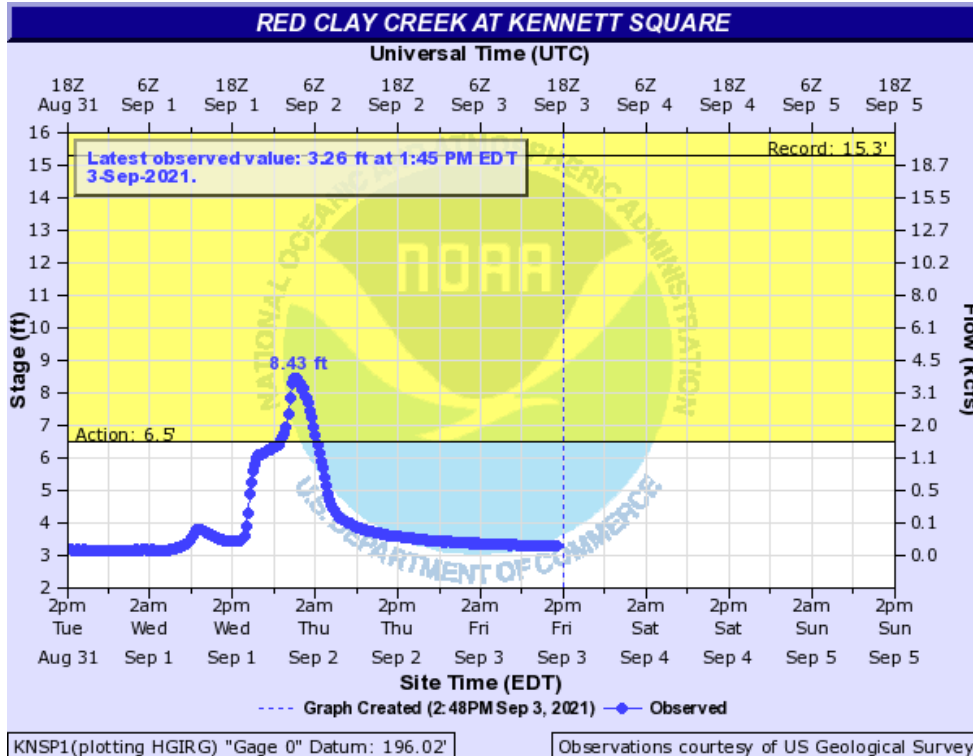


White Clay Creek at Newark, Minor Flood Stage, Peak 13.08 feet.

Annual Hydrologic Conditions Report

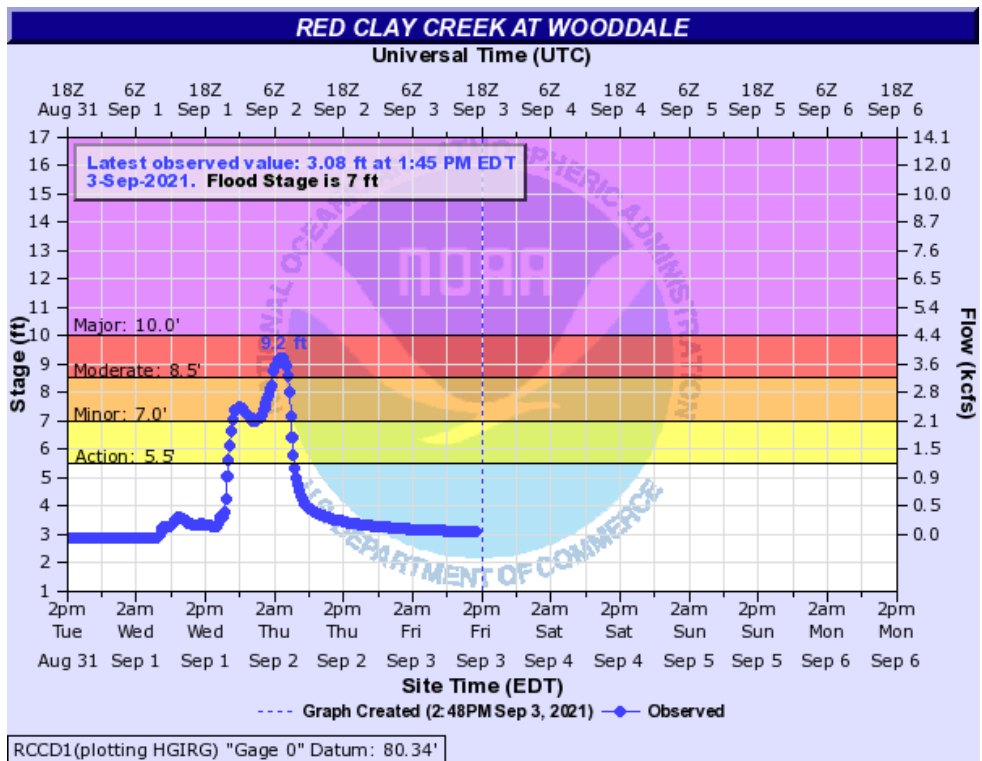


White Clay Creek near Newark, Moderate Flood Stage, Peak 15.77 feet.

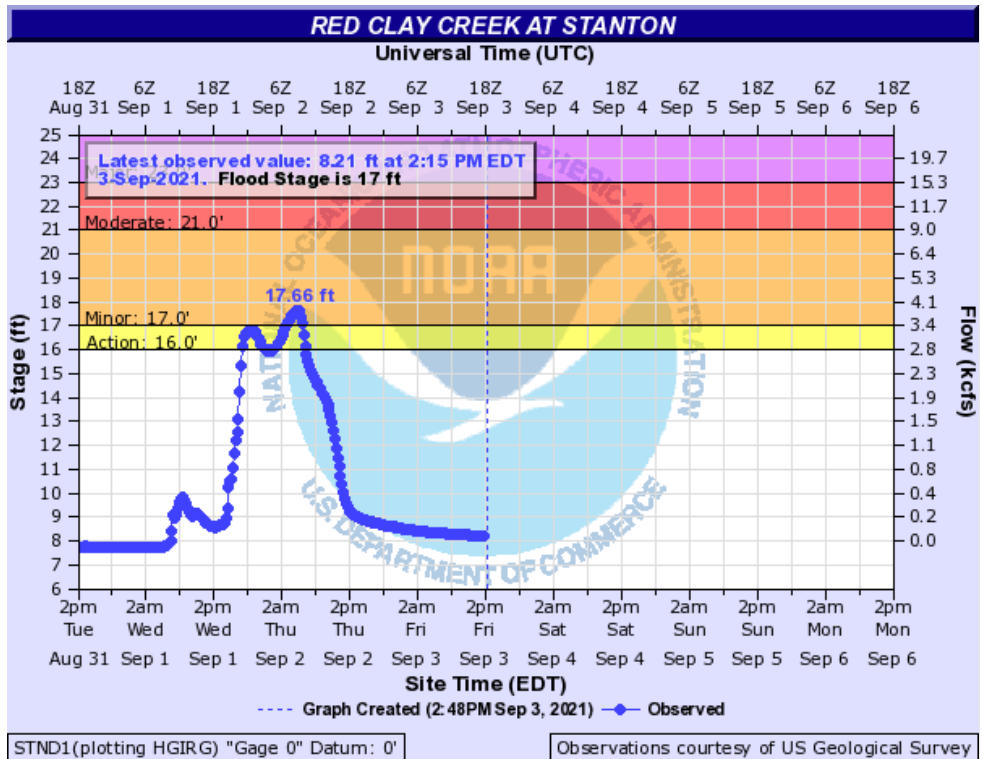


Red Clay Creek near Kennett Square, Action Stage, Peak 8.43 feet.

Annual Hydrologic Conditions Report

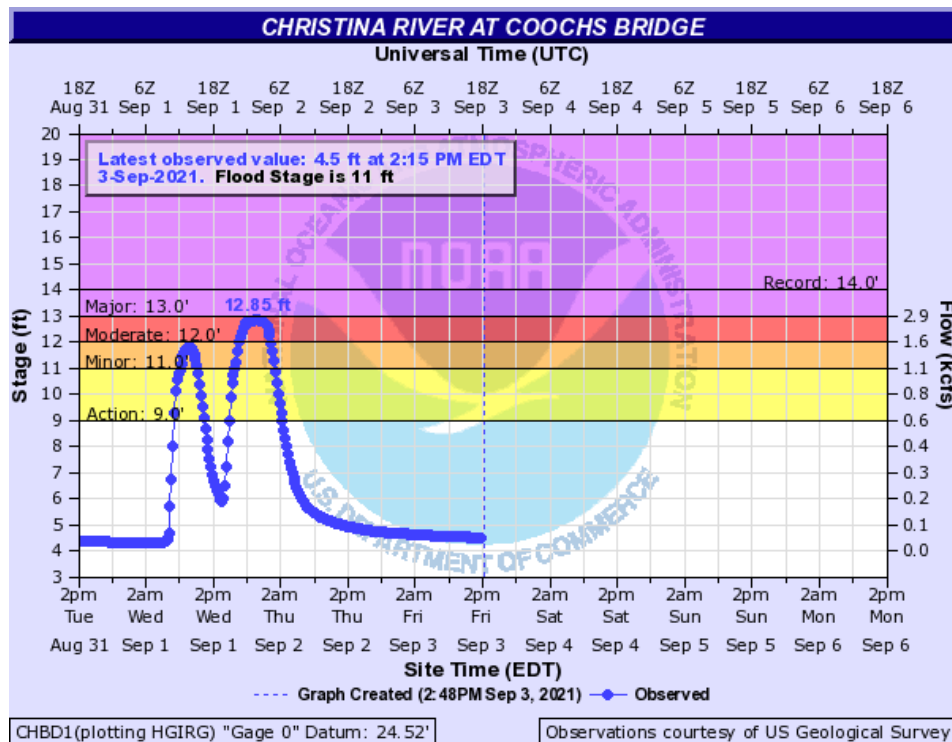


Red Clay Creek at Wooddale, Moderate Flood Stage, Peak 9.2 feet.

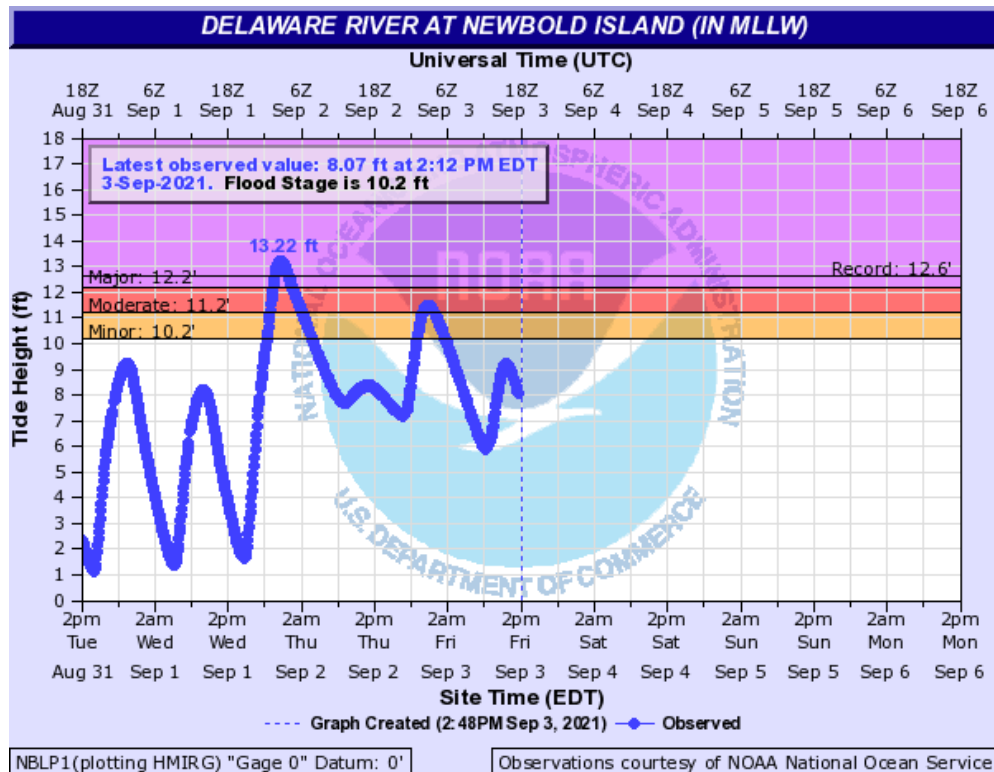


Red Clay Creek at Stanton, Minor Flood Stage, Peak 17.66

Annual Hydrologic Conditions Report

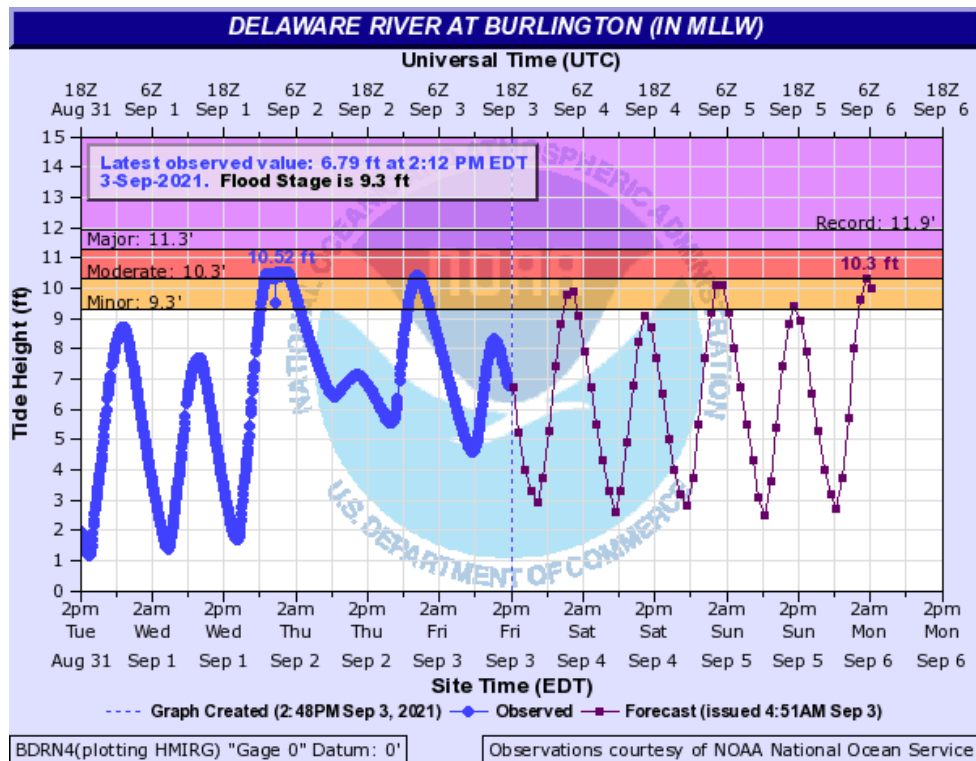


Christina River at Coochs Bridge, Moderate Flood Stage, Peak 12.85 feet.

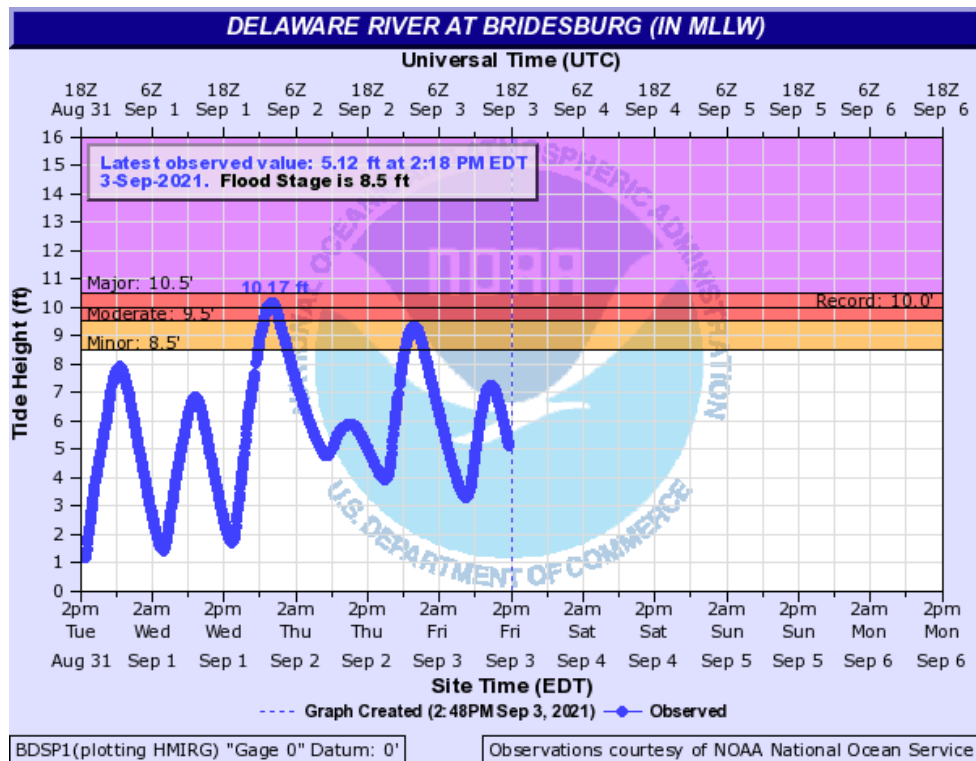


Delaware River at Newbold Island, Major Flood Stage, Peak 13.22 feet.

Annual Hydrologic Conditions Report

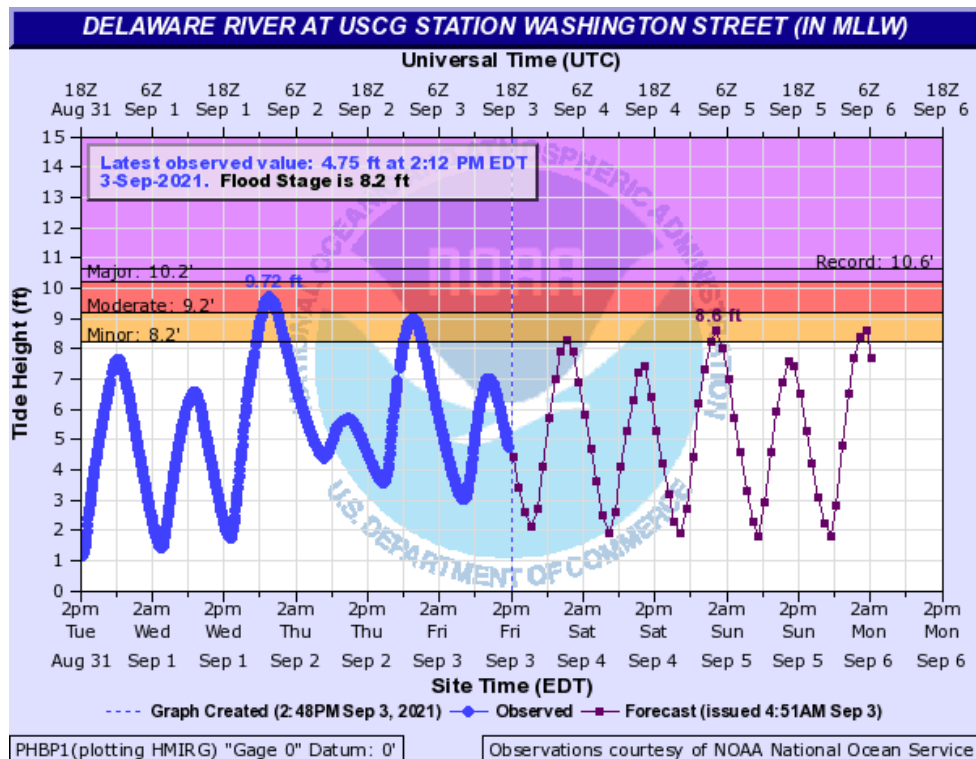


Delaware River at Burlington, Moderate Flood Stage, Peak 10.52 feet.

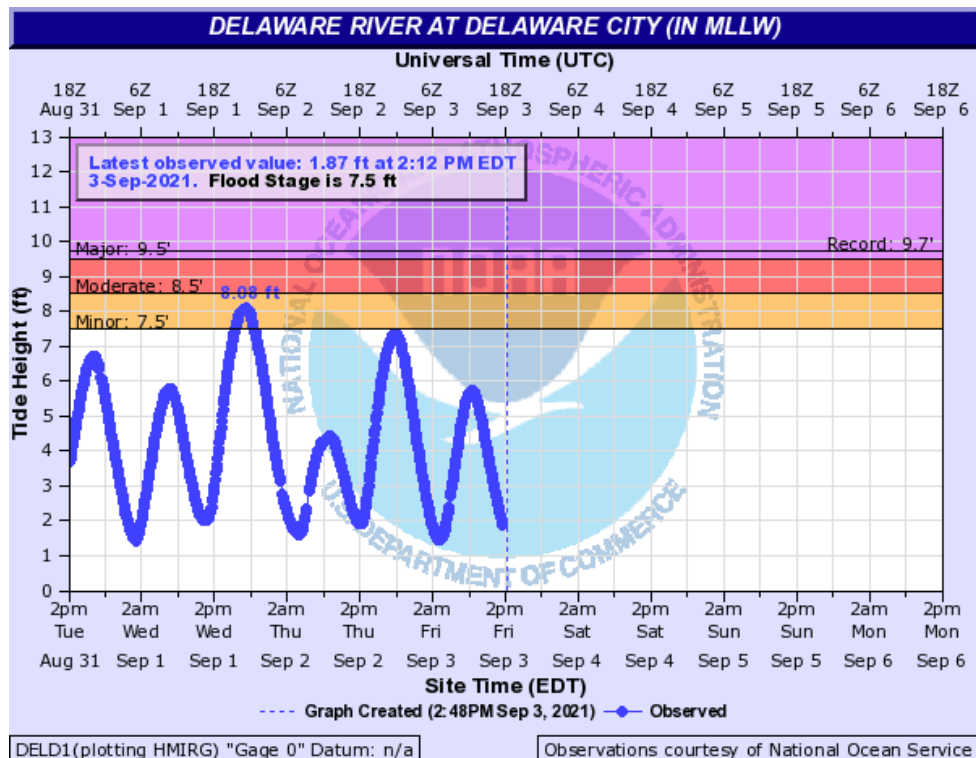


Delaware River at Bridesburg, Moderate Flood Stage, Peak 10.17 feet.

Annual Hydrologic Conditions Report

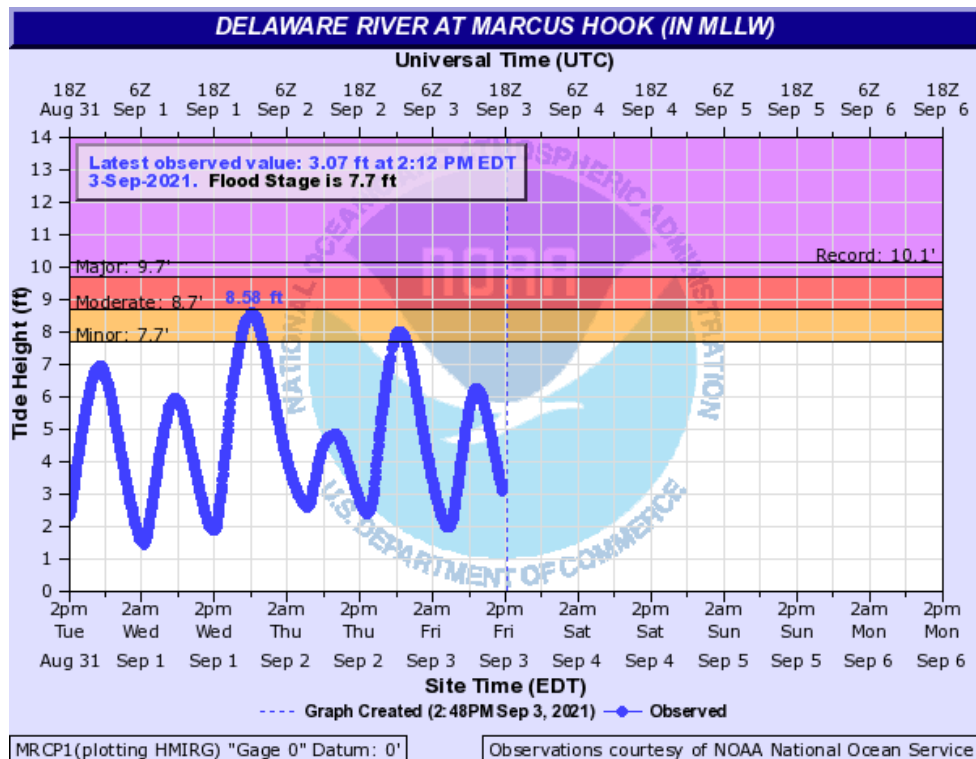


Delaware River at USCG Station Washington Street, Moderate Flood Stage, Peak 9.72 feet.

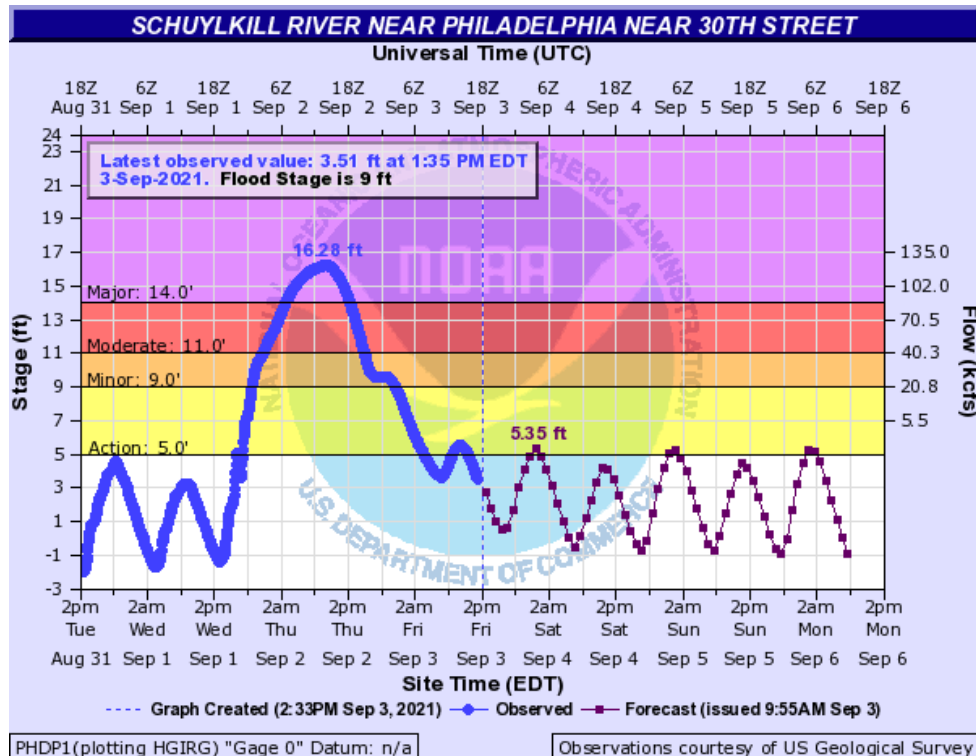


Delaware River at Delaware City, Minor Flood Stage, Peak 8.08 feet.

Annual Hydrologic Conditions Report

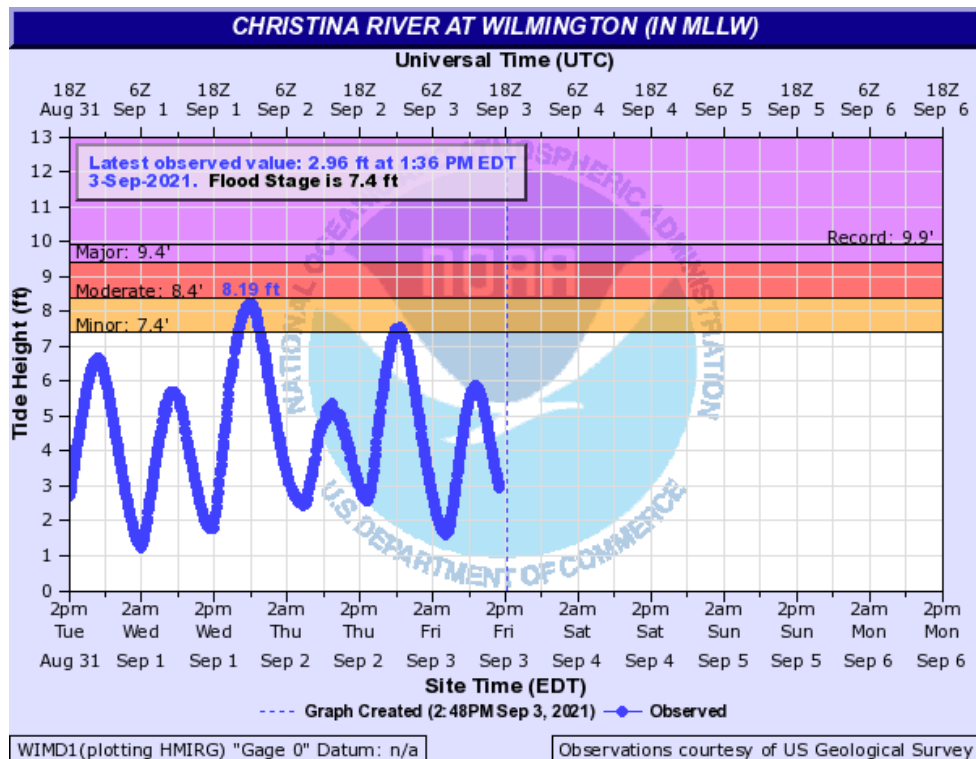


Delaware River at Marcus Hook, Minor Flood Stage, Peak 8.58 feet.

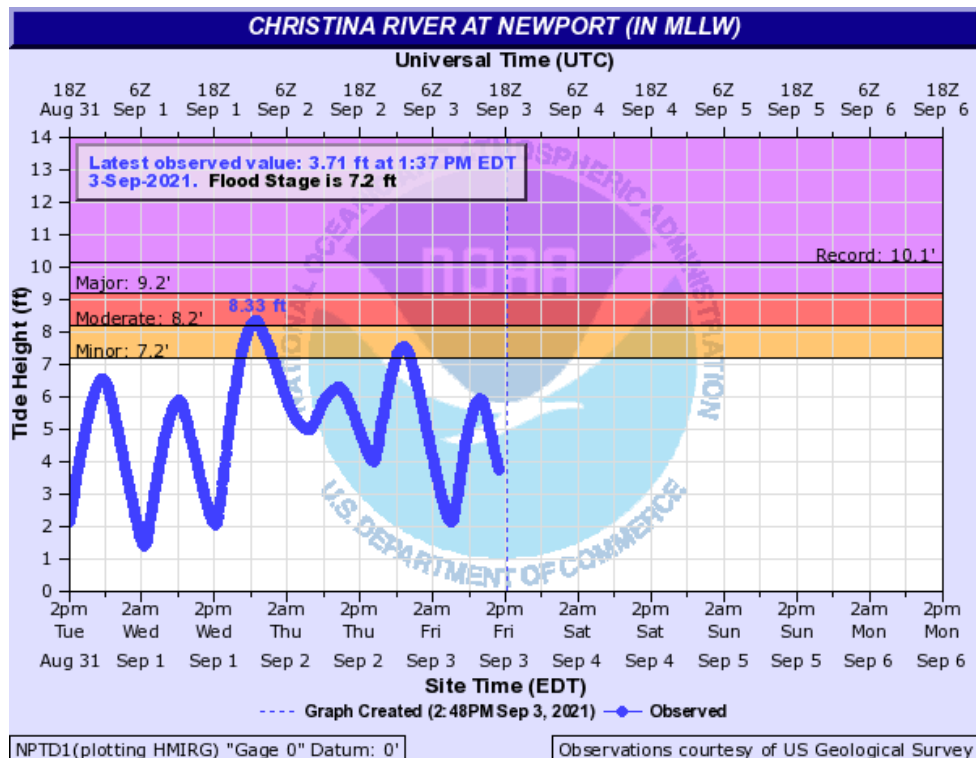


Schuylkill River near Philadelphia near 30th Street, Major Flood Stage, Peak 16.28 feet.

Annual Hydrologic Conditions Report



Christina River at Wilmington, Minor Flood Stage, Peak 8.19 feet.



Christina River at Newport, Moderate Flood Stage, Peak 8.33 feet.

Annual Hydrologic Conditions Report

For official information on the storm, please visit the National Hurricane Center at www.nhc.noaa.gov.

For official information on impacts to the Delaware River Basin, please visit the National Weather Service Mt. Holly website at <https://www.weather.gov/phi/> and the Mid-Atlantic River Forecast Center website at <https://www.weather.gov/marfc/>

APPENDIX E: HYDROGRAPHS FOR THE OCTOBER NOR'EASTER

Hydrographs for the October 26 – October 30 Nor'Easter storm.

Table A1: Flood Locations and Crests (Peak Stage)

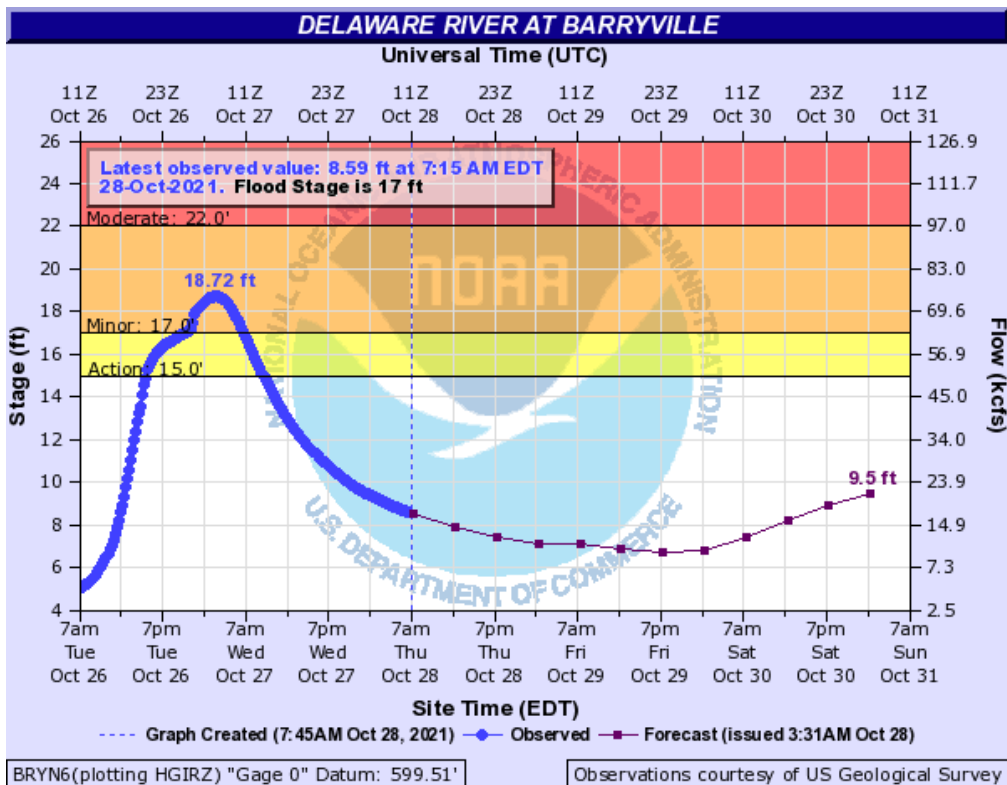
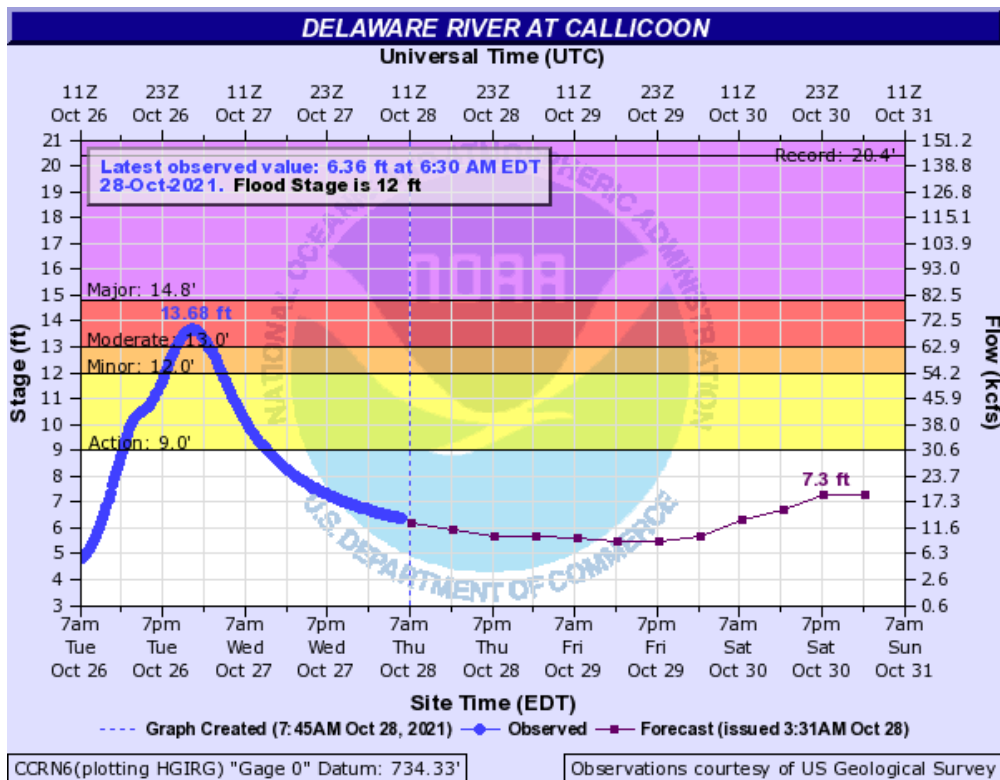
Location	Water Body Type	Peak Stage	Flood Type
Delaware River at Callicoon	Main Stem	13.68	Moderate
Delaware River at Barryville	Main Stem	18.72	Minor
Delaware River at Tocks Island	Main Stem	22.17	Minor
Delaware River at Riegelsville	Main Stem	21.42	Action
Delaware River at Easton	Main Stem	21.49	Action
Delaware River at Frenchtown	Main Stem	14.32	Action
Delaware River at Washington Crossing	Main Stem	13.05	Action
Delaware River at Trenton	Main Stem	17.92	Action
West Branch Delaware River above Delhi	Stream	7.01	Action
West Branch Delaware River at Walton	Stream	9.51	Minor
West Branch Delaware River at Hale Eddy	Stream	9.24	Action
Bushkill Near Arkville	Stream	8.98	Action
Dry Brook at Arkville	Stream	9.71	Action
Beaverkill at Cooks Falls	Stream	13.78	Minor
East Branch Delaware River at Margaretville	Stream	11.25	Minor
East Branch Delaware River at Harvard	Stream	8.06	Action
East Branch Delaware River at Fishs Eddy	Stream	13.15	Minor
Callicoon Creek above Callicoon	Stream	8.24	Moderate
Lackawaxen River near Aldenville	Stream	7.41	Minor
Dyberry Creek near Honesdale	Stream	6.96	Action

Annual Hydrologic Conditions Report

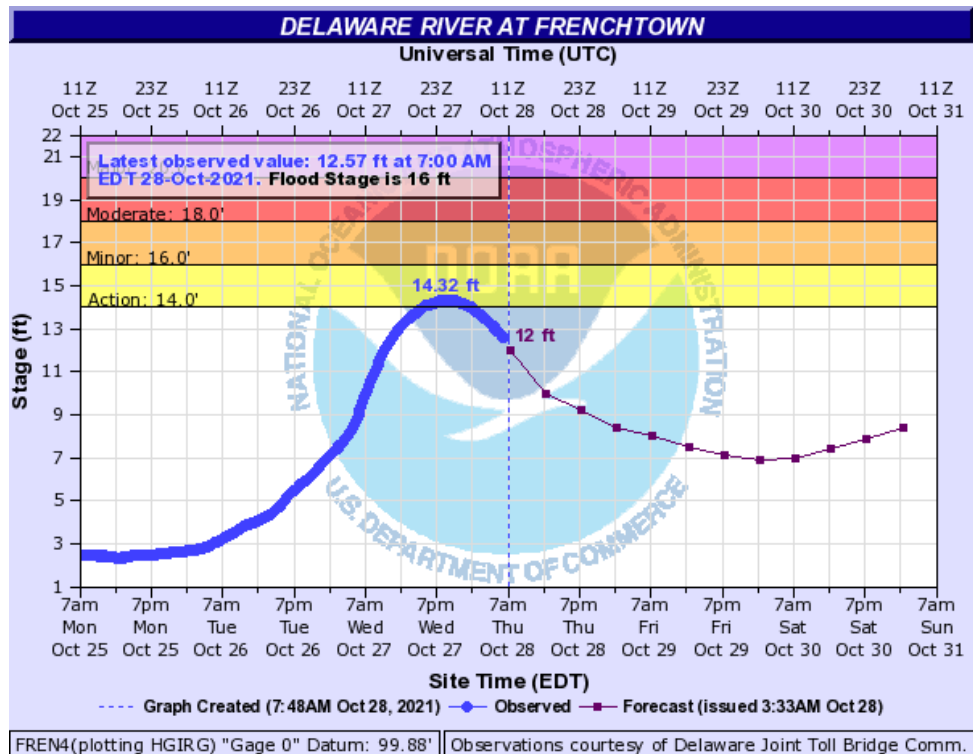
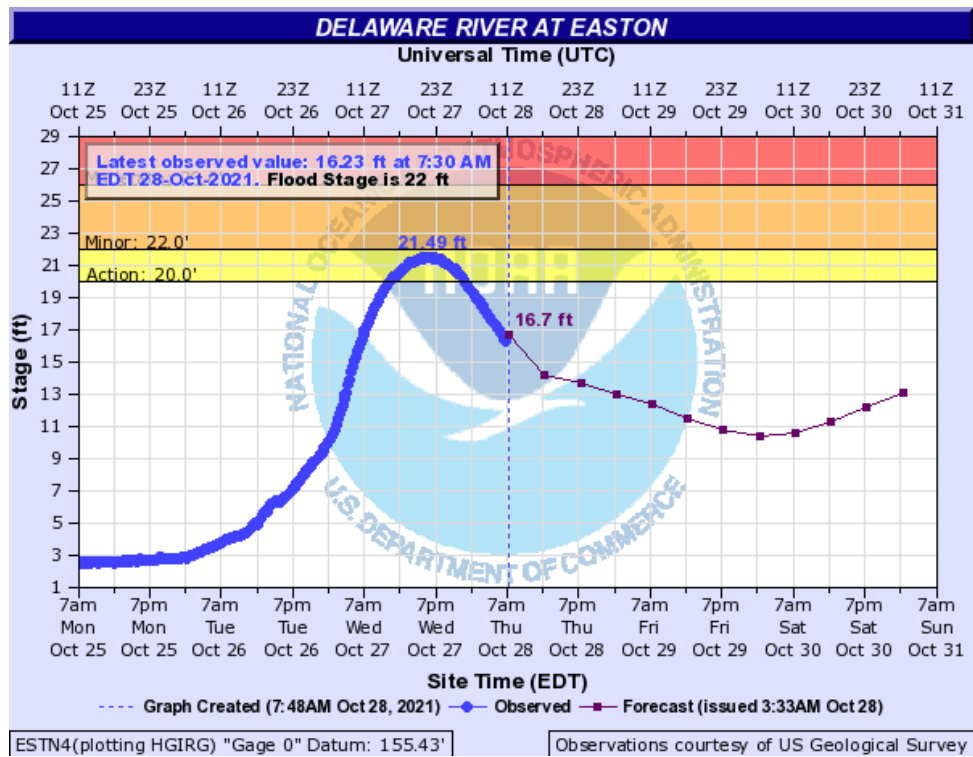
Location	Water Body Type	Peak Stage	Flood Type
Lackawaxen River at Hawley	Stream	10.93	Action
Brodhead Creek at Minisink Hills	Stream	9.47	Action
East Branch Brandywine Creek below Downingtown	Stream	6.17	Action
Delaware River at Burlington	Tidal	10.56	Moderate
Delaware River at Bridesburg*	Tidal	10.59	Major
Delaware River at Delaware City*	Tidal	9.58	Major
Delaware River at Marcus Hook	Tidal	9.76	Major
Delaware River at Newbold Island	Tidal	11.9	Moderate
Delaware River at USCG Station Washington Street	Tidal	10.4	Major
Schuylkill River near Philadelphia near 30th Street	Tidal	7.52	Action
Christina River at Newport	Tidal	9.62	Major
Christina River at Wilmington	Tidal	9.61	Major

* Indicates that a record has been broken at the location

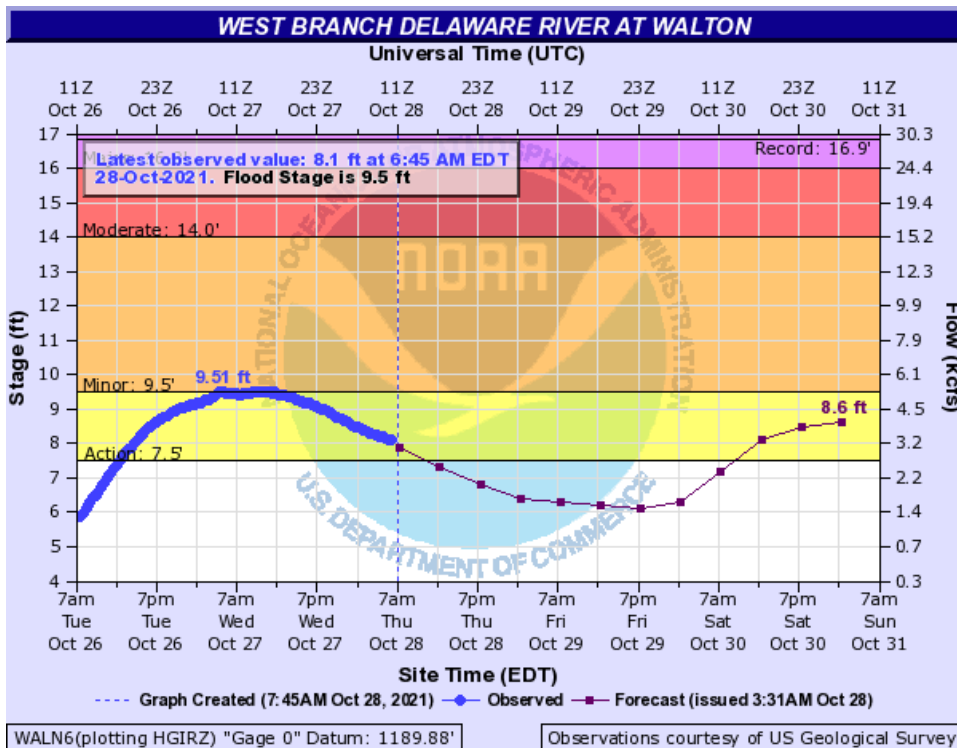
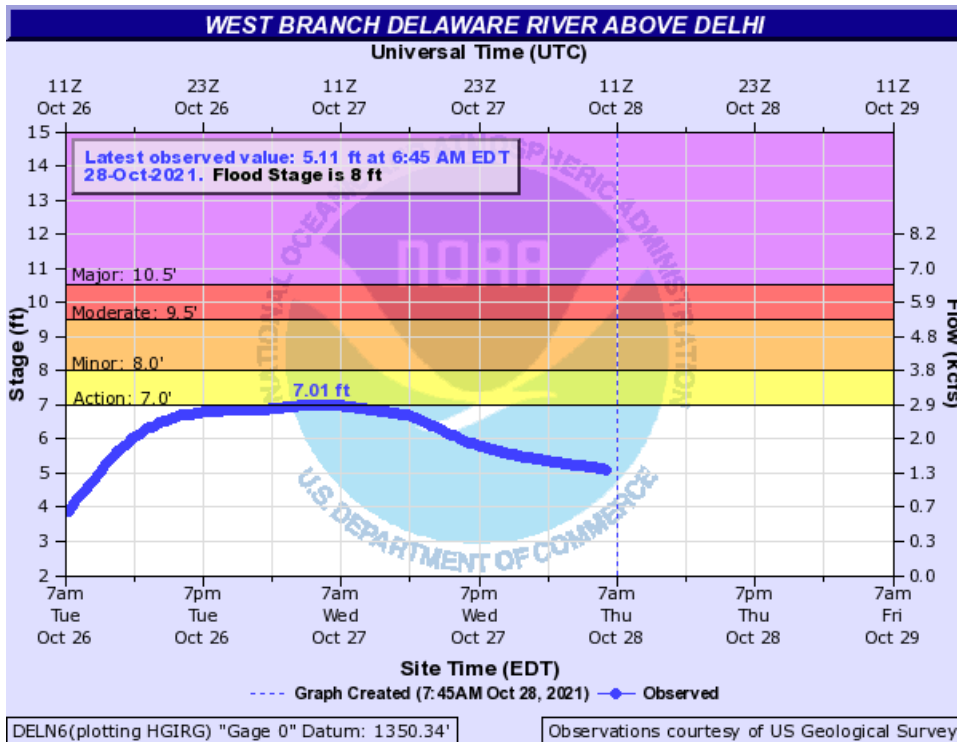
Annual Hydrologic Conditions Report



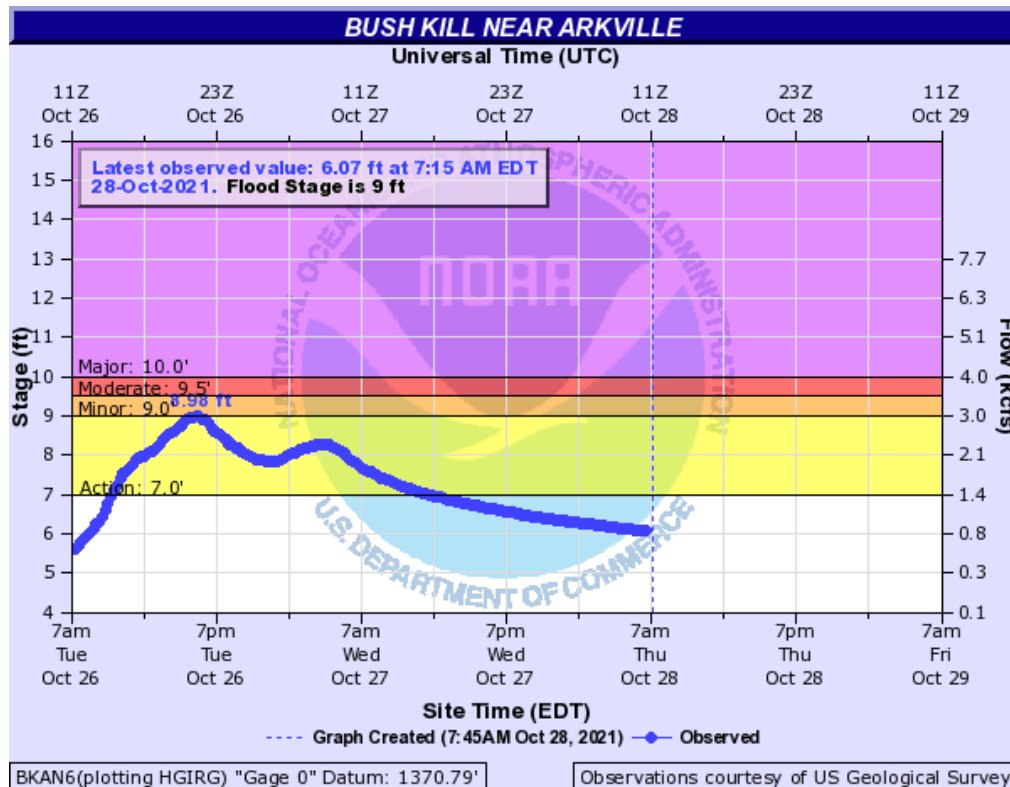
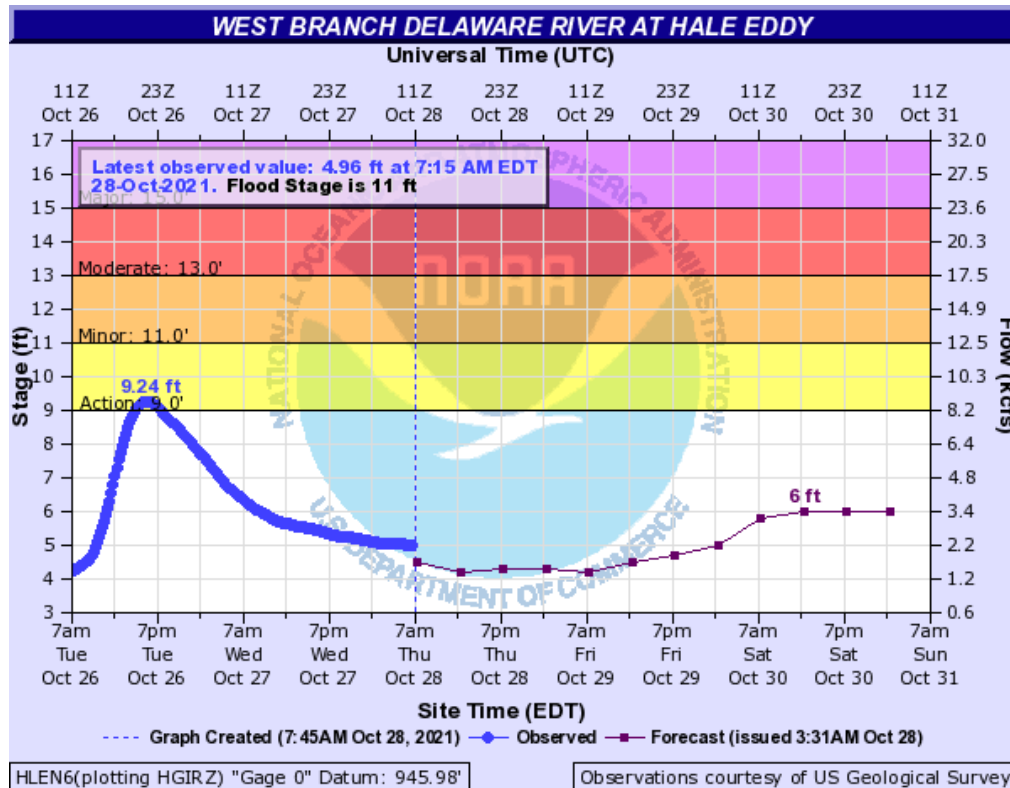
Annual Hydrologic Conditions Report



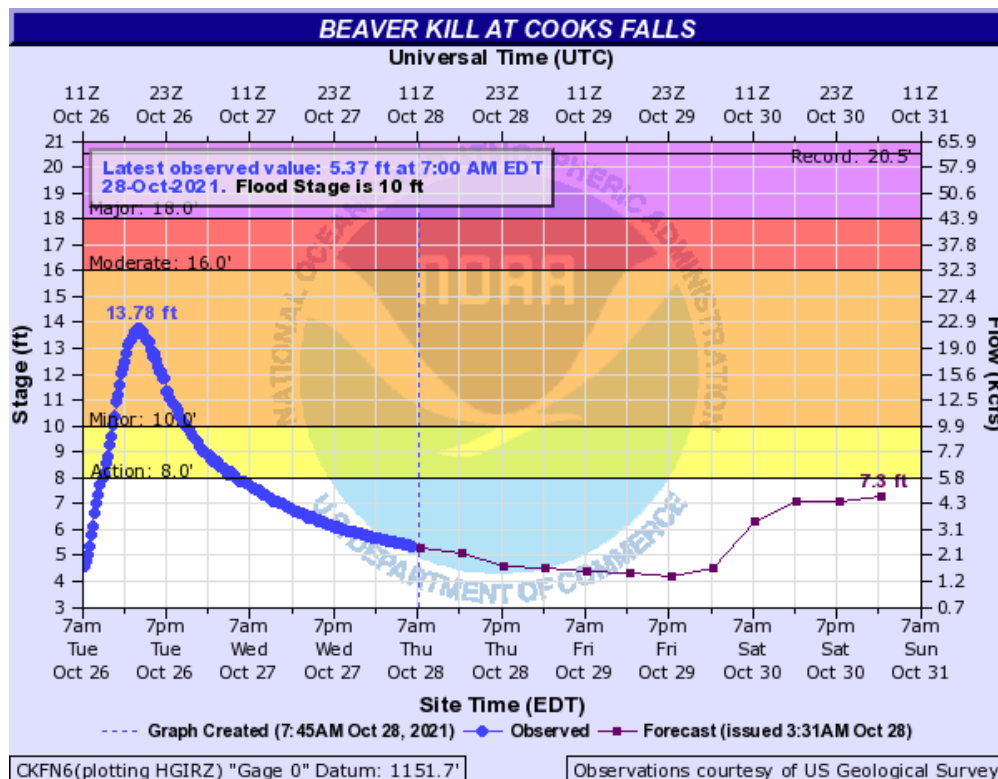
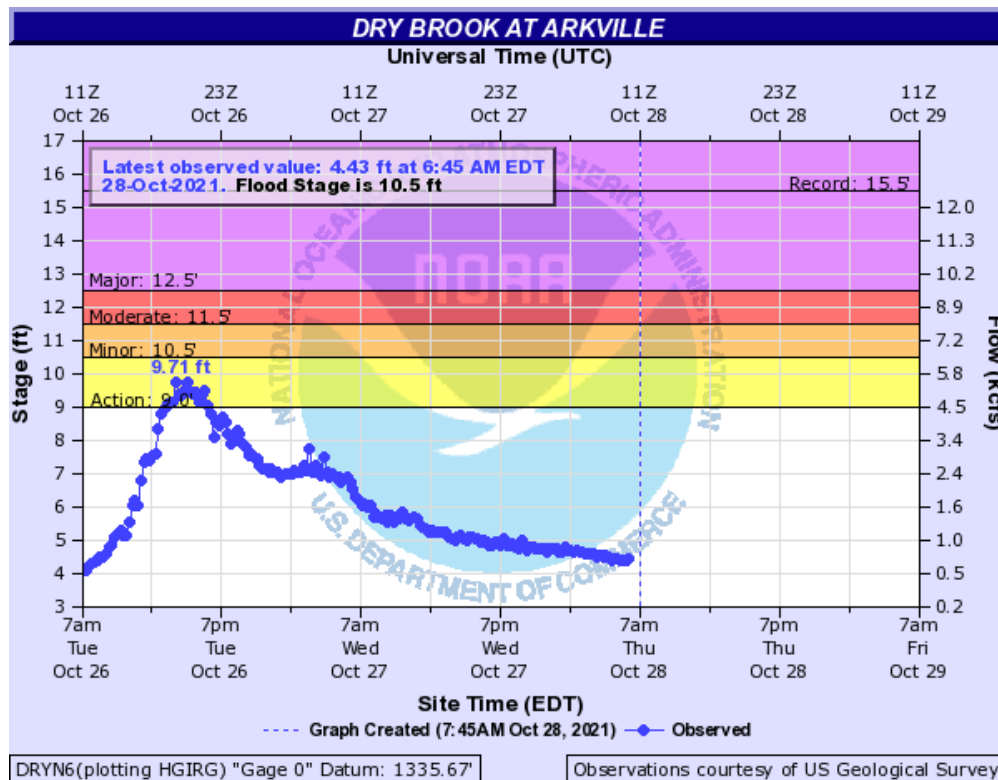
Annual Hydrologic Conditions Report



Annual Hydrologic Conditions Report

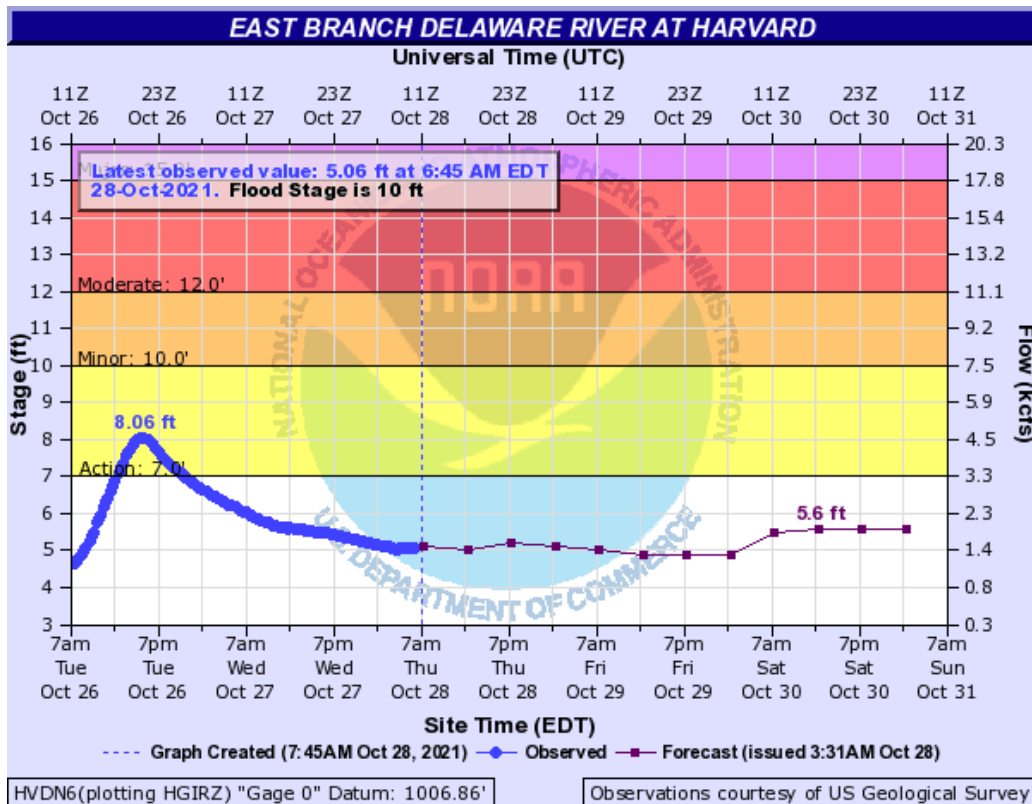
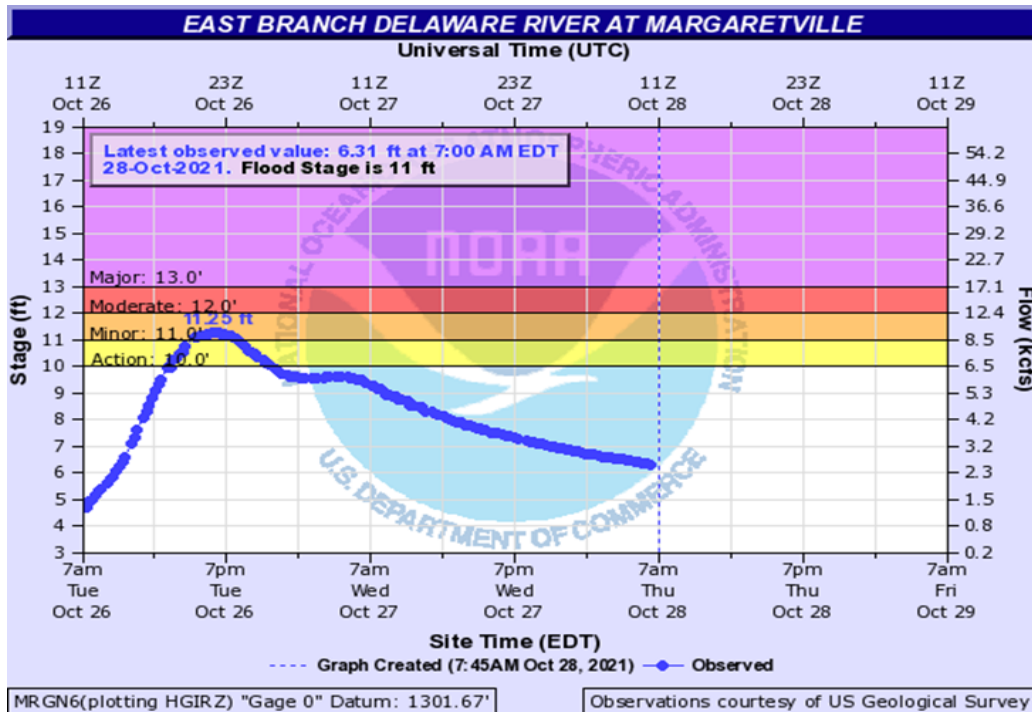


Annual Hydrologic Conditions Report

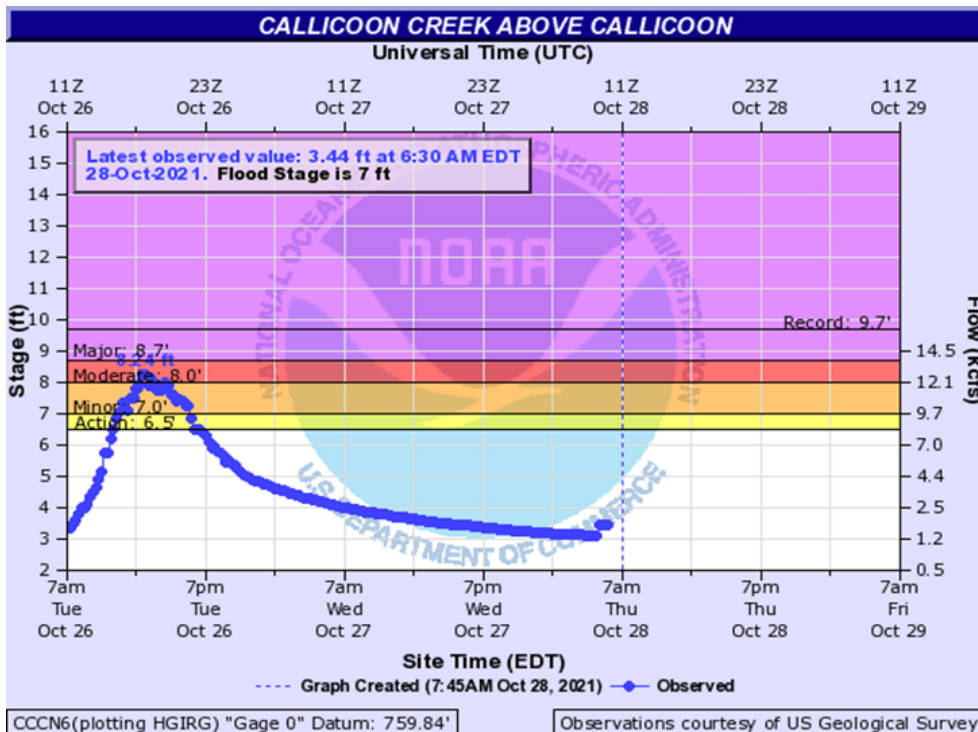
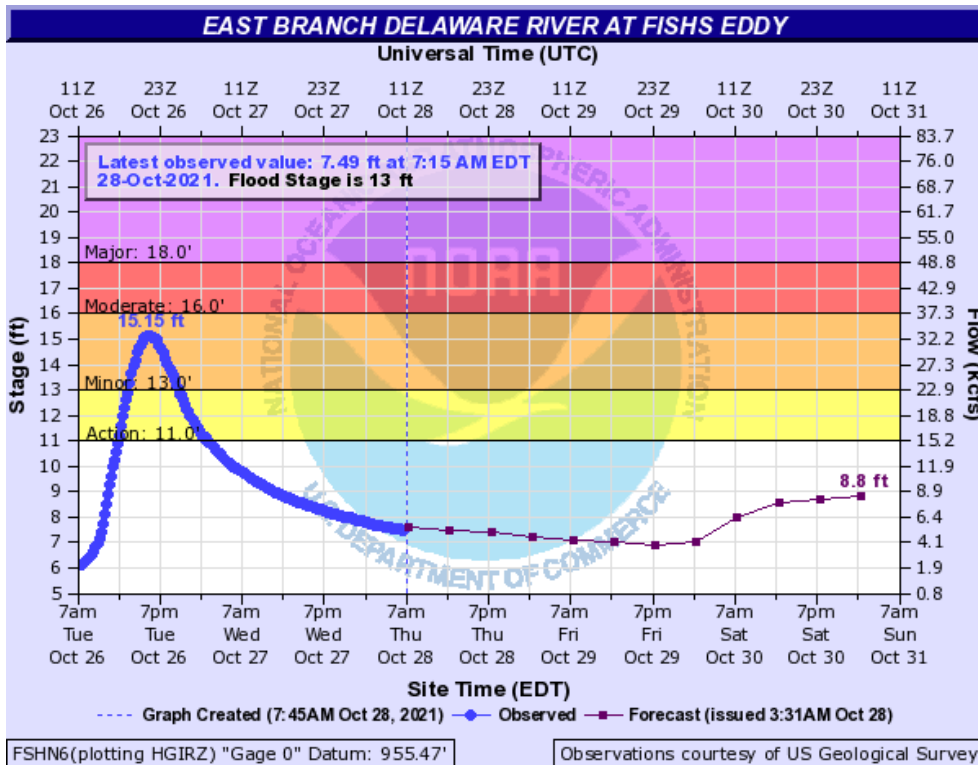




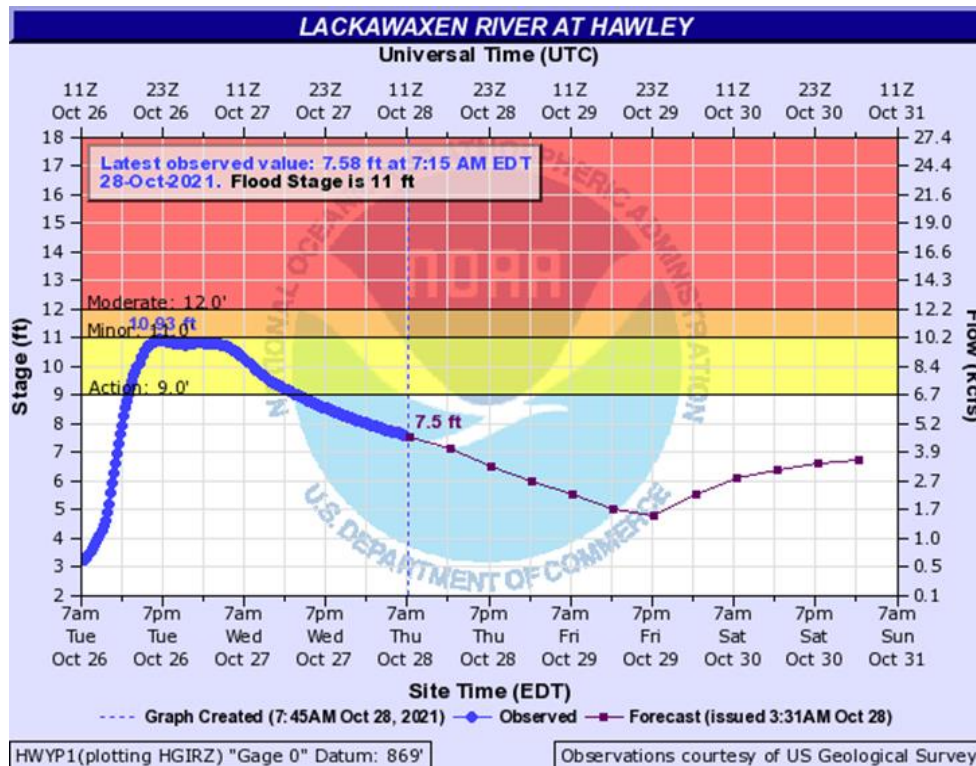
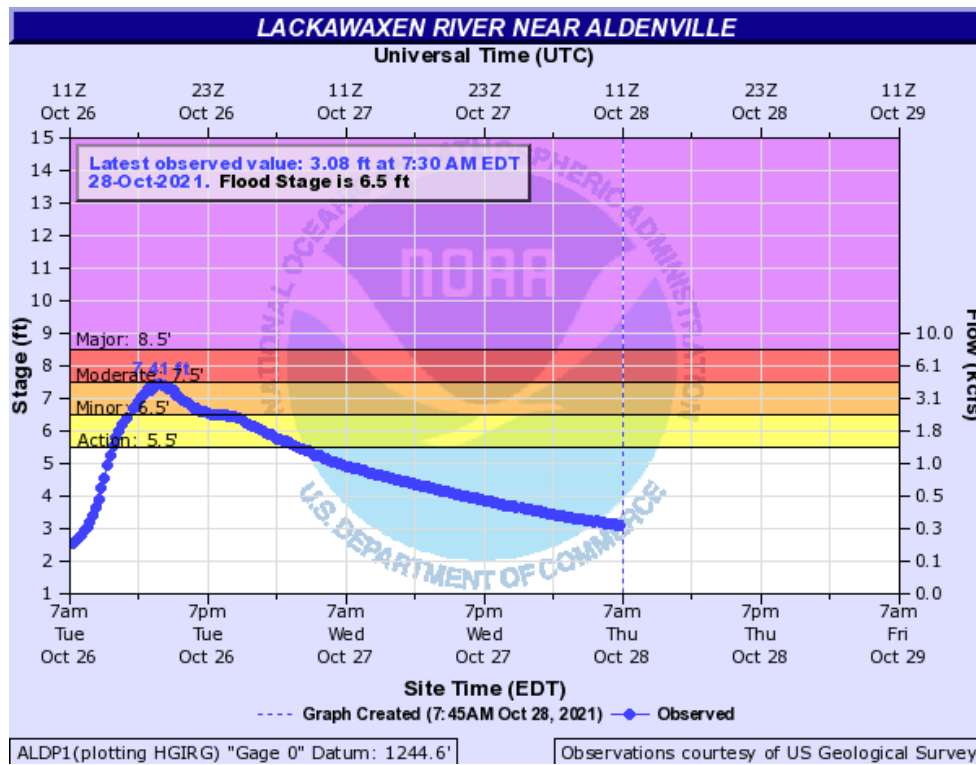
Annual Hydrologic Conditions Report



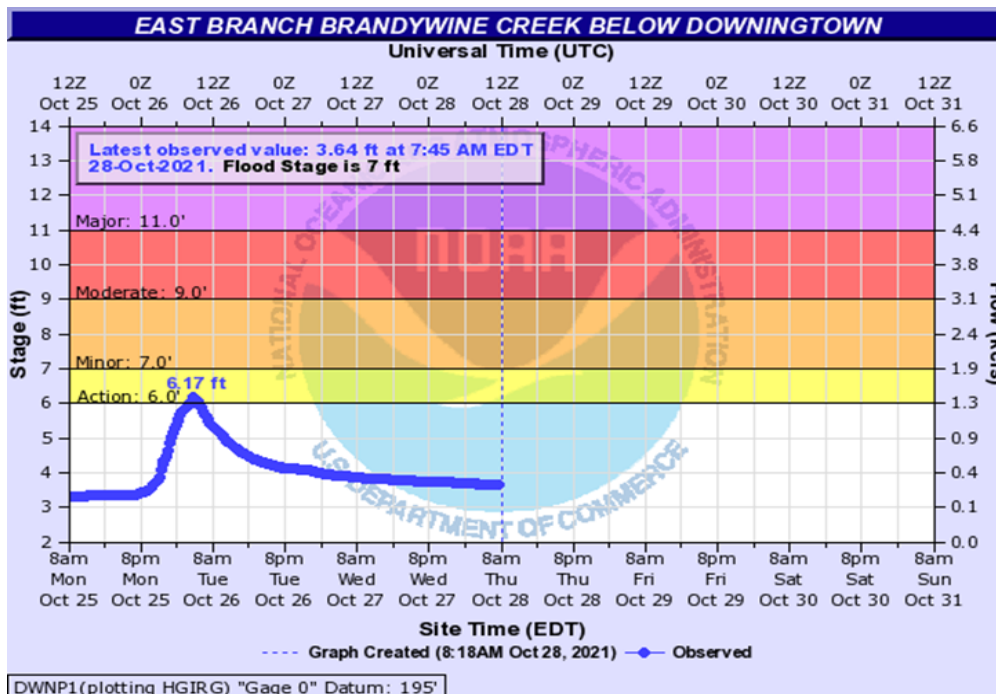
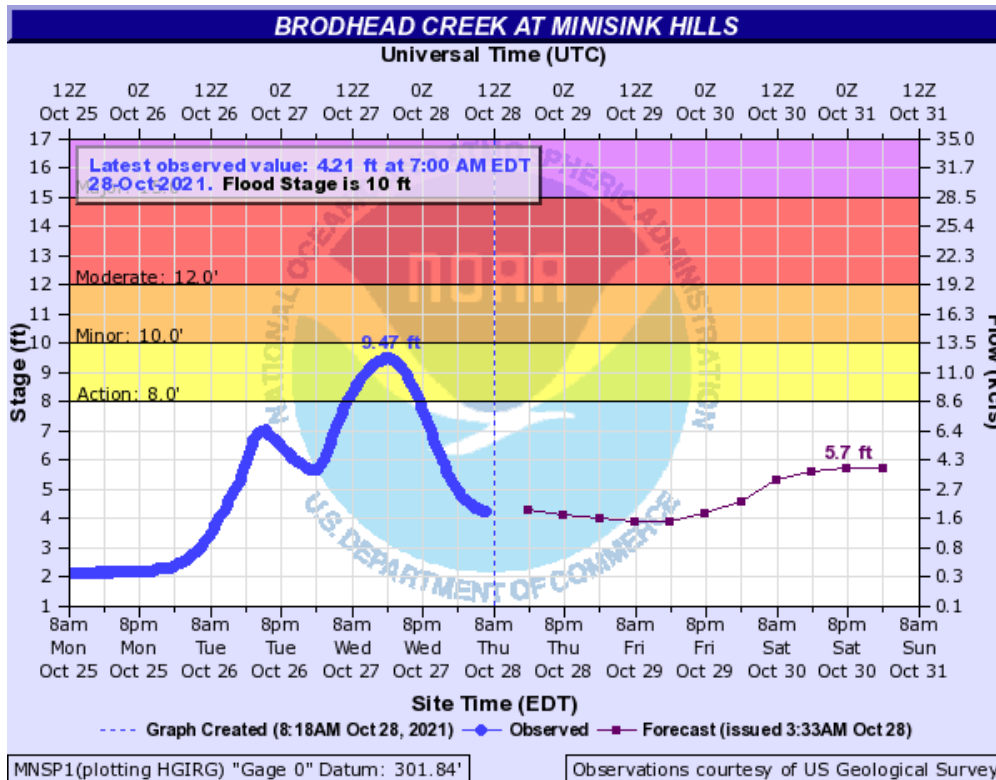
Annual Hydrologic Conditions Report



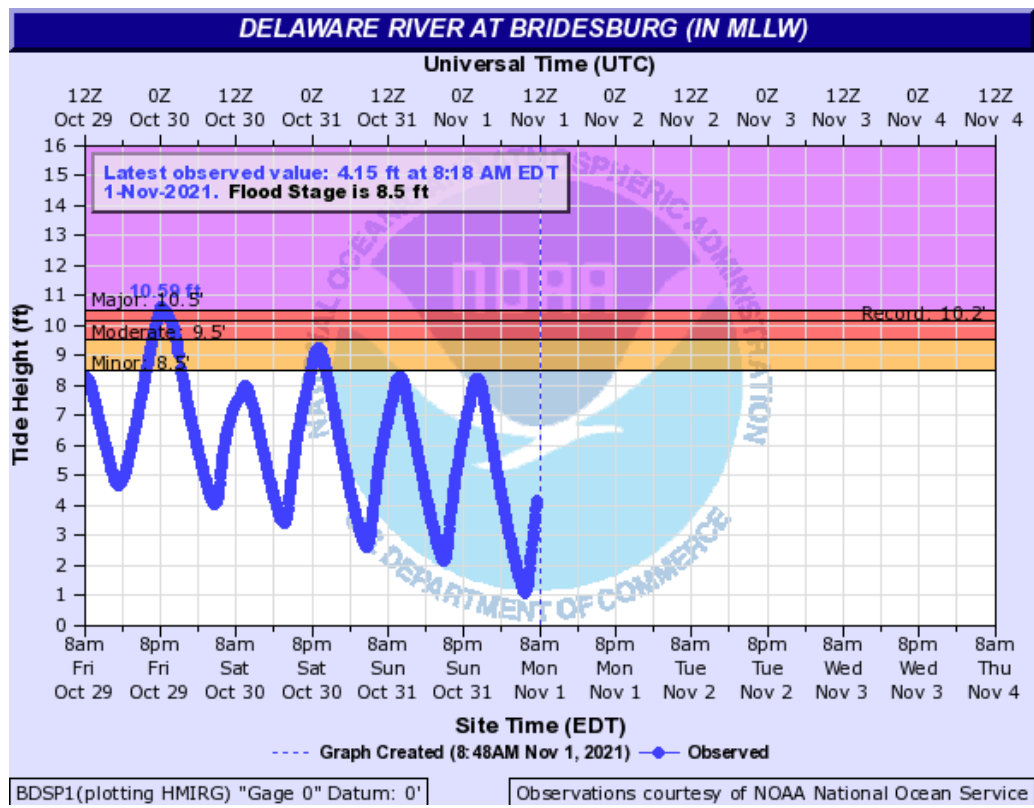
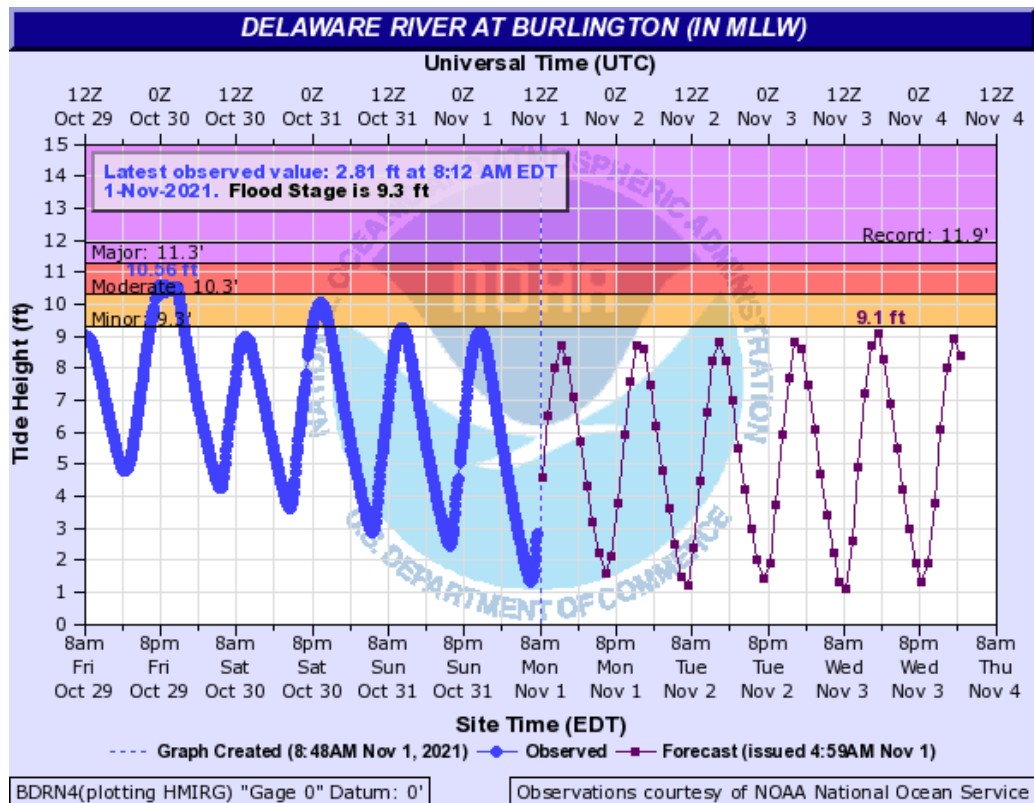
Annual Hydrologic Conditions Report



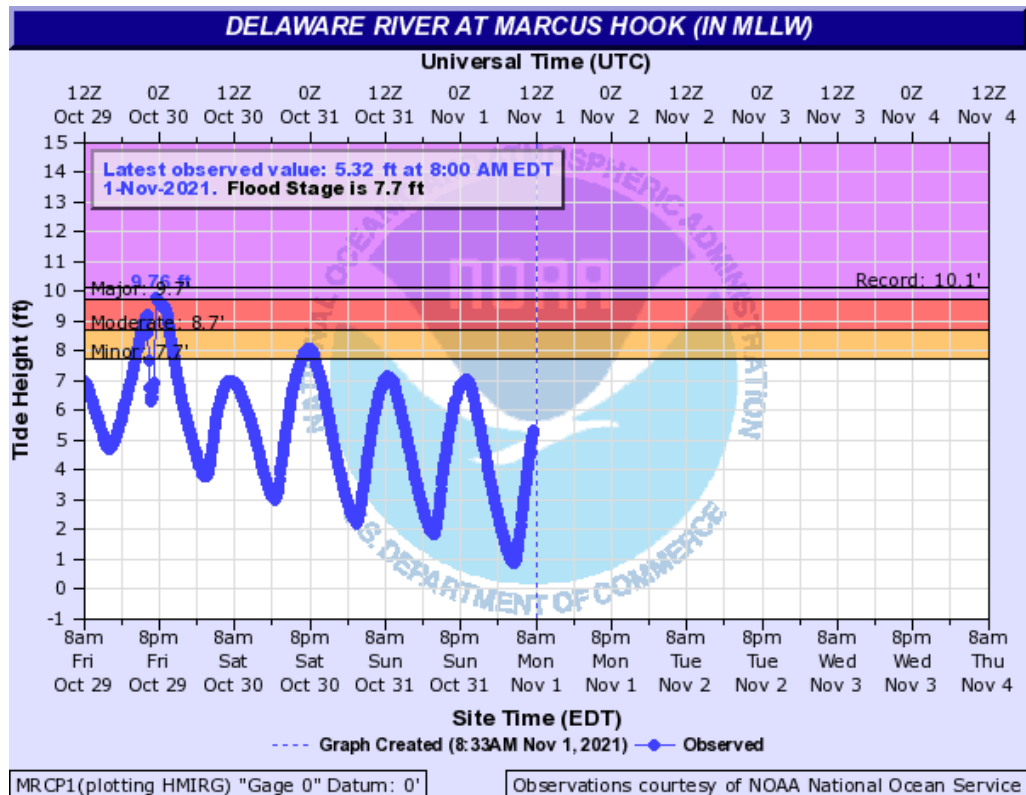
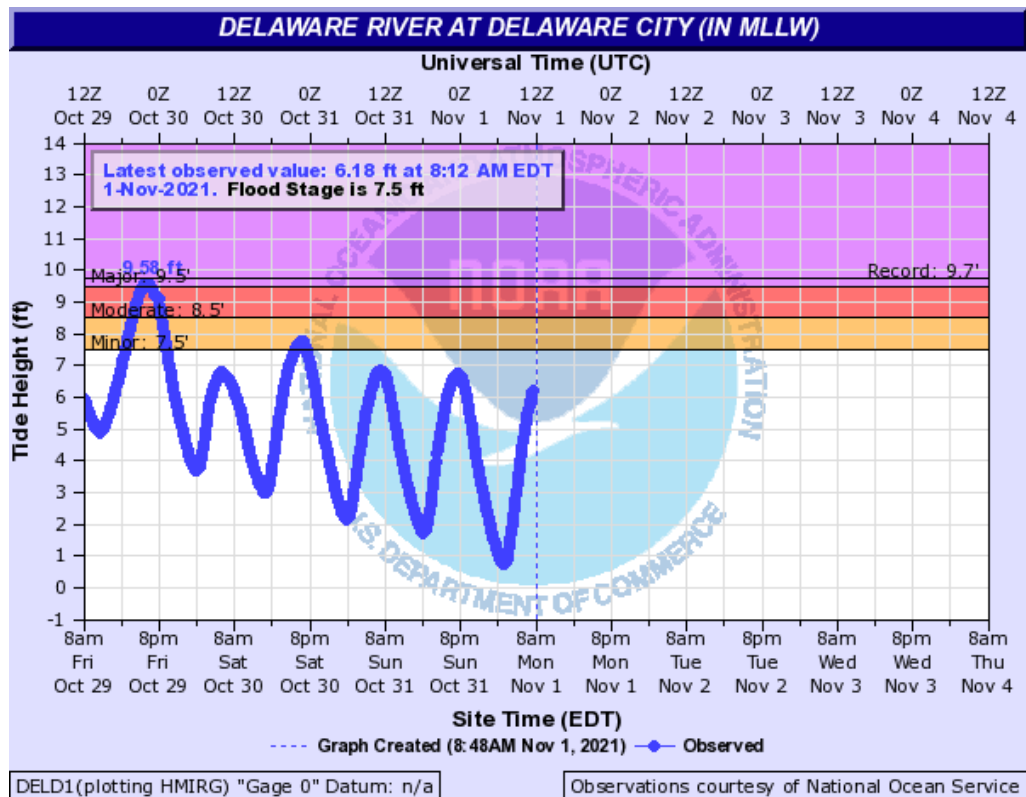
Annual Hydrologic Conditions Report



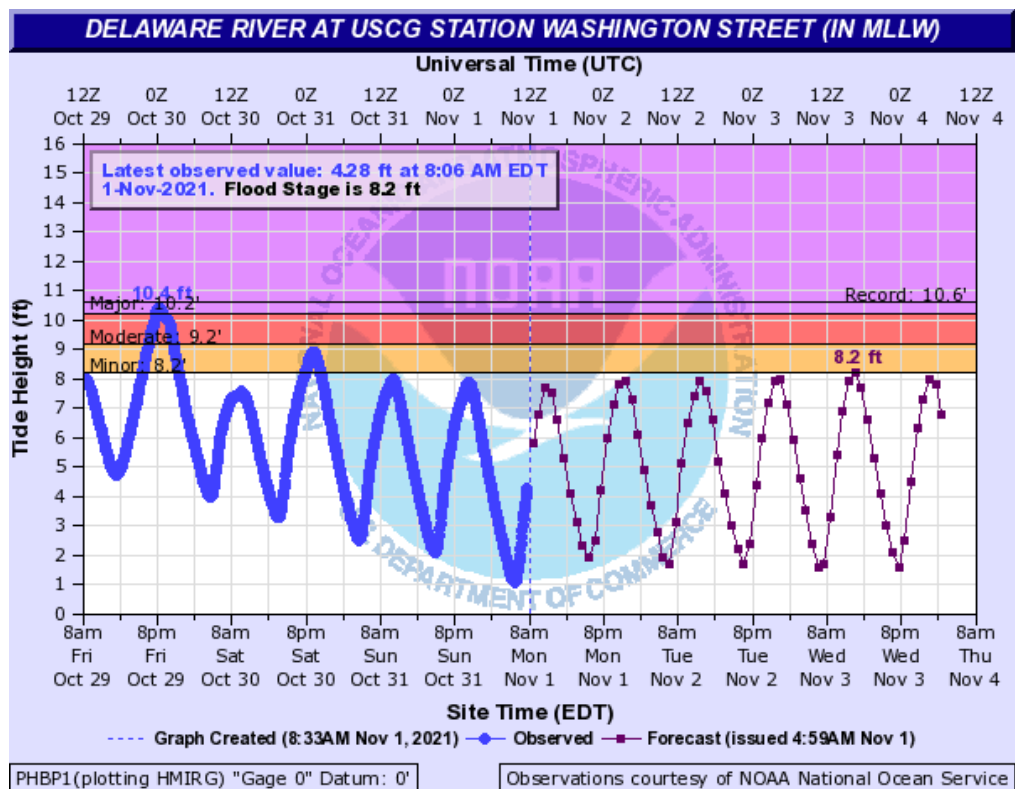
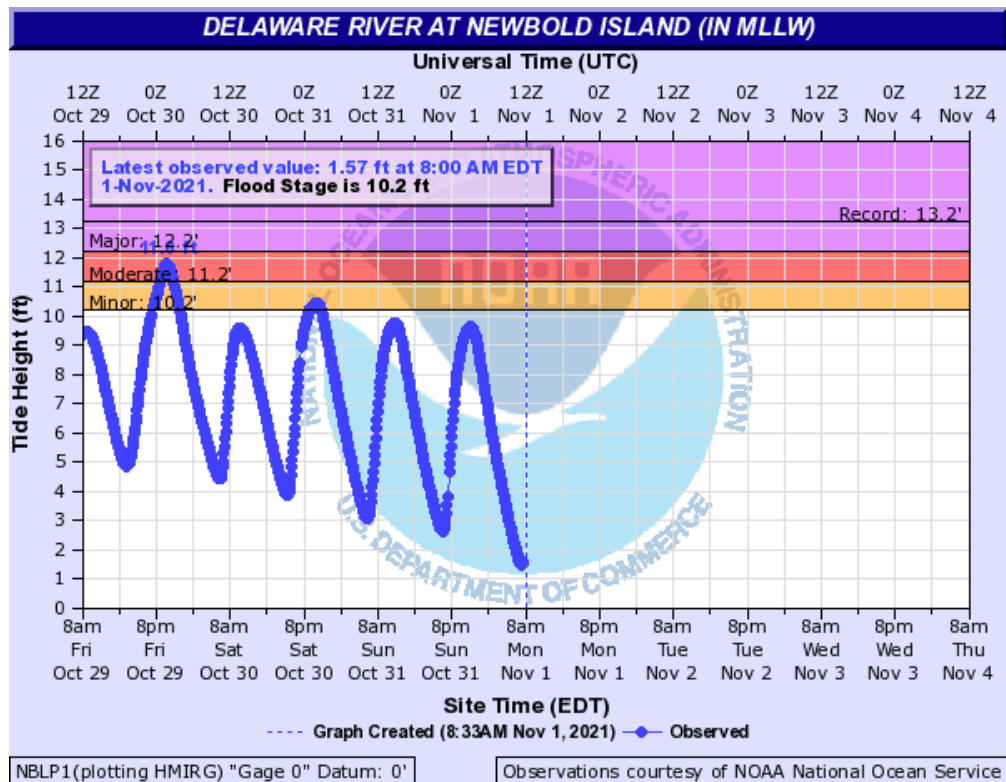
Annual Hydrologic Conditions Report



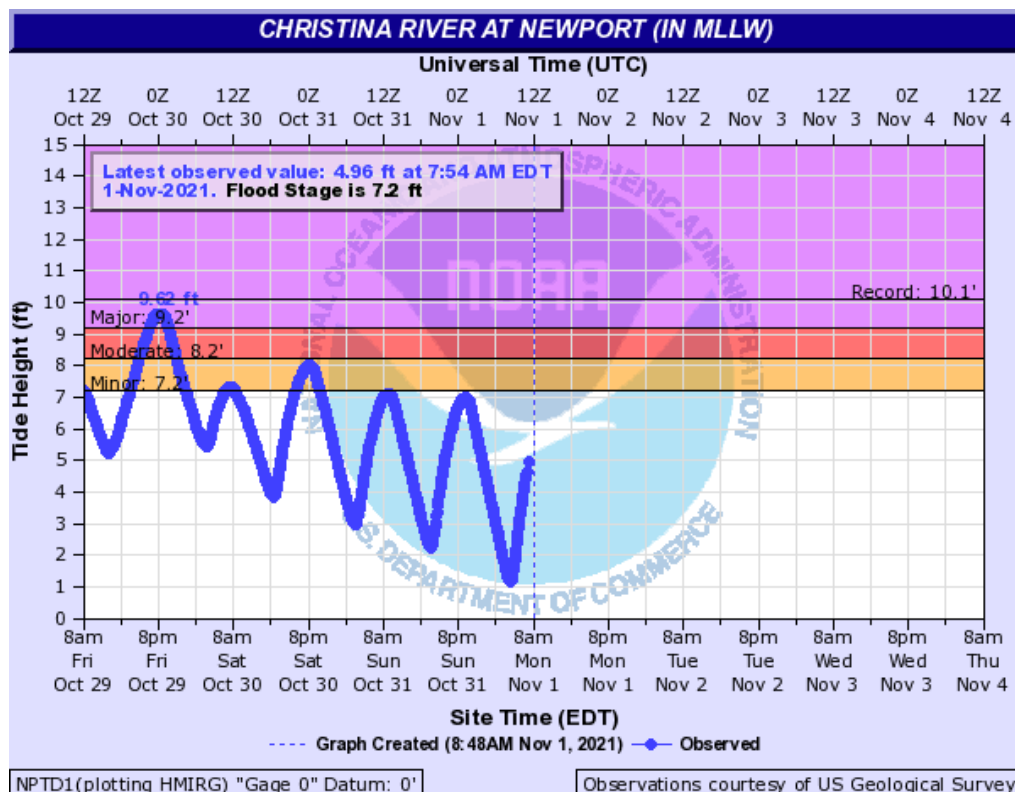
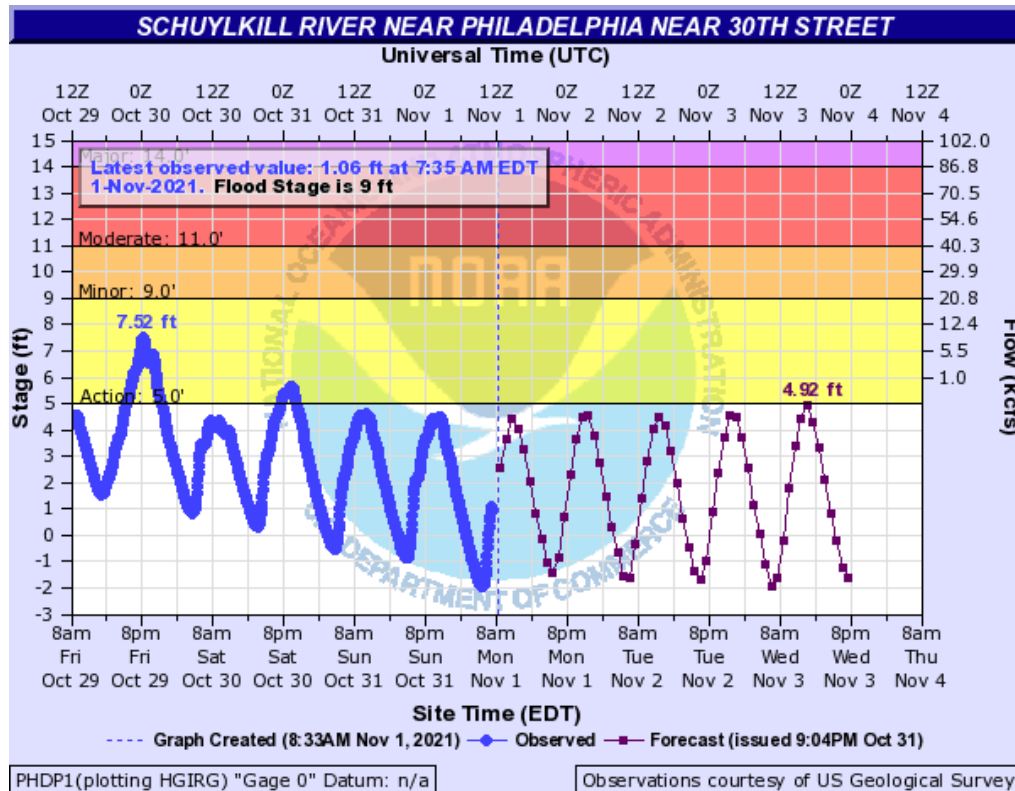
Annual Hydrologic Conditions Report



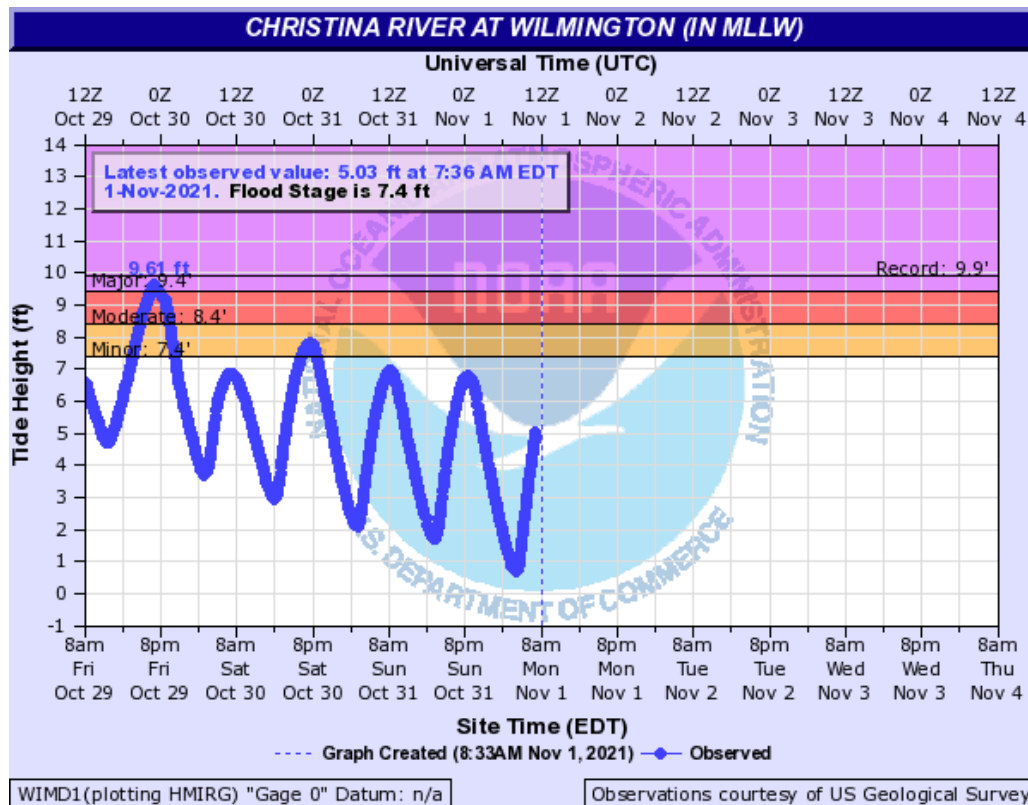
Annual Hydrologic Conditions Report



Annual Hydrologic Conditions Report

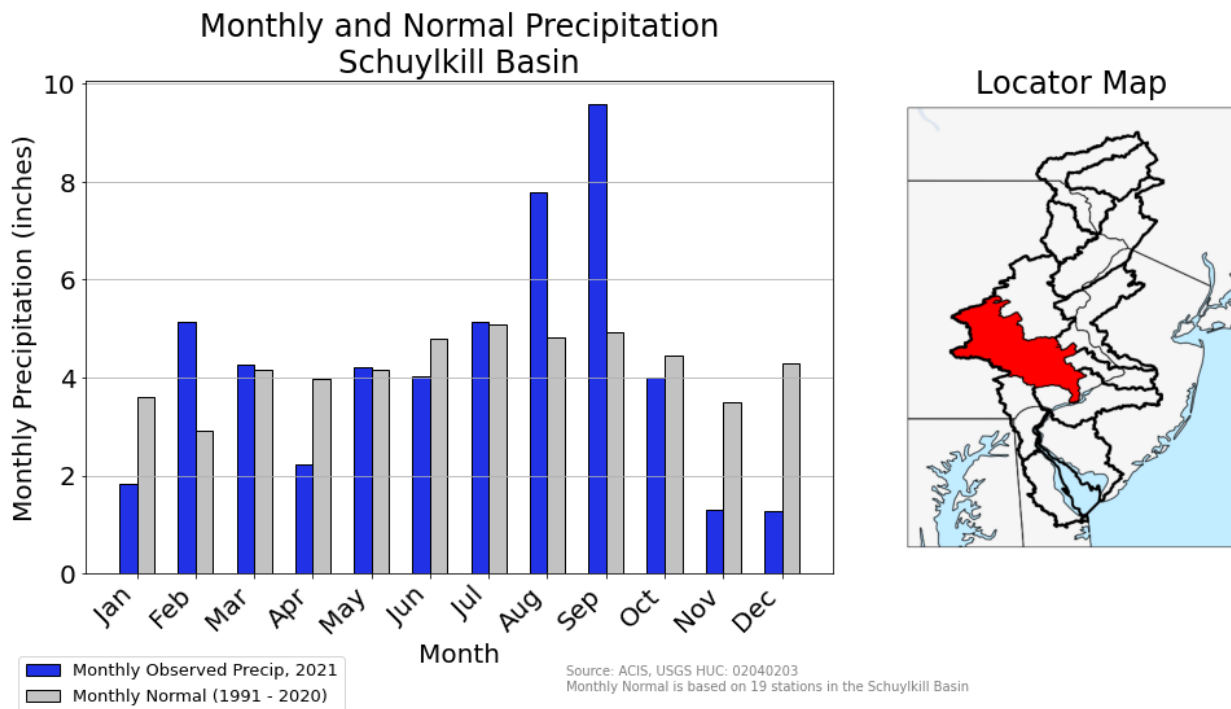


Annual Hydrologic Conditions Report



APPENDIX F: MONTHLY PRECIPITATION COMPARED TO NORMAL

The following figures compare observed to normal monthly precipitation in twelve hydrologic regions across the DRB. The regions are defined by the Hydrologic Unit Code system (HUC) at the eight-digit scale¹⁷. The Applied Climate Information System (ACIS) is a service of the Northeast Regional Climate Center (NRCC) that compiles daily meteorological records across the United States. The daily average of precipitation stations within each HUC is used to calculate the monthly total and normal. In the figures below, the observed precipitation for the year is represented by dark blue bars. The grey bars indicate the normal precipitation using the 30-year period from 1991 to 2020, in accordance with the current definition for normal precipitation set by NOAA¹⁸. A locator map is included with each figure.

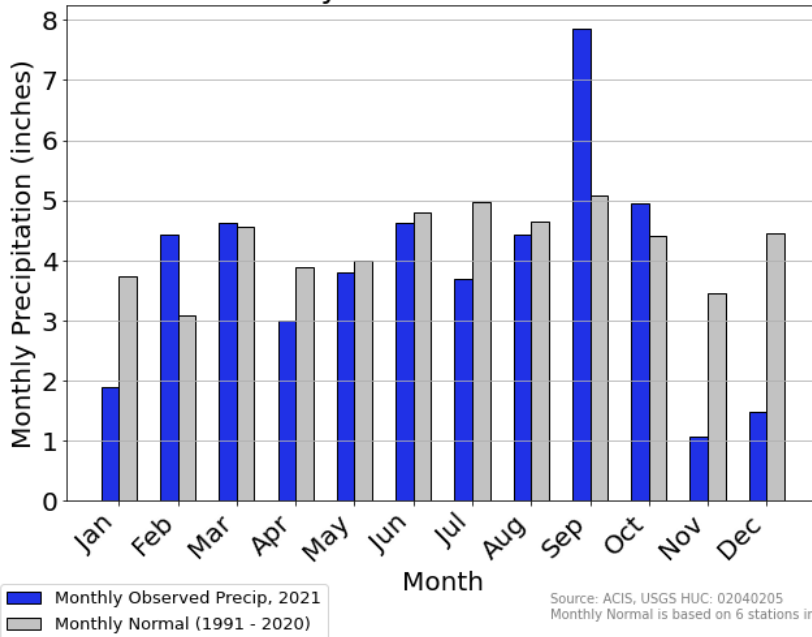


¹⁷ <https://nas.er.usgs.gov/hucs.aspx>

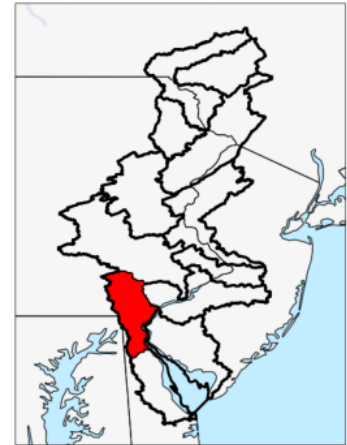
¹⁸ <https://www.ncei.noaa.gov/products/land-based-station/us-climate-normals>

Annual Hydrologic Conditions Report

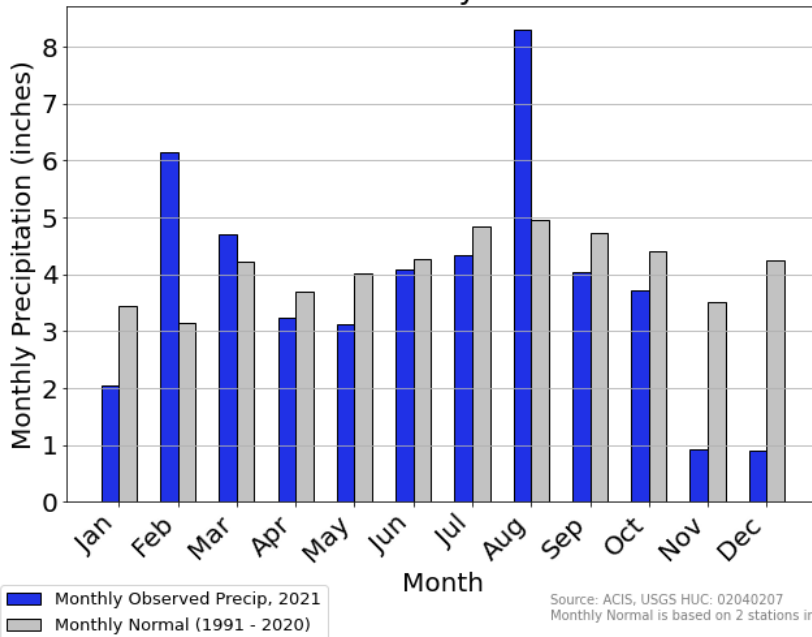
**Monthly and Normal Precipitation
 Brandywine-Christina Basin**



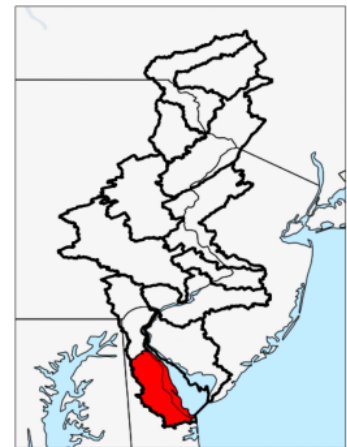
Locator Map



**Monthly and Normal Precipitation
 Broadkill-Smyrna Basin**

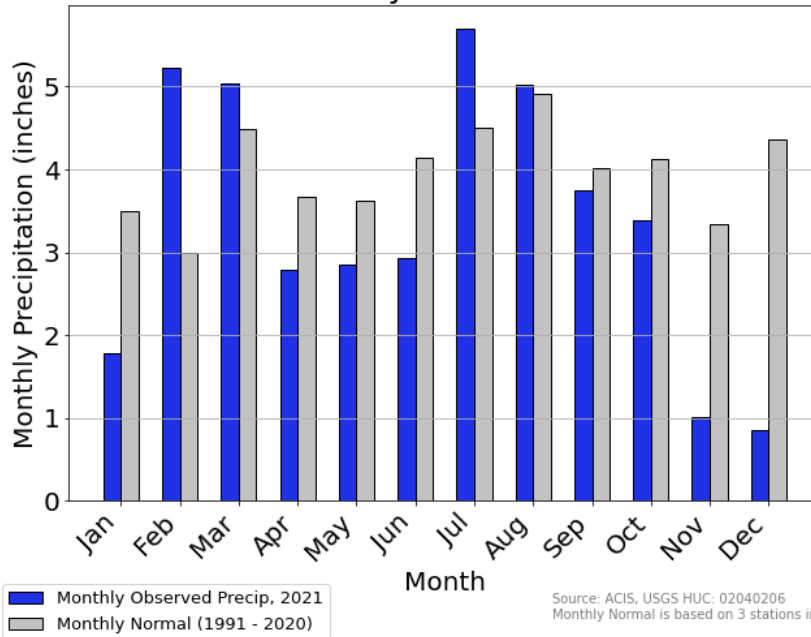


Locator Map

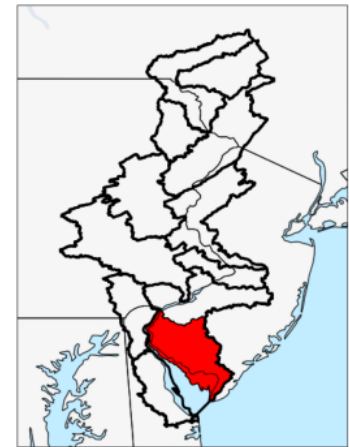


Annual Hydrologic Conditions Report

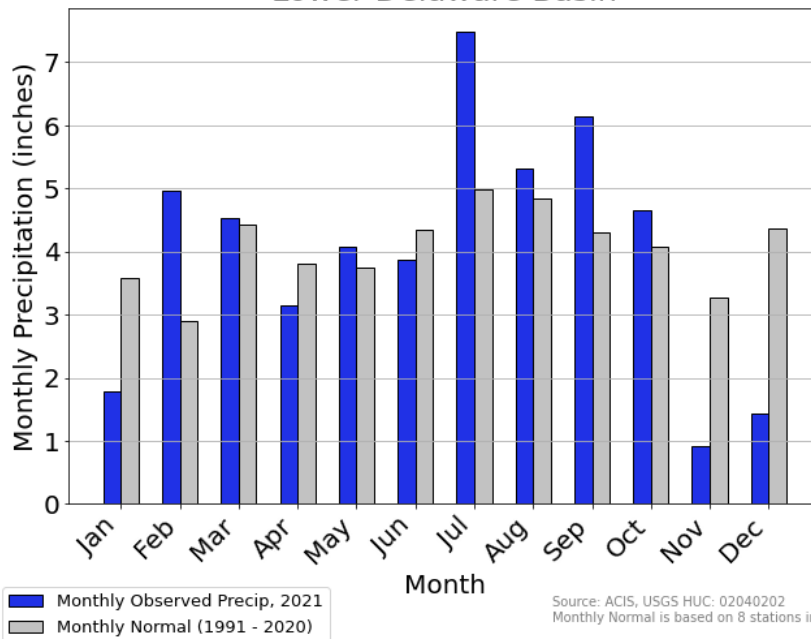
Monthly and Normal Precipitation Cohansey-Maurice Basin



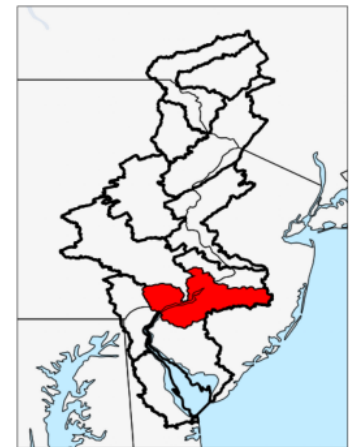
Locator Map



Monthly and Normal Precipitation Lower Delaware Basin

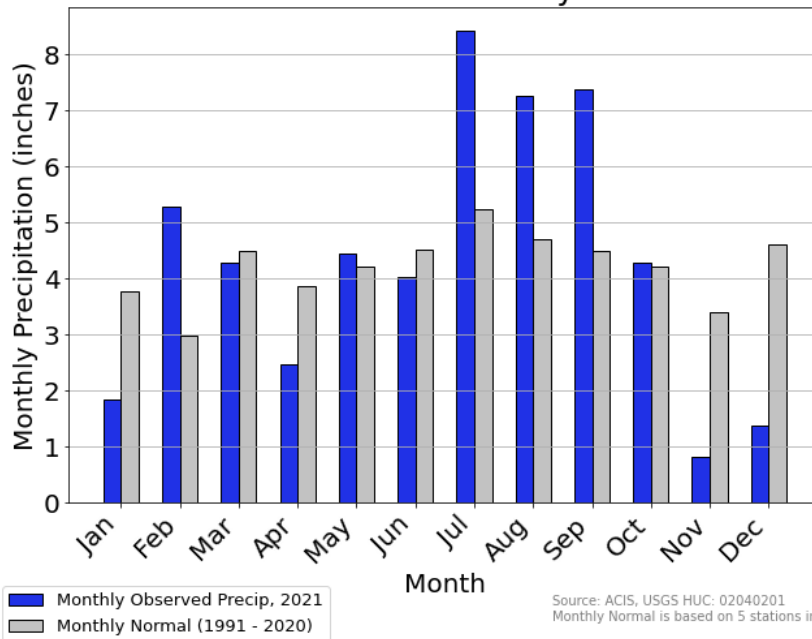


Locator Map

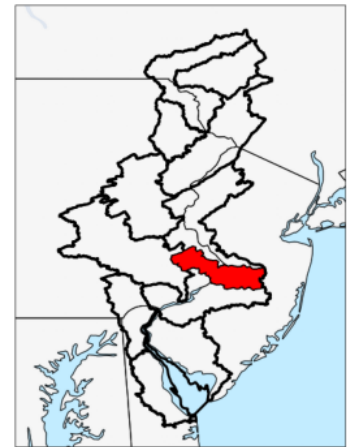


Annual Hydrologic Conditions Report

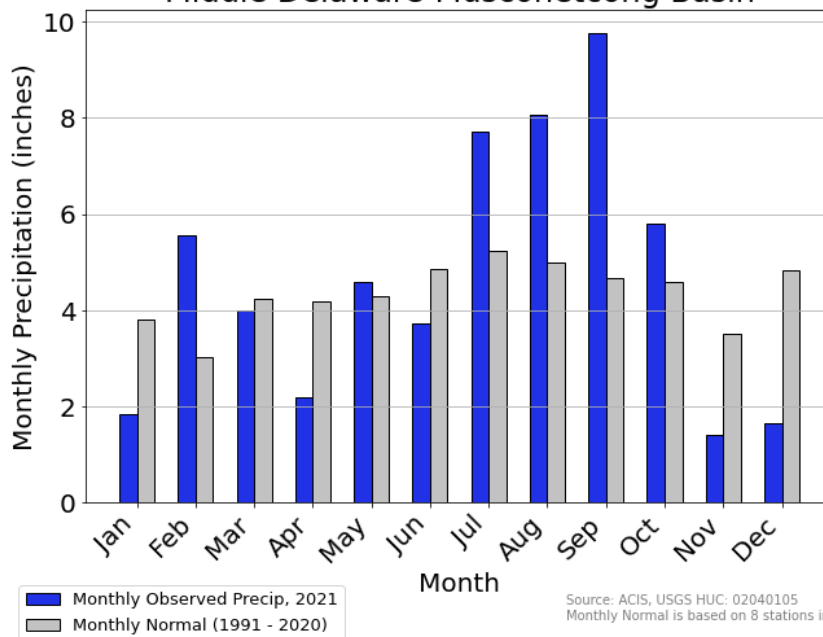
Monthly and Normal Precipitation Crosswicks-Neshaminy Basin



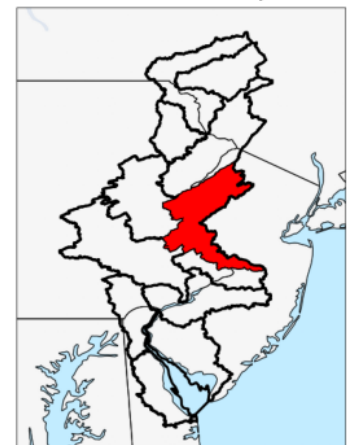
Locator Map



Monthly and Normal Precipitation Middle Delaware-Musconetcong Basin

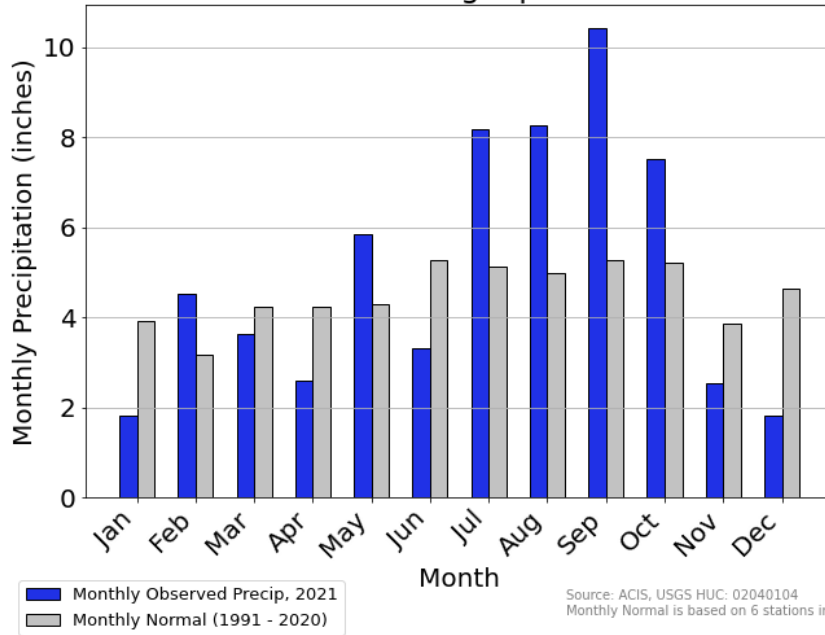


Locator Map

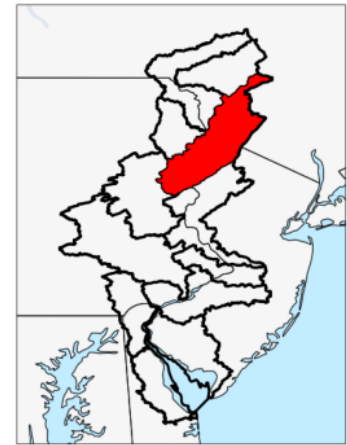


Annual Hydrologic Conditions Report

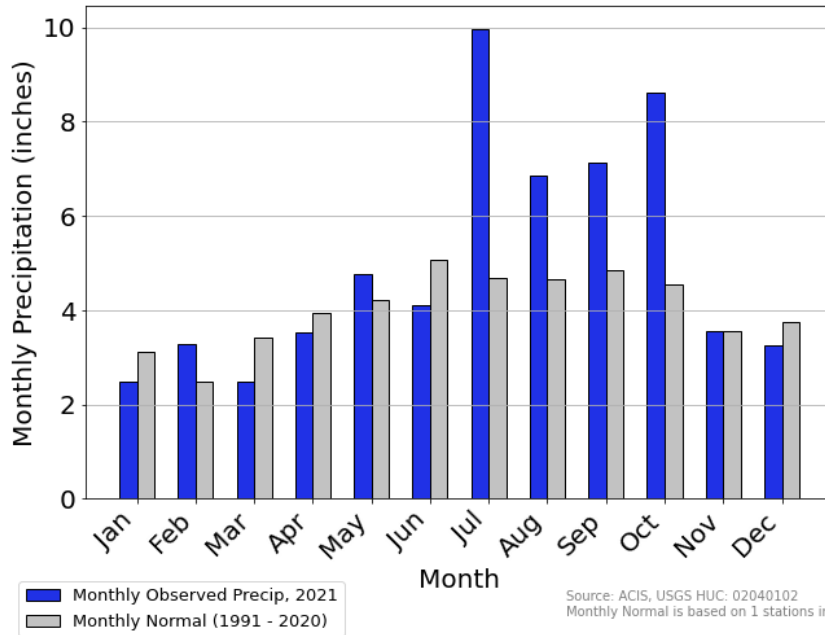
**Monthly and Normal Precipitation
 Middle Delaware-Mongaup-Brodhead Basin**



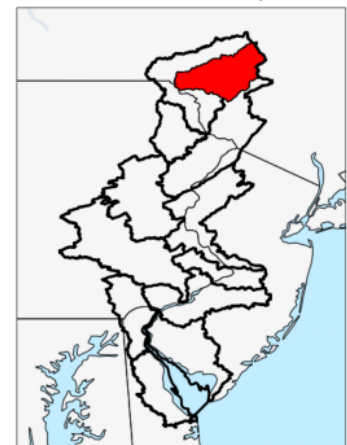
Locator Map



**Monthly and Normal Precipitation
 East Branch Delaware Basin**

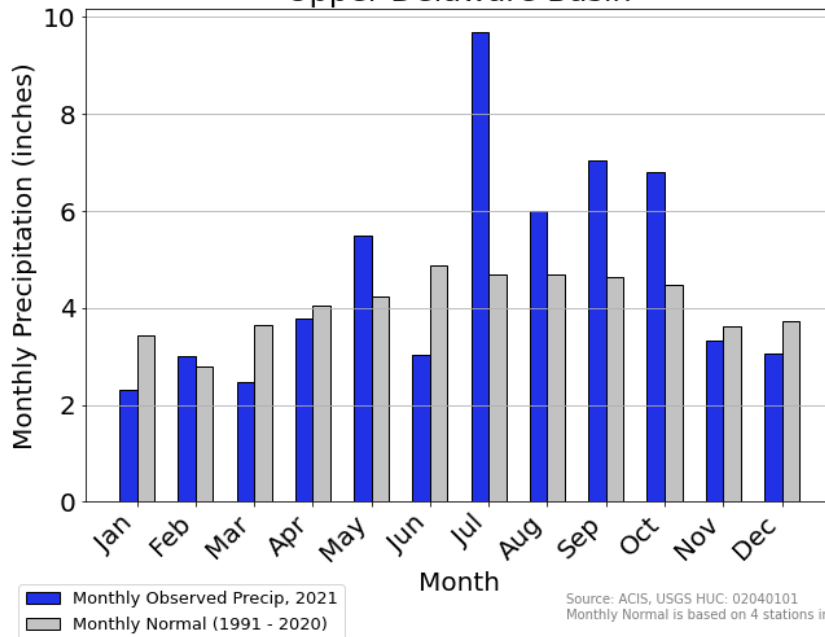


Locator Map

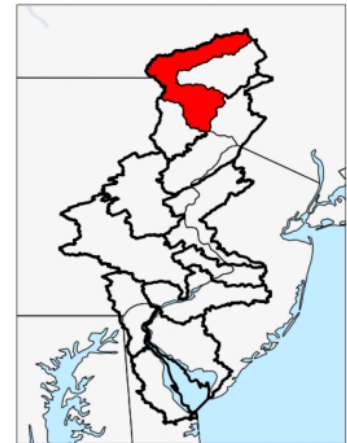


Annual Hydrologic Conditions Report

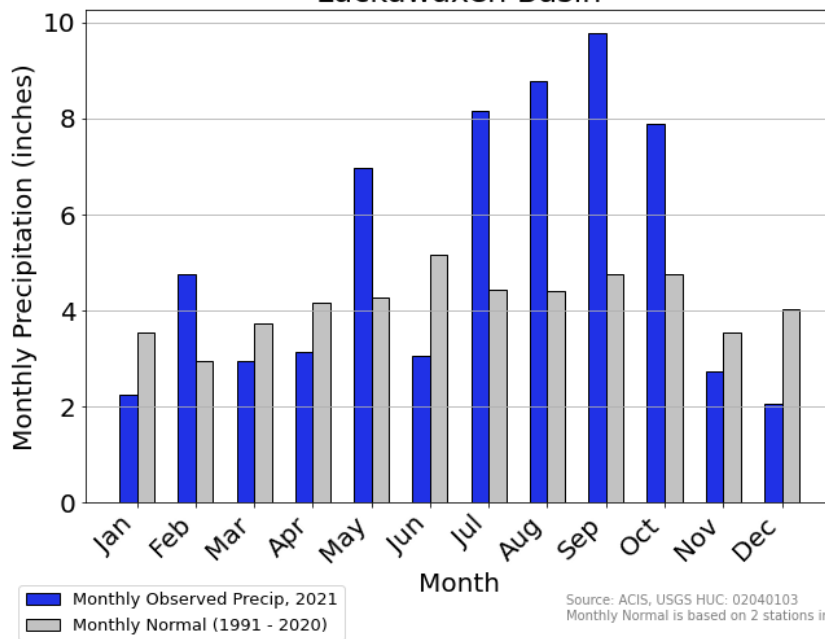
Monthly and Normal Precipitation Upper Delaware Basin



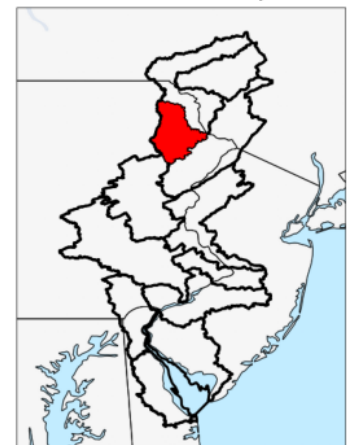
Locator Map



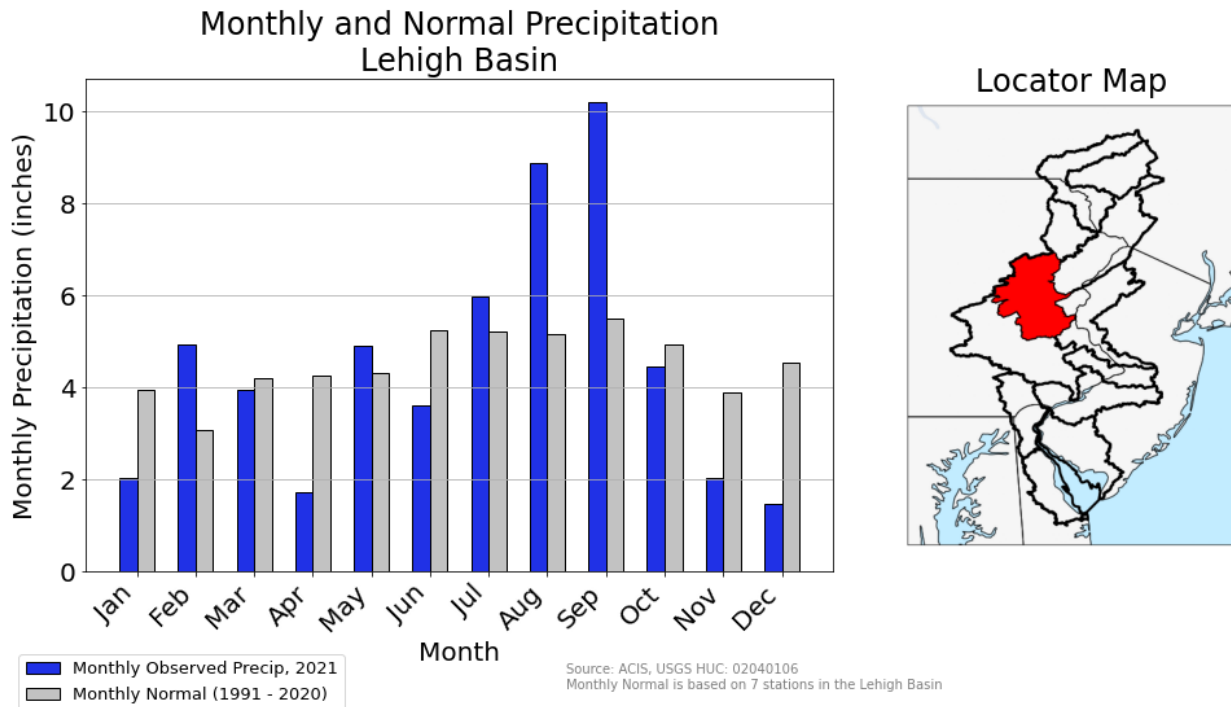
Monthly and Normal Precipitation Lackawaxen Basin



Locator Map



Annual Hydrologic Conditions Report



ⁱ Photo Credit: Patrick Rago, DRBC.

ⁱⁱ Tropical Storm Fred had transitioned to extra-tropical before impacting the Delaware River Basin

ⁱⁱⁱ The Iowa Environmental Mesonet is a well-known data repository that archives weather observations across the country at high resolution time scales (5 minutes). Higher resolution time scales were necessary for this graphic to visualize the high amount of rain that fell over a short period of time.