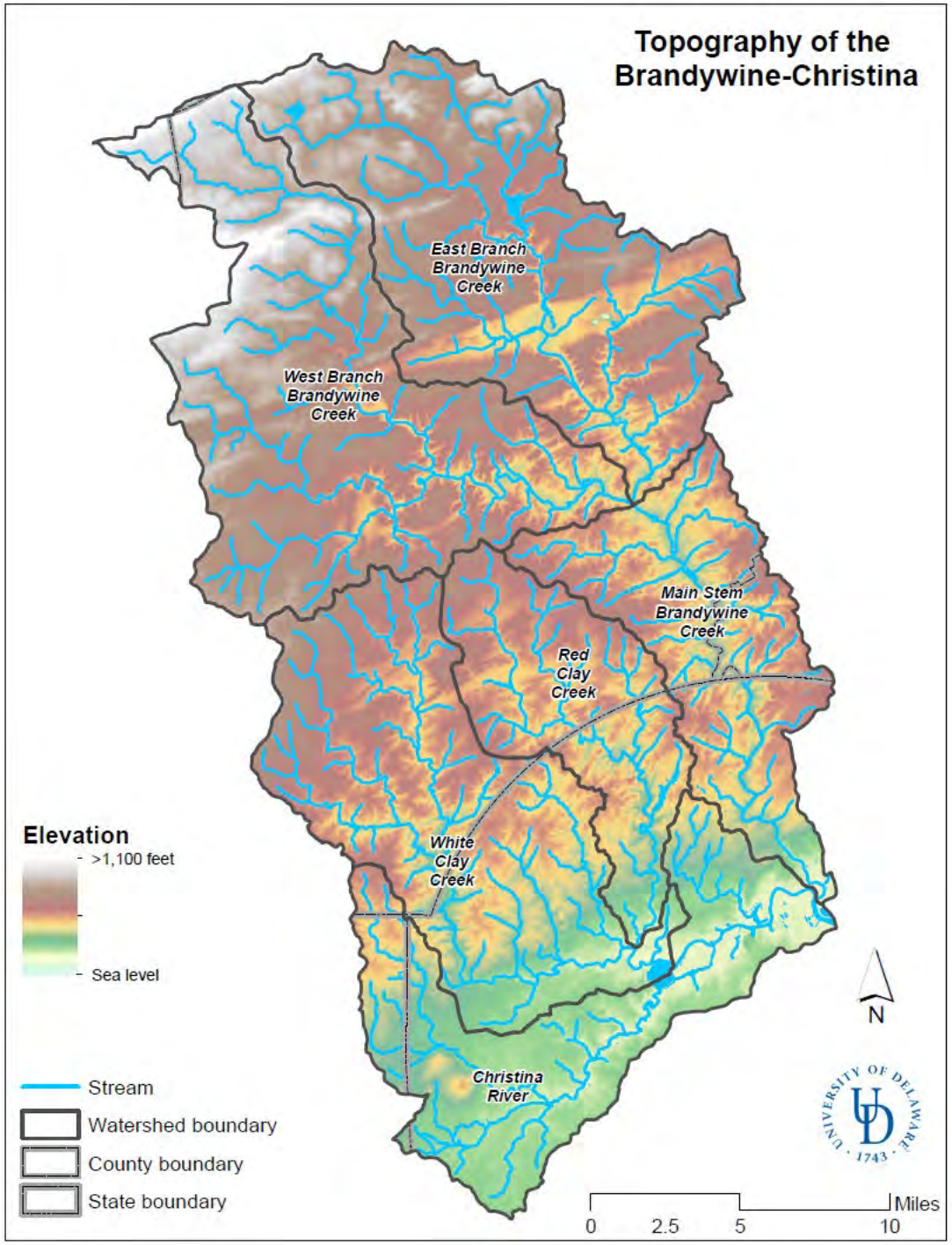
Tropical Storm Ida Remnants Brandywine River at Chadds Ford, Penna. Sep 1-2, 2021

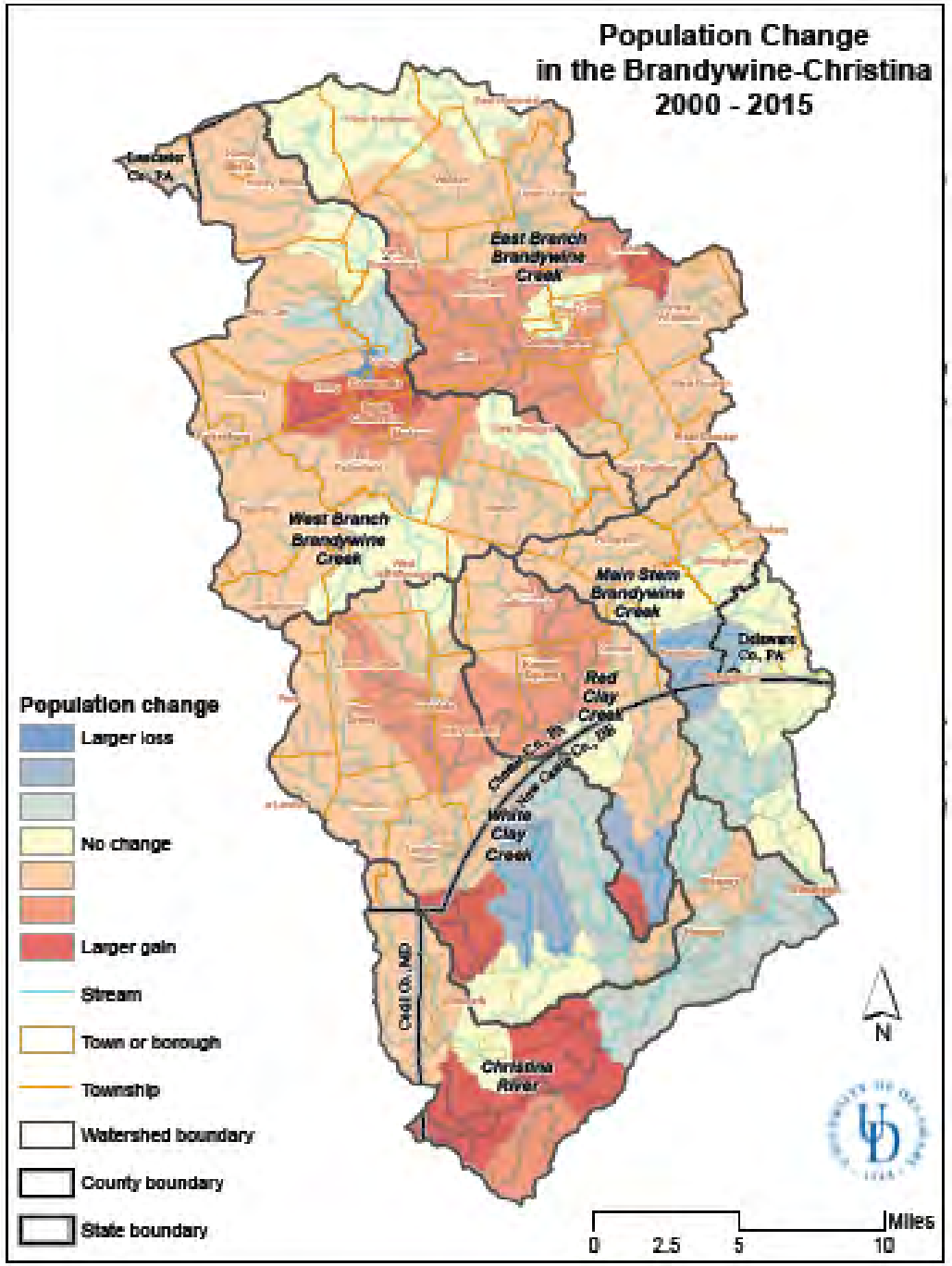
The UDWRC utilized the HECRAS hydraulic model developed by FEMA and LIDAR mapping to examine the effects of Tropical Storm Ida remnants along the Brandywine River in Chadds Ford, Penna. on Sep 1-2, 2021.



Ida's flood wave was accentuated by the inherently steep Piedmont topography in the funnel shaped Brandywine River watershed. Peak rainfall (>8 in) above Coatesville and Downingtown, PA caused runoff that flowed down from 1,000 ft above sea level in the Welsh mountains (the foothills of the Appalachians) and the flow siphoned down to Chadds Ford, Pa then to Delaware at William Penn's 1682 arc boundary that now separates the once co-joined states.

Brandywine Watershed	2000 Pop.	2015 Pop.	Change Pop.
DE	44,866	45,392	526
PA	187,760	212,370	24,610
Total	232,625	257,763	25,138

From 2000 to 2015, from the US Census the population of the Brandywine River watershed above Chadds Ford, PA grew by almost 25,000. This is equivalent to adding another West Chester and Kennett Square boroughs and associated urban land to the watershed.



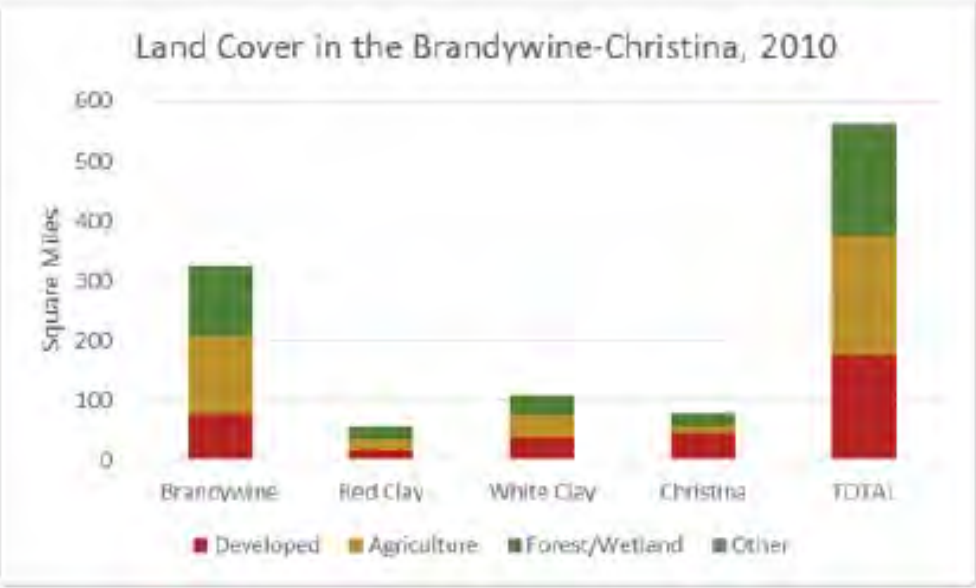


FIGURE 5-3 Proportion of major land cover types in the Brandywine-Christina watershed, 2010. (NOAA C-CAP)

About 20% of the Brandywine watershed is developed.

From 1996 to 2010 the Brandywine watershed gained 9 square miles of developed land or 380 acres per year. That is a gain of about 300 football fields of urban land annually

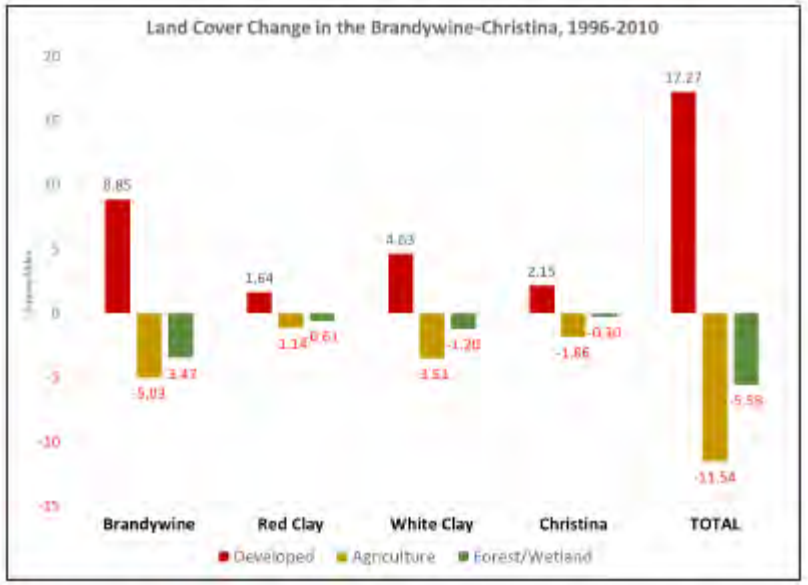
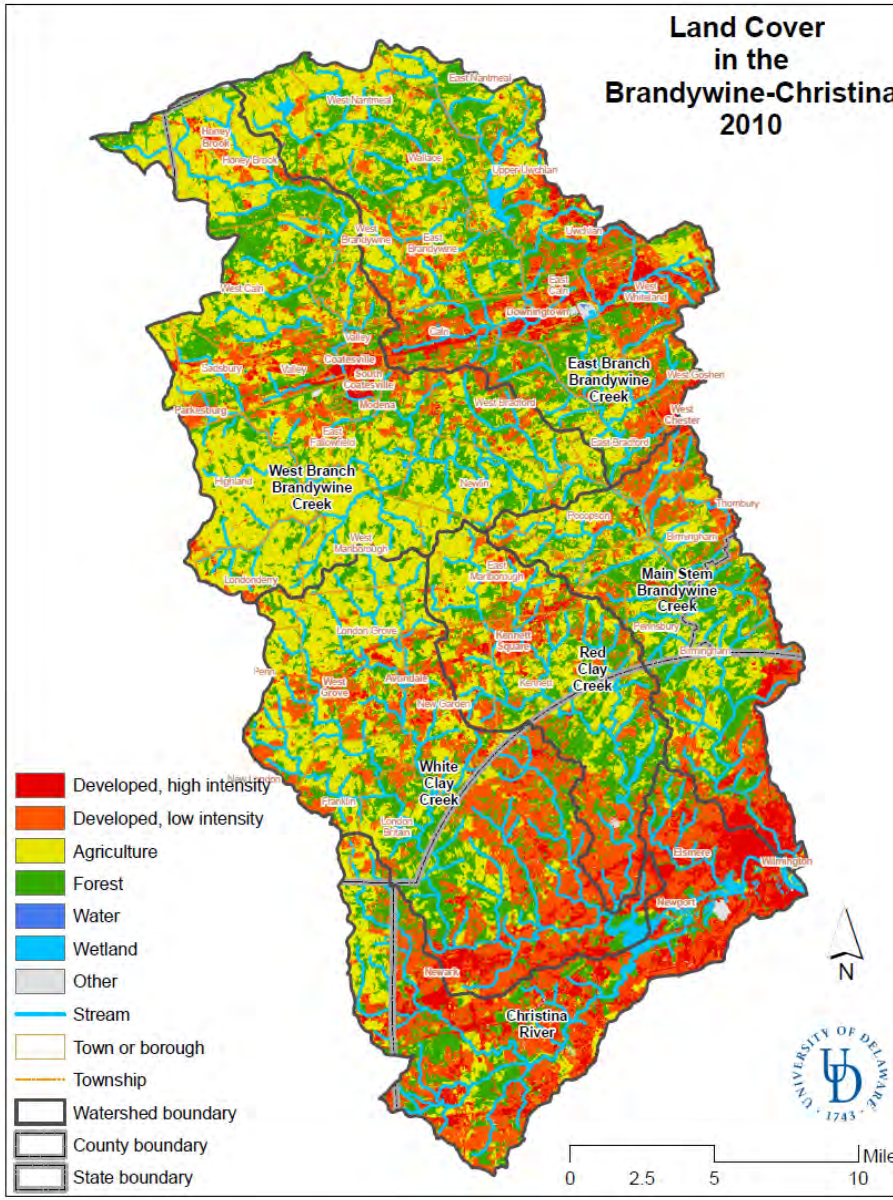


FIGURE 5-8 Change in major land cover types in the Brandywine-Christina watershed, by watershed, 1996 to 2010. (NOAA C-CAP)



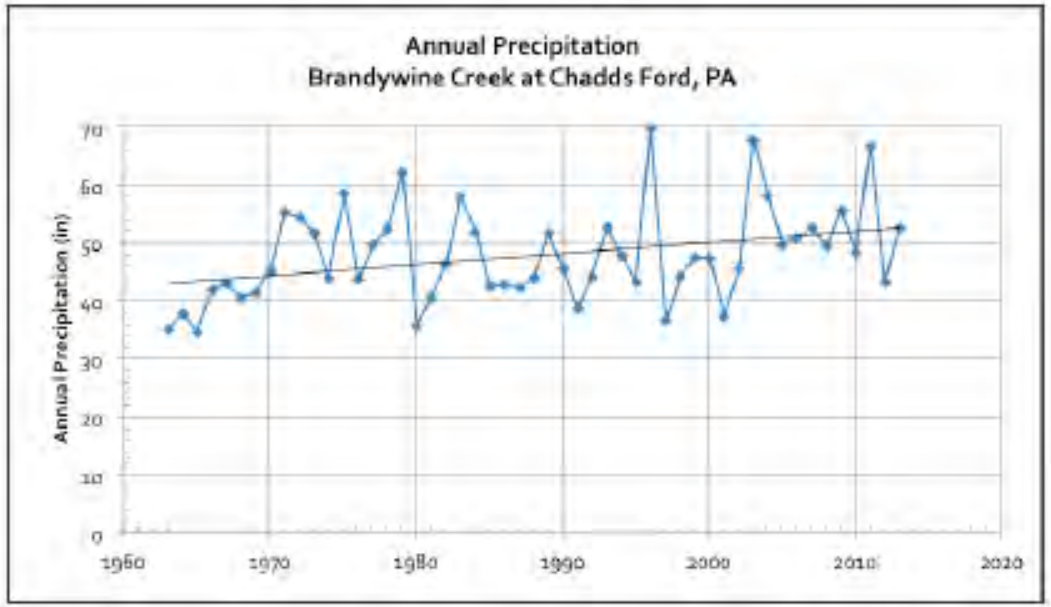


Figure 3-2 Annual Precipitation at Brandywine Creek at Chadds Ford, PA. (National Weather Service)

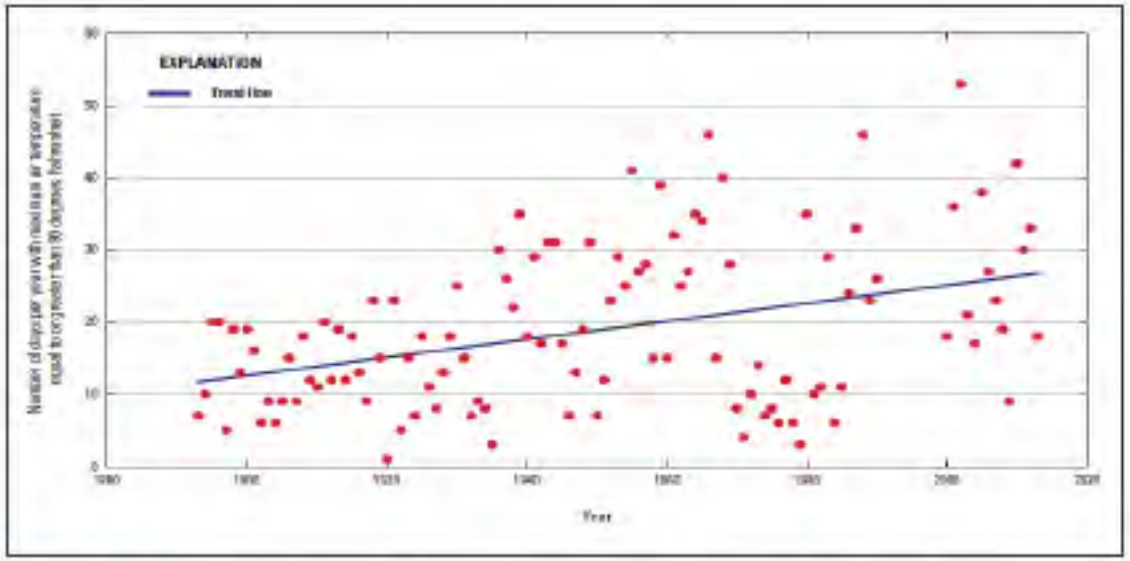


Figure 3-3 Number of days per year with maximum air temperature greater than 90°F in Chester County, Pennsylvania, 1893-2013. (Sloto and Reif 2017)

Precipitation and temperatures are rising in the Brandywine River watershed. As temperatures rise the atmosphere holds more water vapor available for storms like Ida.

This is explained in thermodynamics by the Clausius-Clapeyron relationship that for every 2 degrees F rise in temperature the atmosphere can hold 7% more water vapor.

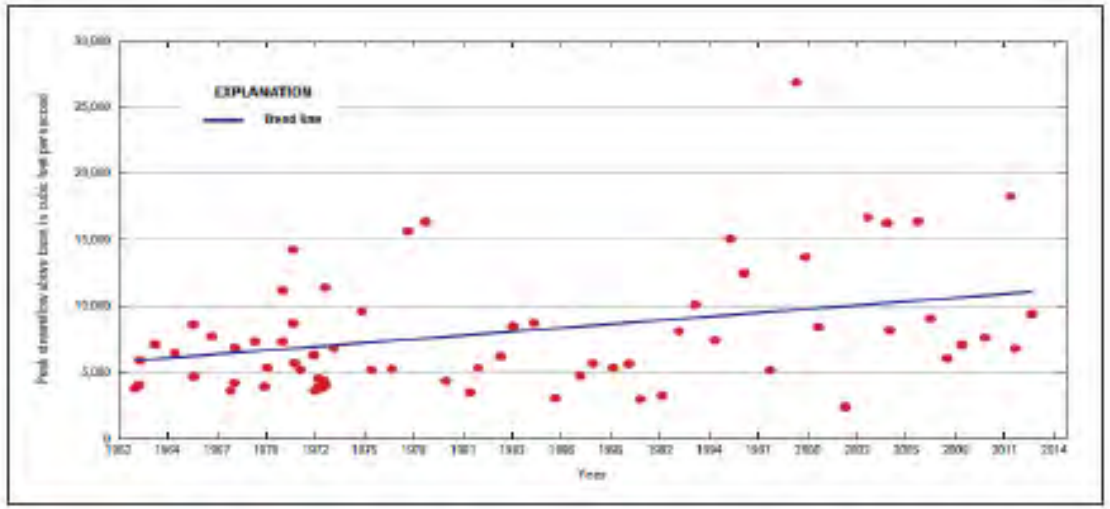
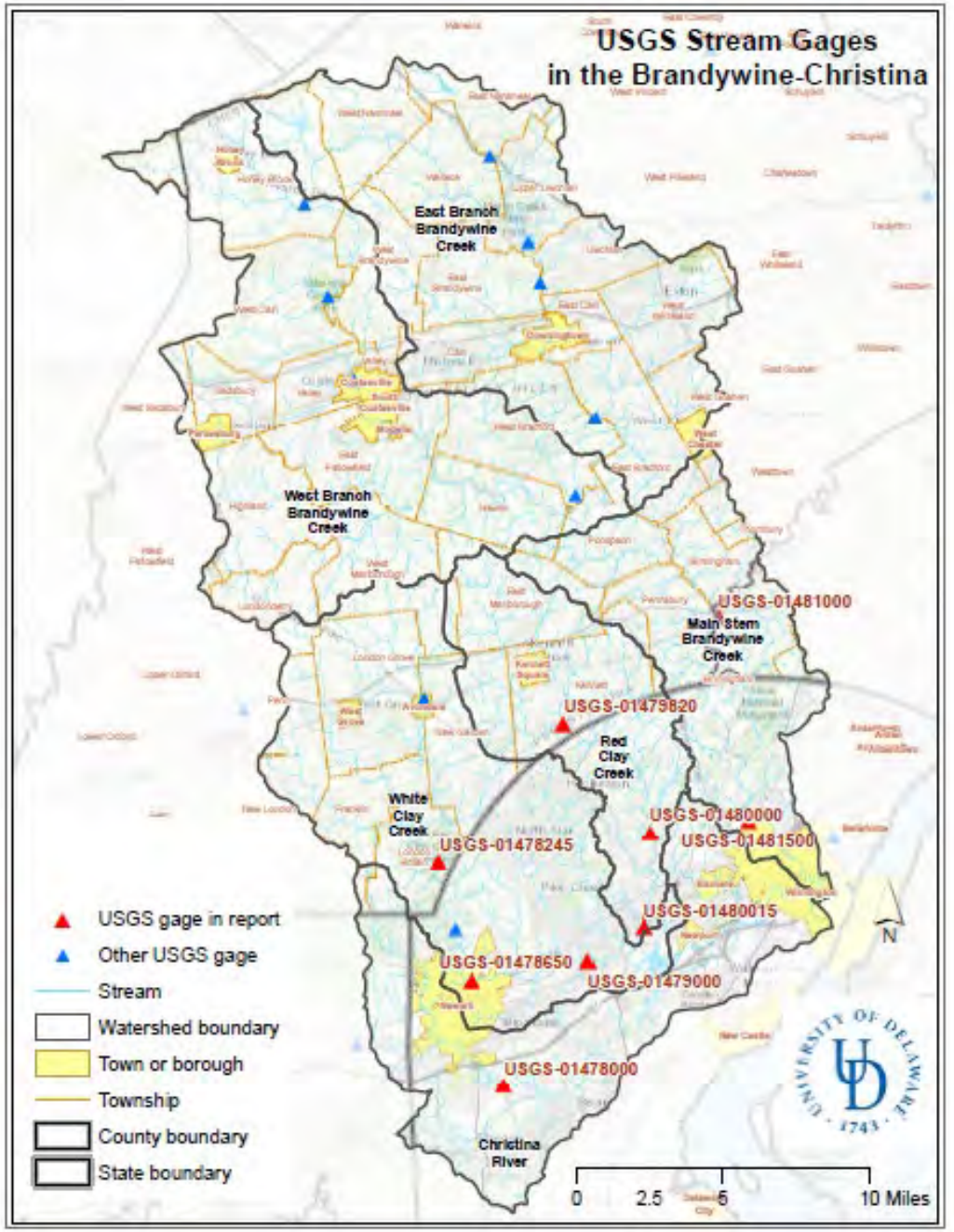


Figure 3-5 Peak streamflow at Brandywine Creek at Chadds Ford, PA, 1962-2012. (Sloto and Reif 2017)

BRANDYWINE CREEK AT CHADDS FORD, PA			
Date	**Peak Discharge (cfs)**	**Named Storm**	**Flood Frequency**
9/17/99	26,900	Floyd	>50-yr
6/22/72	23,800	Agnes	>50-yr
5/1/14	22,200	Unnamed	>10-yr
8/28/11	18,300	Irene	>10-yr
3/5/20	17,200	Unnamed	>10-yr
8/9/42	16,800	Unnamed	>10-yr
9/15/03	16,700	Henri	>10-yr
8/4/15	16,500	Unnamed	>10-yr
8/19/55	16,400	Unnamed	>10-yr
1/25/79	16,400	Unnamed	>10-yr
9/2/21	33,000	Ida	>100-yr



Peak streamflows (floods) are increasing in the Brandywine watershed

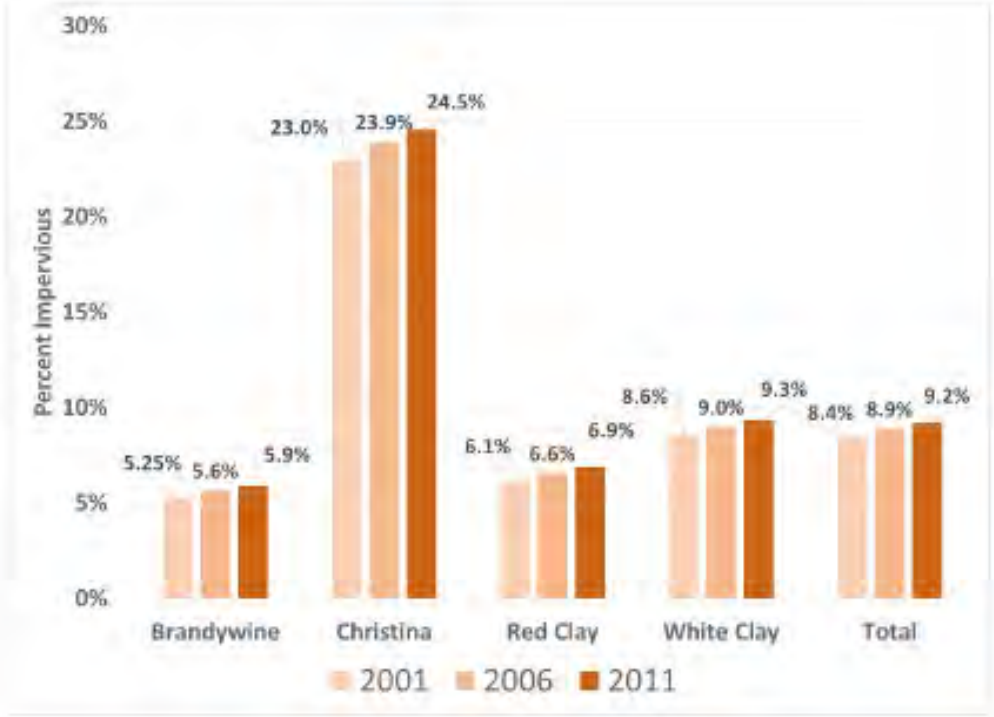


FIGURE 5-21 Imperviousness by year and watershed, 2001, 2006, and 2011. (USGS NLCD)

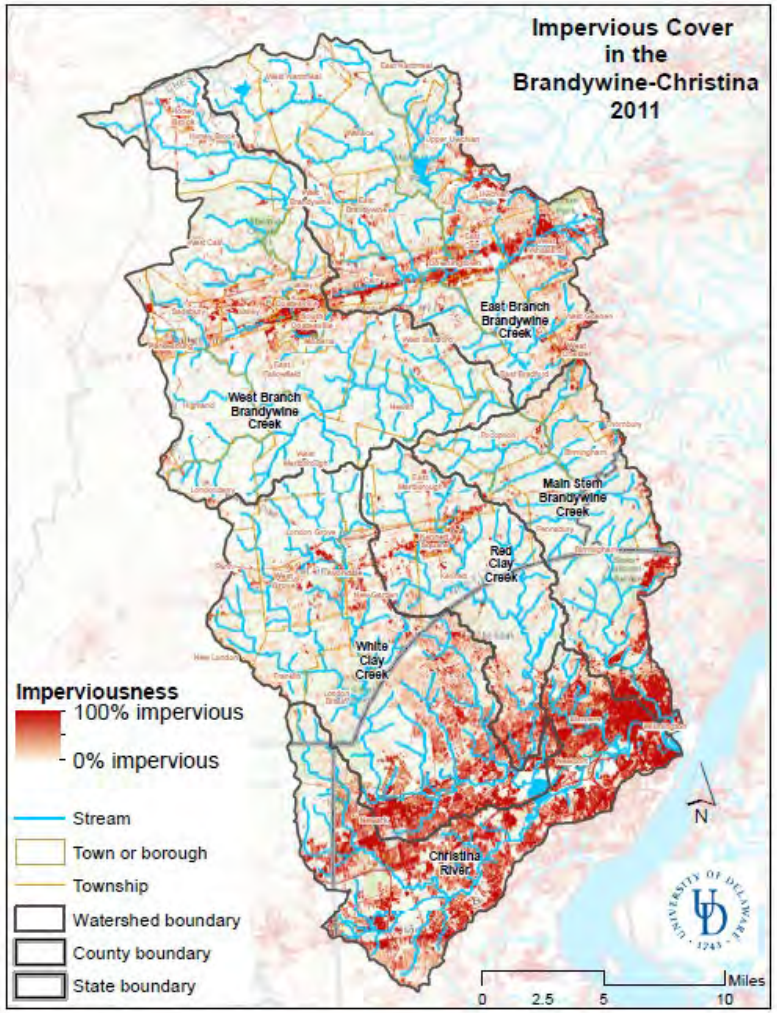


FIGURE 5-16 Developed imperviousness in the Brandywine-Christina watershed, 2011. (USGS NLCD)

While developed land and population in the Brandywine watershed has increased, an associated rise in impervious cover has not been observed. Impervious cover has increased from just 5.25% in 2001 to 5.9% in 2011. This impervious cover of about 6% is quite low in the watershed field the deleterious effects of impervious cover on flooding are usually observed when watershed impervious cover exceeds 15% to 20%.

Protected Type	Brandywine (acres)	Percentage of Watershed
Eased/fee-owned to land trusts	32,322	16%
County/state ag. Easements	11,879	6%
Public lands	12,303	6%
Other protected (HOA, etc.)	7,882	4%
Total Protected Lands	64,386	31%

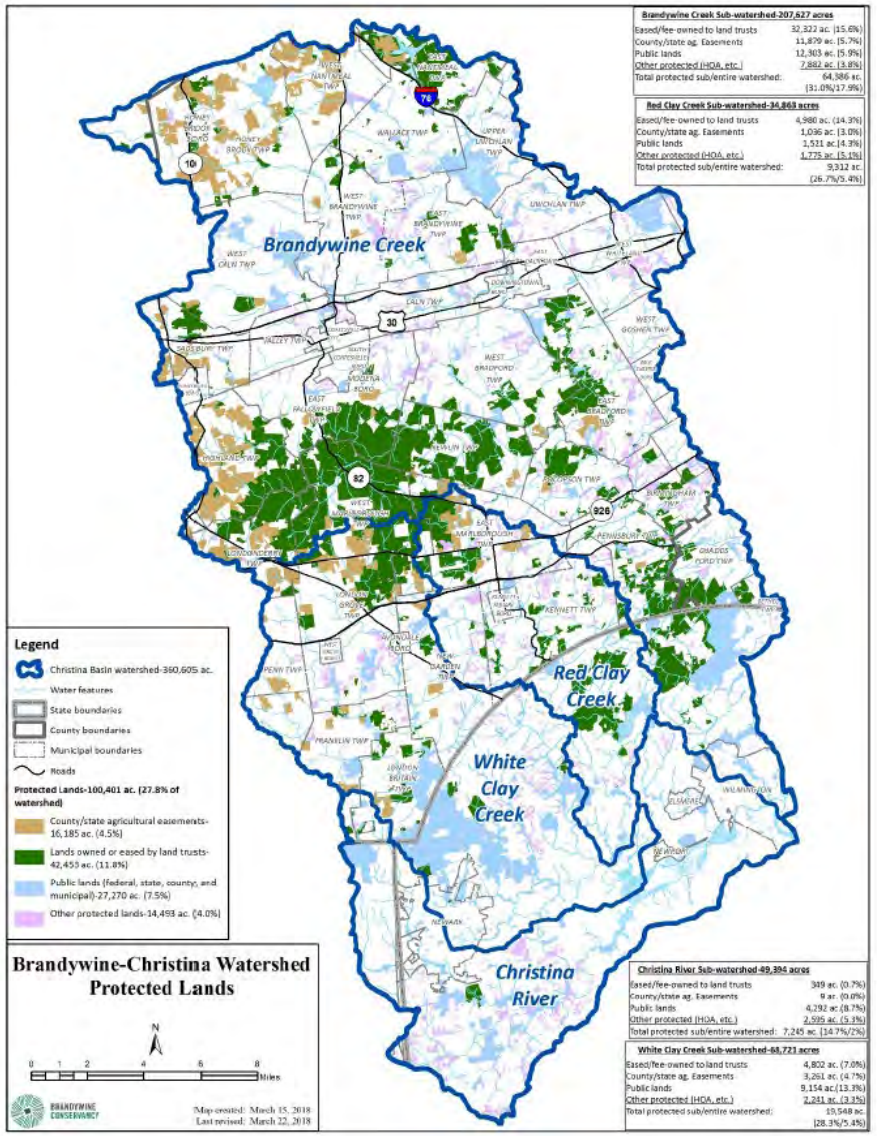
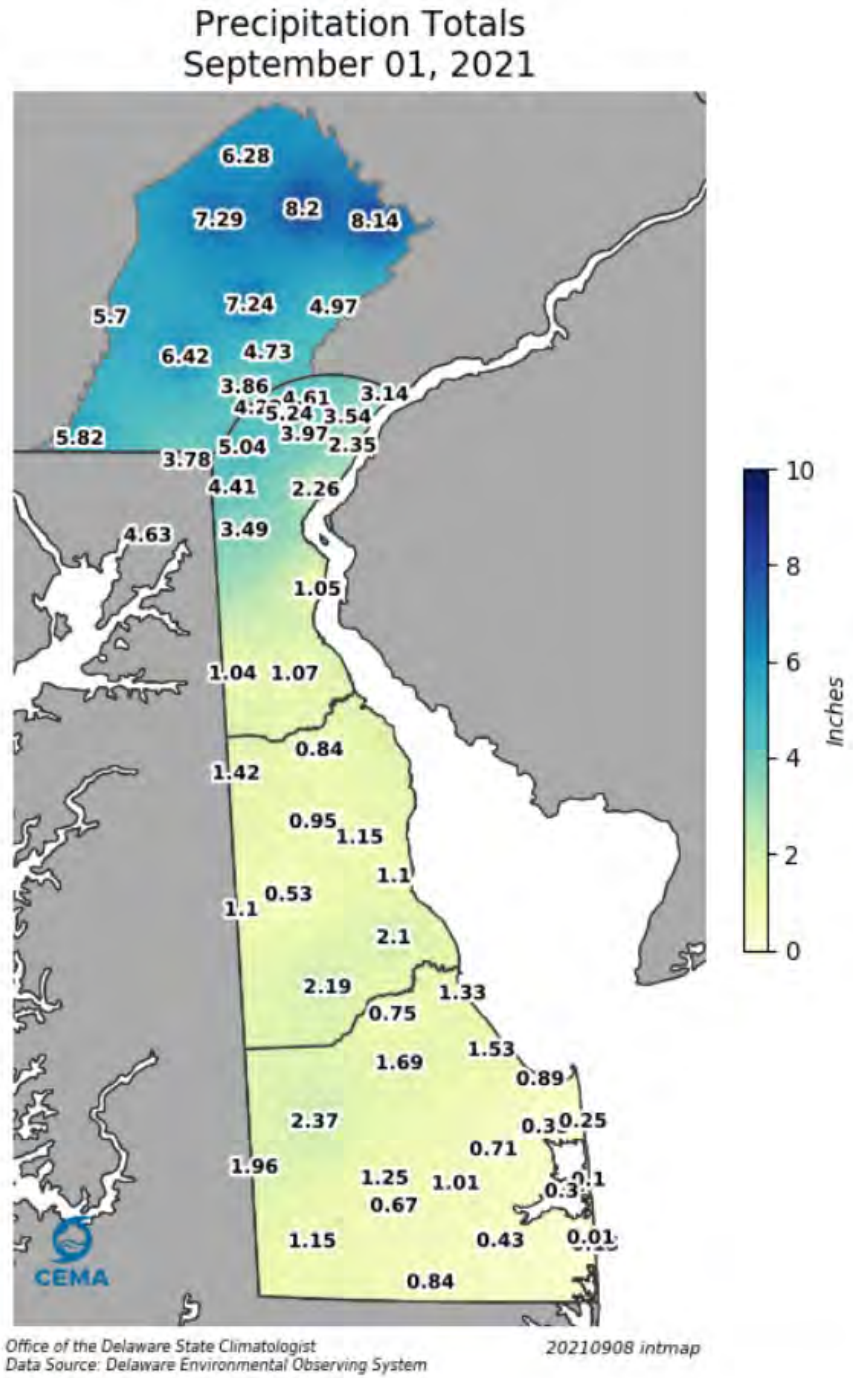


FIGURE 5-25 Protected lands in the Brandywine-Christina watershed. (Brandywine Conservancy)

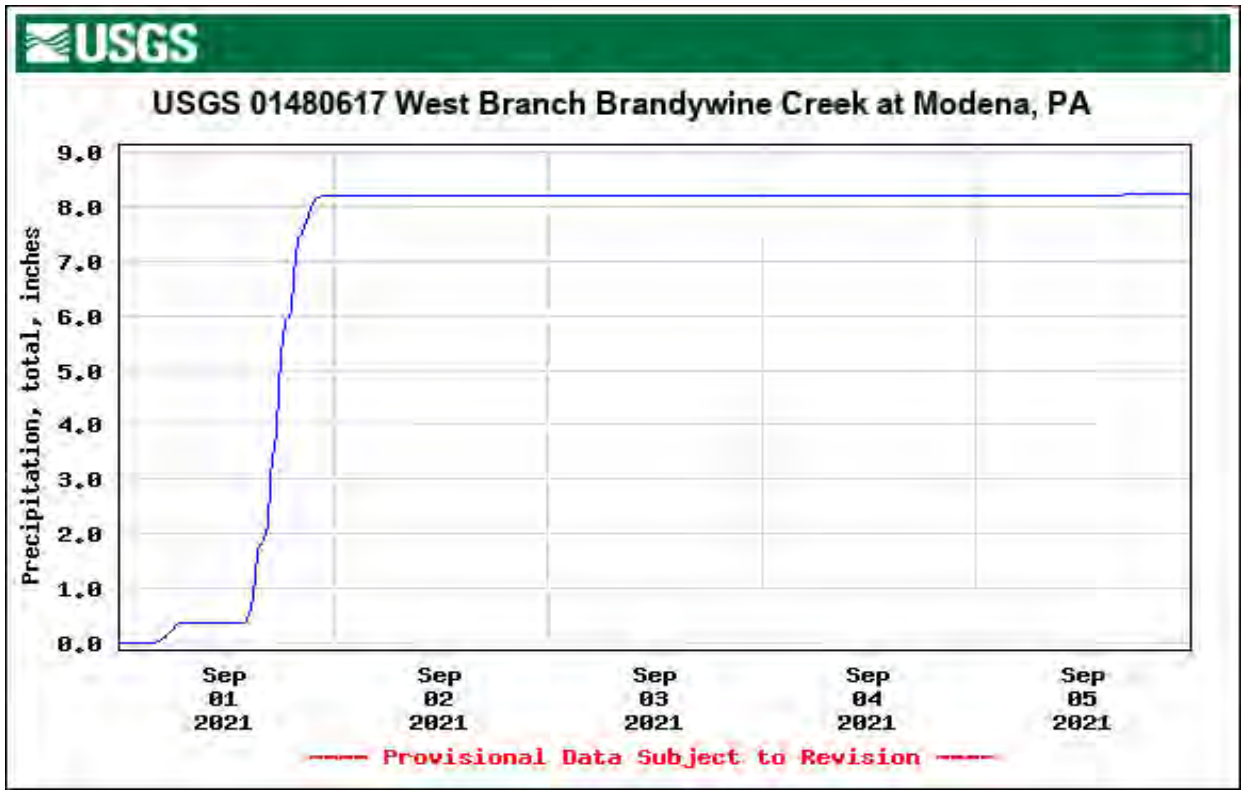
The increase in population and developed land in the Brandywine watershed is offset by the high amount of protected Land a full 1/3 of the watershed are protected lands and this ratio exceeds the % recommended by Harvard biologist E.O. Wilson in his 2016 book and the UN and Dept. of Interior in the 30 for 30 program to protect 30% of the Earth and the nation's land and water.

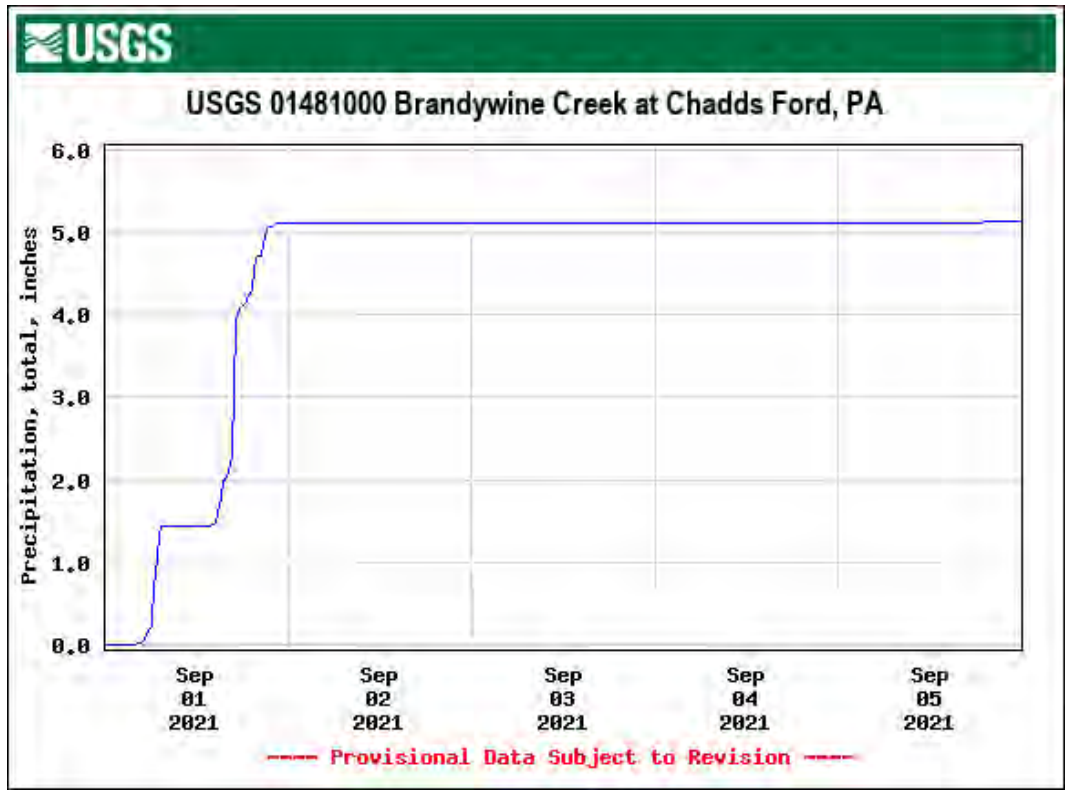


The remnants of Tropical Storm Ida left 7.29 inches of rain in the headwaters of the Brandywine River watershed at Glenmoore and 8.2 inches at Chester Springs in Chester County, Pennsylvania. From USGS, the precipitation was 8.2 inches at Modena and 5.1 inches at Chadds Ford. From NOAA Atlas 14, the 100-yr, 24-hr storm is 7.62 inches (8.0 inches).

The max. rainfall intensity was 1.88 inches at 5 pm 9/1/21 at Glenmoore and 1.54 inches at 5 pm on at Chester Springs. These readings exceed the 100-yr rainfall intensity for 3-hr time of concentration of 1.3 in/hr.

By rainfall volume (in) and intensity (in/hr) Ida was > 100-yr storm.


USGS
USGS 01480617 West Branch Brandywine Creek at Modena, PA
Precipitation, total, inches
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Sep 01 2021
Sep 02 2021
Sep 03 2021
Sep 04 2021
Sep 05 2021
---- Provisional Data Subject to Revision ----


USGS
USGS 01481000 Brandywine Creek at Chadds Ford, PA
Precipitation, total, inches
6.0
5.0
4.0
3.0
2.0
1.0
0.0
Sep 01 2021
Sep 02 2021
Sep 03 2021
Sep 04 2021
Sep 05 2021
---- Provisional Data Subject to Revision ----

Glenmoore, PA-Springton Manor Station

ID	DSGM	Network	DEOS
City/State	Glenmoore/PA	Elevation	620 ft.
Latitude	40° 4' N	Longitude	75° 47' W

24-Hour Summary for September 1, 2021

Hour	Temp (°F)	Temp (°C)	Dew Point (°F)	Dew Point (°C)	Rel Hum. (%)	Wind Spd. (MPH)	Wind Spd. (m/s)	Wind Dir (°)	Wind Gust (MPH)	Wind Gust (m/s)	Heat Index (°F)	Heat Index (°C)	Wind Chill (°F)	Wind Chill (°C)	SLP (mbar)	Sol. Rad. (W.m-2)	Rainfall (in)	Rainfall (mm)	Hour
0	68.7	20.4	67.6	19.8	96	0.3	0.1	353.7 (N)	2.0@00:20	0.9	N/A	N/A	N/A	N/A	1009.6	0	0.00	0.0	0
1	68.7	20.4	67.8	19.9	97	0.4	0.2	63.8 (ENE)	1.6@01:50	0.7	N/A	N/A	N/A	N/A	1009.7	0	0.00	0.0	1
2	68.6	20.3	67.8	19.9	98	0.5	0.2	319.3 (NW)	2.1@02:40	0.9	N/A	N/A	N/A	N/A	1009.5	0	0.00	0.0	2
3	68.3	20.2	67.6	19.8	98	0.5	0.2	70.5 (ENE)	2.4@03:45	1.1	N/A	N/A	N/A	N/A	1009.6	0	0.04	1.0	3
4	68.0	20.0	67.3	19.6	98	0.4	0.2	46.3 (NE)	2.6@04:45	1.1	N/A	N/A	N/A	N/A	1009.3	0	0.07	1.8	4
5	67.4	19.7	66.8	19.3	98	0.8	0.4	61.8 (ENE)	4.5@05:50	2.0	N/A	N/A	N/A	N/A	1009.1	0	0.11	2.8	5
6	67.1	19.5	66.5	19.2	98	1.6	0.7	84.5 (E)	6.5@06:40	2.9	N/A	N/A	N/A	N/A	1008.8	2	0.08	2.0	6
7	67.2	19.6	66.6	19.2	98	2.2	1.0	99.0 (E)	9.0@07:30	4.0	N/A	N/A	N/A	N/A	1008.9	19	0.00	0.0	7
8	67.5	19.7	66.9	19.4	98	2.0	0.9	62.5 (ENE)	7.7@09:00	3.5	N/A	N/A	N/A	N/A	1008.7	46	0.00	0.0	8
9	67.4	19.7	66.8	19.3	98	2.7	1.2	85.4 (E)	9.6@09:25	4.3	N/A	N/A	N/A	N/A	1007.9	47	0.00	0.0	9
10	67.0	19.5	66.2	19.0	97	2.5	1.1	83.9 (E)	8.1@11:00	3.6	N/A	N/A	N/A	N/A	1008.0	51	0.00	0.0	10
11	67.2	19.5	66.0	18.9	96	2.5	1.1	84.7 (E)	9.6@11:10	4.3	N/A	N/A	N/A	N/A	1007.2	83	0.00	0.0	11
12	67.4	19.7	66.5	19.2	97	2.4	1.1	65.3 (ENE)	9.4@12:55	4.2	N/A	N/A	N/A	N/A	1006.6	70	0.01	0.3	12
13	67.5	19.7	66.5	19.2	97	3.2	1.4	77.0 (ENE)	12.5@13:40	5.6	N/A	N/A	N/A	N/A	1005.6	60	0.00	0.0	13
14	67.7	19.8	67.0	19.5	98	2.8	1.3	45.4 (NE)	13.7@14:25	6.1	N/A	N/A	N/A	N/A	1003.6	16	0.71	18.0	14
15	68.1	20.1	67.5	19.7	98	2.8	1.2	35.6 (NE)	9.9@15:15	4.4	N/A	N/A	N/A	N/A	1002.7	10	0.97	24.6	15
16	67.7	19.8	67.1	19.5	98	3.2	1.4	51.0 (NE)	9.3@17:00	4.1	N/A	N/A	N/A	N/A	1001.4	9	1.42	36.1	16
17	66.7	19.3	66.1	18.9	98	4.1	1.8	23.7 (NNE)	15.2@17:50	6.8	N/A	N/A	N/A	N/A	1000.[illegible]	3	1.88	47.[illegible]	17
18	64.5	18.0	63.9	17.7	98	2.9	1.3	19.8 (NNE)	12.3@18:25	5.5	N/A	N/A	N/A	N/A	1000.4	10	0.81	20.6	18
19	64.2	17.9	63.7	17.6	98	3.5	1.5	19.6 (NNE)	12.1@20:00	5.4	N/A	N/A	N/A	N/A	1000.7	1	0.44	11.2	19
20	63.4	17.5	62.8	17.1	98	5.9	2.6	25.0 (NNE)	15.8@20:50	7.1	N/A	N/A	N/A	N/A	1001.4	0	0.26	6.6	20
21	62.5	17.0	61.9	16.6	98	6.7	3.0	30.2 (NNE)	20.1@22:00	9.0	N/A	N/A	N/A	N/A	1002.4	0	0.45	11.4	21
22	62.5	16.9	61.4	16.3	96	6.2	2.8	41.9 (NE)	17.6@22:05	7.9	N/A	N/A	N/A	N/A	1003.1	0	0.03	0.8	22
23	62.0	16.7	61.3	16.3	97	4.8	2.1	18.5 (NNE)	16.1@23:55	7.2	N/A	N/A	N/A	N/A	1004.1	0	0.01	0.3	23

Summary

High Temp. (°F)	Low Temp. (°F)	Avg. Temp. (°F)	Avg. Dew Point (°F)	Avg. Rel Hum (%)	Avg. Wind Spd (MPH)	Avg. Wind Dir (°)	Peak Gust (MPH)	Max. Heat Index (°F)	Min. Wind Chill (°F)	Total Rainfall (in)
69.0	61.6	66.6	65.8	97	2.7	51.6 (NE)	20.1	N/A	N/A	7.29

Note: All observations were obtained from the Delaware Environmental Observing System network

Chester Springs, PA-Park Station

ID	DWPK	Network	DEOS
City/State	Chester Springs/PA	Elevation	354 ft.
Latitude	40° 5' N	Longitude	75° 37' W

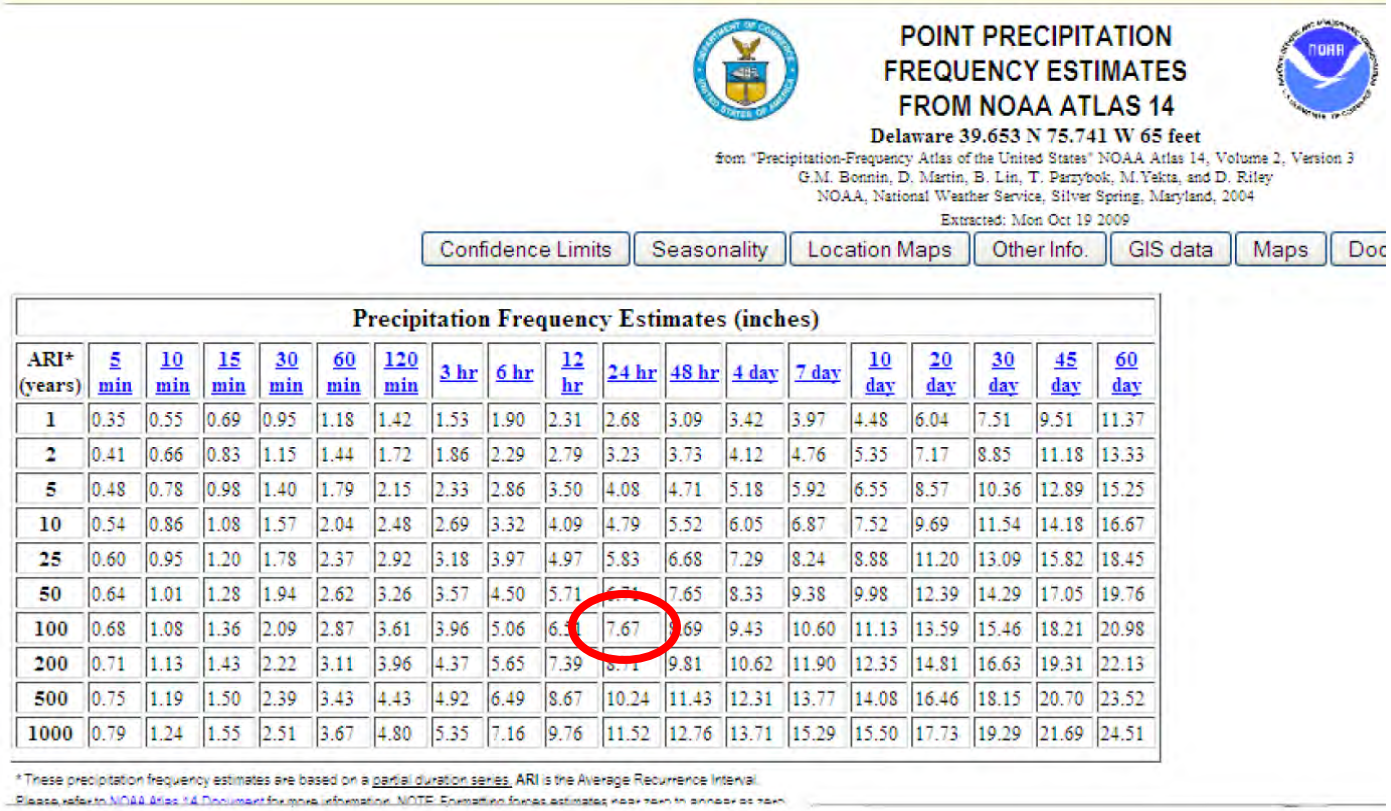
24-Hour Summary for September 1, 2021

Hour	Temp (°F)	Temp (°C)	Dew Point (°F)	Dew Point (°C)	Rel Hum. (%)	Wind Spd. (MPH)	Wind Spd. (m/s)	Wind Dir (°)	Wind Gust (MPH)	Wind Gust (m/s)	Heat Index (°F)	Heat Index (°C)	Wind Chill (°F)	Wind Chill (°C)	SLP (mbar)	Sol. Rad. (W.m-2)	Rainfall (in)	Rainfall (mm)	Hour
0	69.6	20.9	68.4	20.2	96	0.2	0.1	77.5 (ENE)	1.6@01:00	0.7	N/A	N/A	N/A	N/A	1010.5	0	0.00	0.0	0
1	69.5	20.8	68.6	20.3	97	1.2	0.5	163.8 (SSE)	2.5@01:45	1.1	N/A	N/A	N/A	N/A	1010.6	0	0.00	0.0	1
2	69.3	20.7	68.6	20.3	98	0.7	0.3	172.1 (S)	2.3@02:15	1.0	N/A	N/A	N/A	N/A	1010.5	0	0.00	0.0	2
3	69.3	20.7	68.7	20.4	98	0.5	0.2	87.9 (E)	2.6@04:00	1.1	N/A	N/A	N/A	N/A	1010.7	0	0.01	0.3	3
4	69.1	20.6	68.7	20.4	99	0.9	0.4	341.4 (NNW)	3.7@04:55	1.7	N/A	N/A	N/A	N/A	1010.4	0	0.05	1.3	4
5	68.7	20.4	68.3	20.2	99	1.1	0.5	31.4 (NNE)	3.9@05:20	1.8	N/A	N/A	N/A	N/A	1010.3	0	0.11	2.8	5
6	68.4	20.2	67.9	19.9	98	1.8	0.8	23.0 (NNE)	7.2@06:55	3.2	N/A	N/A	N/A	N/A	1009.9	2	0.12	3.0	6
7	68.1	20.1	67.5	19.7	98	1.2	0.5	93.8 (E)	5.3@08:00	2.4	N/A	N/A	N/A	N/A	1009.9	21	0.01	0.3	7
8	68.2	20.1	67.3	19.6	97	2.2	1.0	46.6 (NE)	9.9@08:20	4.4	N/A	N/A	N/A	N/A	1009.7	55	0.00	0.0	8
9	68.0	20.0	67.0	19.4	96	3.1	1.4	50.9 (NE)	9.4@10:00	4.2	N/A	N/A	N/A	N/A	1009.2	58	0.00	0.0	9
10	68.0	20.0	66.4	19.1	95	3.3	1.5	43.4 (NE)	11.0@10:10	4.9	N/A	N/A	N/A	N/A	1009.0	96	0.00	0.0	10
11	68.4	20.2	66.7	19.3	94	2.8	1.2	40.3 (NE)	8.0@11:55	3.6	N/A	N/A	N/A	N/A	1008.3	104	0.00	0.0	11
12	68.9	20.5	66.7	19.3	93	2.8	1.2	42.3 (NE)	9.6@12:35	4.3	N/A	N/A	N/A	N/A	1007.6	103	0.00	0.0	12
13	69.6	20.9	67.4	19.7	93	2.8	1.2	43.8 (NE)	8.5@13:55	3.8	N/A	N/A	N/A	N/A	1007.0	90	0.00	0.0	13
14	69.8	21.0	68.3	20.2	95	3.1	1.4	48.1 (NE)	11.2@14:40	5.0	N/A	N/A	N/A	N/A	1004.7	33	0.16	4.1	14
15	69.2	20.7	68.5	20.3	98	3.1	1.4	352.2 (N)	9.9@15:15	4.4	N/A	N/A	N/A	N/A	1003.5	8	1.58	40.1	15
16	68.4	20.2	68.0	20.0	99	3.9	1.7	22.5 (NNE)	12.7@16:55	5.7	N/A	N/A	N/A	N/A	1002.7	6	1.04	26.4	16
17	68.0	20.0	67.7	19.8	99	3.5	1.6	337.8 (NNW)	11.9@17:05	5.3	N/A	N/A	N/A	N/A	1001.8	2	1.54	39.1	17
18	66.1	18.9	65.6	18.7	98	4.4	2.0	354.5 (N)	13.3@18:35	5.9	N/A	N/A	N/A	N/A	1001.1	6	[illegible]	23.1	18
19	65.3	18.5	64.9	18.3	99	3.6	1.6	359.3 (N)	10.9@20:00	4.9	N/A	N/A	N/A	N/A	1001.4	1	1.11	28.2	19
20	64.3	17.9	63.7	17.6	98	6.5	2.9	1.0 (N)	15.9@20:35	7.1	N/A	N/A	N/A	N/A	1002.3	0	0.59	15.0	20
21	63.5	17.5	62.5	17.0	97	7.9	3.5	5.4 (N)	17.9@21:25	8.0	N/A	N/A	N/A	N/A	1002.9	0	0.56	14.2	21
22	62.8	17.1	61.8	16.6	97	6.7	3.0	9.2 (N)	19.0@22:05	8.5	N/A	N/A	N/A	N/A	1004.2	0	0.40	10.2	22
23	62.7	17.1	61.7	16.5	97	5.5	2.5	359.1 (N)	13.2@23:15	5.9	N/A	N/A	N/A	N/A	1004.5	0	0.01	0.3	23

Summary

High Temp. (°F)	Low Temp. (°F)	Avg. Temp. (°F)	Avg. Dew Point (°F)	Avg. Rel Hum (%)	Avg. Wind Spd (MPH)	Avg. Wind Dir (°)	Peak Gust (MPH)	Max. Heat Index (°F)	Min. Wind Chill (°F)	Total Rainfall (in)
69.9	62.6	67.6	66.7	97	3.0	26.5 (NNE)	19.0	N/A	N/A	8.20

Note: All observations were obtained from the Delaware Environmental Observing System network



POINT PRECIPITATION FREQUENCY ESTIMATES FROM NOAA ATLAS 14

Delaware 39.653 N 75.741 W 65 feet

from "Precipitation-Frequency Atlas of the United States" NOAA Atlas 14, Volume 2, Version 3
G.M. Bonnin, D. Martin, B. Lin, T. Parzybok, M.Yekta, and D. Riley
NOAA, National Weather Service, Silver Spring, Maryland, 2004

Extracted: Mon Oct 19 2009

Confidence Limits | Seasonality | Location Maps | Other Info. | GIS data | Maps | Doc

Precipitation Frequency Estimates (inches)

ARI* (years)	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day	7 day	10 day	20 day	30 day	45 day	60 day
1	0.35	0.55	0.69	0.95	1.18	1.42	1.53	1.90	2.31	2.68	3.09	3.42	3.97	4.48	6.04	7.51	9.51	11.37
2	0.41	0.66	0.83	1.15	1.44	1.72	1.86	2.29	2.79	3.23	3.73	4.12	4.76	5.35	7.17	8.85	11.18	13.33
5	0.48	0.78	0.98	1.40	1.79	2.15	2.33	2.86	3.50	4.08	4.71	5.18	5.92	6.55	8.57	10.36	12.89	15.25
10	0.54	0.86	1.08	1.57	2.04	2.48	2.69	3.32	4.09	4.79	5.52	6.05	6.87	7.52	9.69	11.54	14.18	16.67
25	0.60	0.95	1.20	1.78	2.37	2.92	3.18	3.97	4.97	5.83	6.68	7.29	8.24	8.88	11.20	13.09	15.82	18.45
50	0.64	1.01	1.28	1.94	2.62	3.26	3.57	4.50	5.71	6.71	7.65	8.33	9.38	9.98	12.39	14.29	17.05	19.76
100	0.68	1.08	1.36	2.09	2.87	3.61	3.96	5.06	6.51	7.67	8.69	9.43	10.60	11.13	13.59	15.46	18.21	20.98
200	0.71	1.13	1.43	2.22	3.11	3.96	4.37	5.65	7.39	8.71	9.81	10.62	11.90	12.35	14.81	16.63	19.31	22.13
500	0.75	1.19	1.50	2.39	3.43	4.43	4.92	6.49	8.67	10.24	11.43	12.31	13.77	14.08	16.46	18.15	20.70	23.52
1000	0.79	1.24	1.55	2.51	3.67	4.80	5.35	7.16	9.76	11.52	12.76	13.71	15.29	15.50	17.73	19.29	21.69	24.51

* These precipitation frequency estimates are based on a partial duration series. ARI is the Average Recurrence Interval.

Figure 6-11
24-Hour Rainfall Depths for Delaware for TR-55 Graphical Method

NRCS Type II, 24-Hour Duration			
Storm Event	County		
	New Castle	Kent	Sussex
1-yr	2.7	2.7	2.8
2-yr	3.2	3.3	3.4
5-yr	4.1	4.3	4.4
10-yr	4.8	5.2	5.3
25-yr	6.0	6.5	6.7
50-yr	6.9	7.6	7.9
100-yr	8.0	8.9	9.2
500-yr	10.9	12.6	13.0

	RAINFALL INTENSITY (in/hr)					
Tc (min)	2 YEARS	5 YEARS	10 YEARS	25 YEARS	50 YEARS	100 YEARS
0						
5	4.97	5.83	6.42	7.13	7.60	8.06
10	3.97	4.67	5.13	5.68	6.05	6.40
15	3.33	3.94	4.33	4.80	5.10	5.40
30	2.30	2.80	3.13	3.55	3.84	4.13
60	1.44	1.79	2.04	2.37	2.60	2.85
120	0.87	1.08	1.24	1.45	1.61	1.77
180	0.62	0.79	0.89	1.05	1.18	1.30
360	0.38	0.48	0.55	0.66	0.74	0.83
720	0.23	0.29	0.34	0.41	0.47	0.53
1440	0.13	0.17	0.20	0.25	0.29	0.34

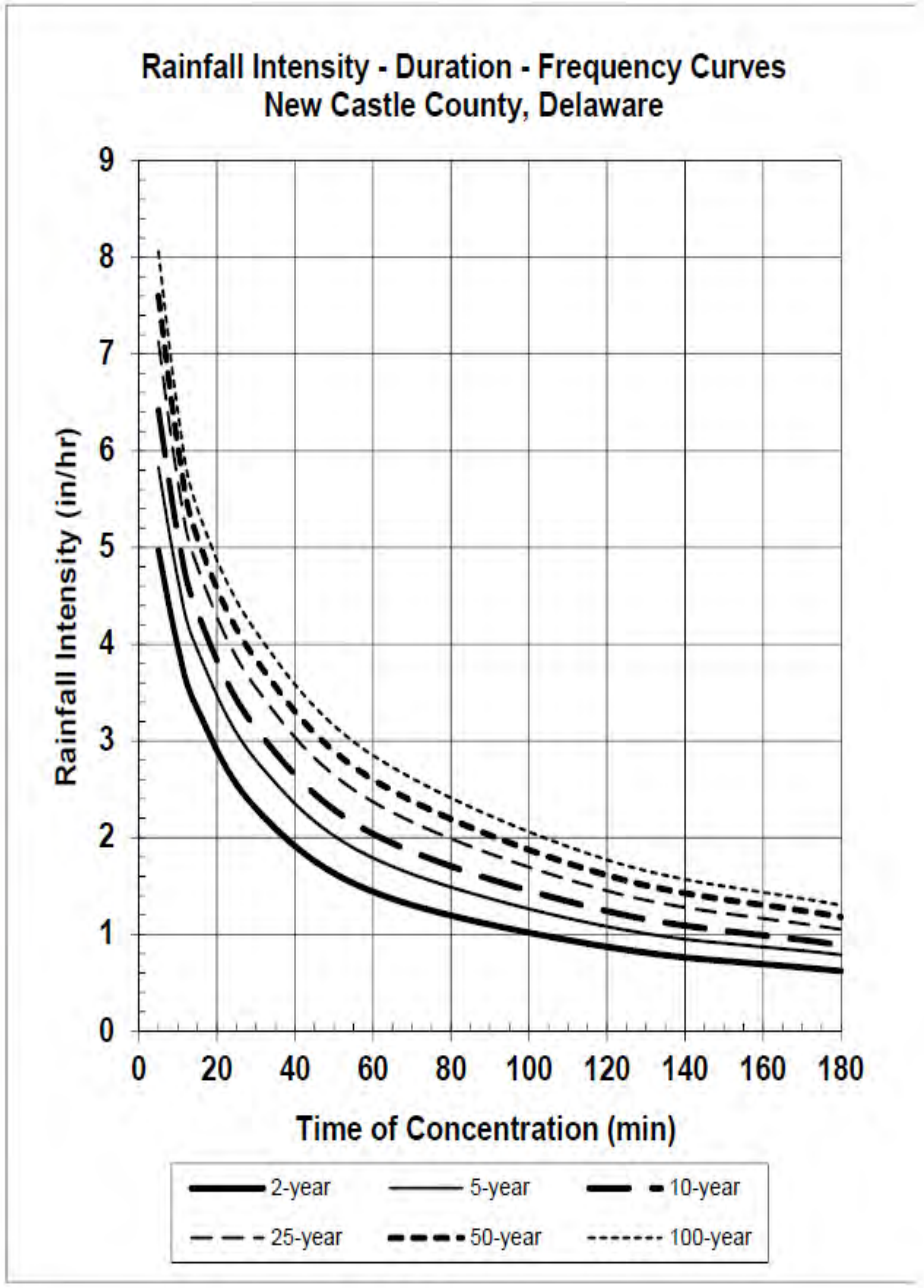
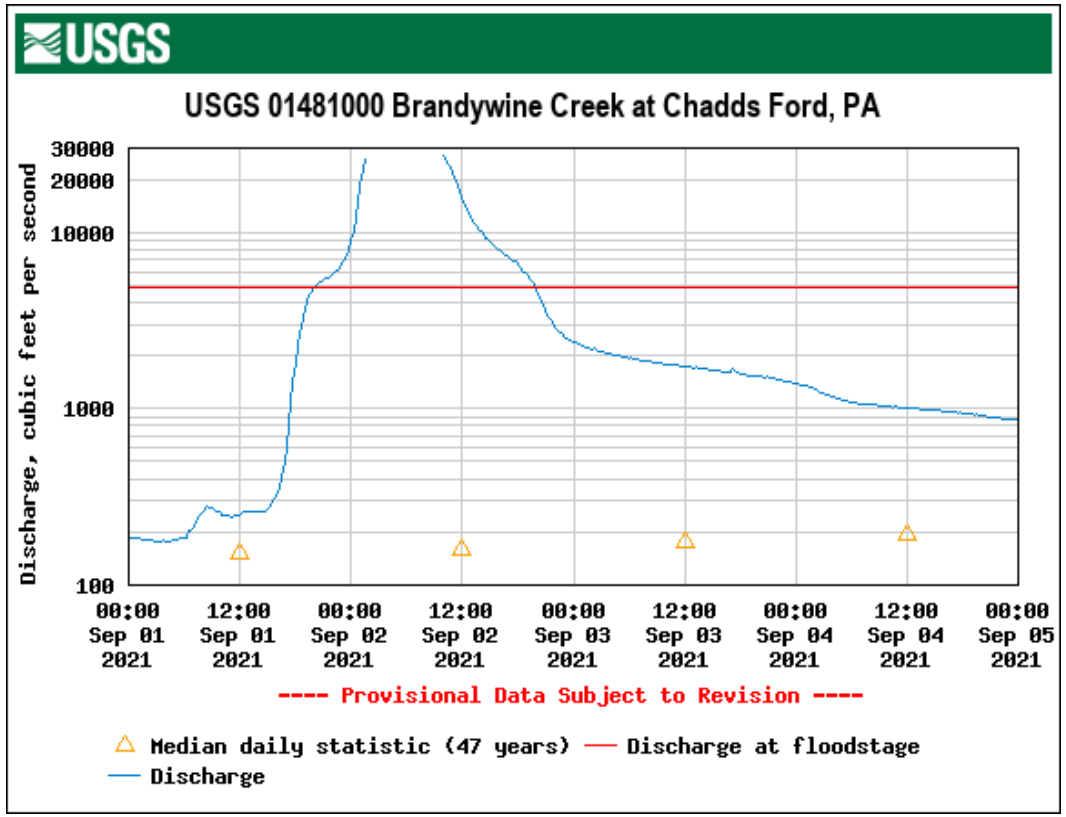


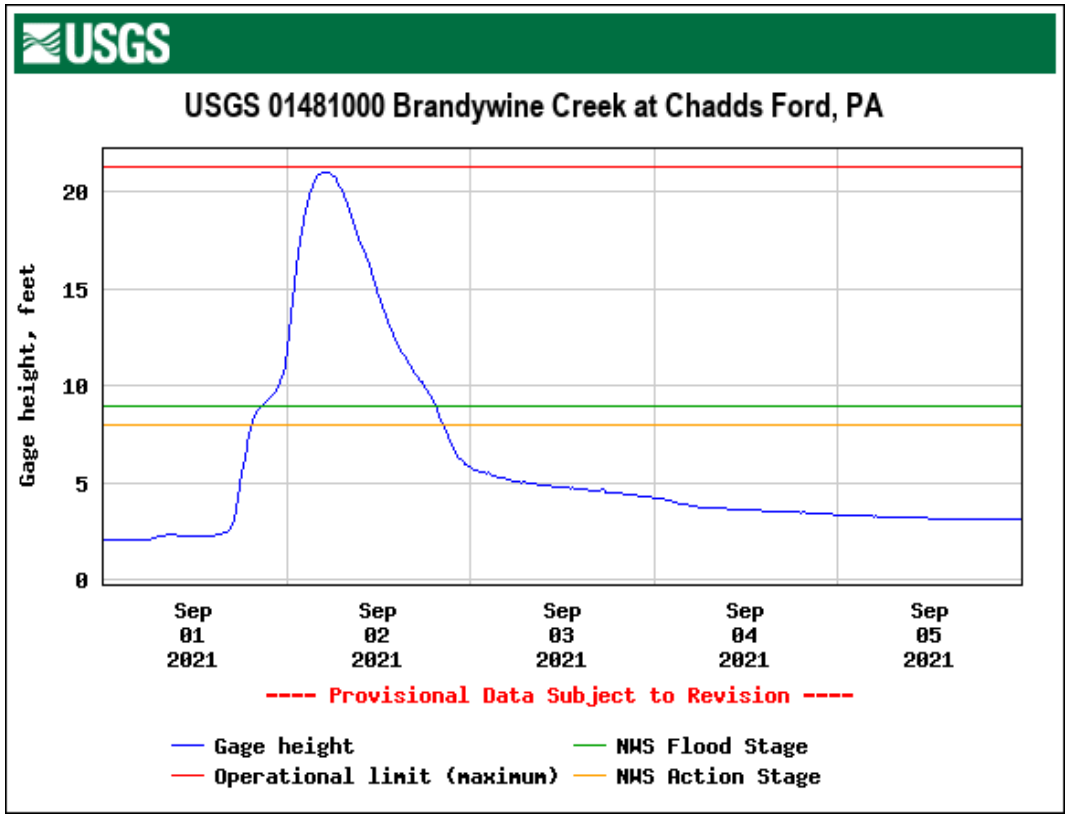
Table 10: Summary of Discharges – continued

Flooding Source	Location	Drainage Area (Square Miles)	Peak Discharge (cfs)				
			10% Annual Chance	4% Annual Chance	2% Annual Chance	1% Annual Chance	0.2% Annual Chance
Brandywine Creek	At a point approximately 100 feet upstream of its confluence with Cossart Run	295.2	16,872	*	27,166	32,205	45,609
Brandywine Creek	Approximately 90 feet upstream of the confluence with Craig Run	292.4	16,710	*	26,904	31,895	45,169
Brandywine Creek	Approximately 90 feet upstream of its confluence with Harvey Run	288	16,459	*	26,501	31,417	44,492
Brandywine Creek	At USGS gaging station No. 01481000	288	16,440	*	26,470	31,380	44,440
Brandywine Creek	At a point approximately 100 feet upstream of its confluence with Ring Run	285.3	16,306	*	26,254	31,123	44,077
Brandywine Creek	Approximately 100 feet upstream of its confluence with Brinton Run	283.7	16,214	*	26,107	30,949	43,830
Brandywine Creek	Approximately 90 feet upstream of its confluence with Bennetts Run	278.6	15,922	*	25,636	30,391	43,039

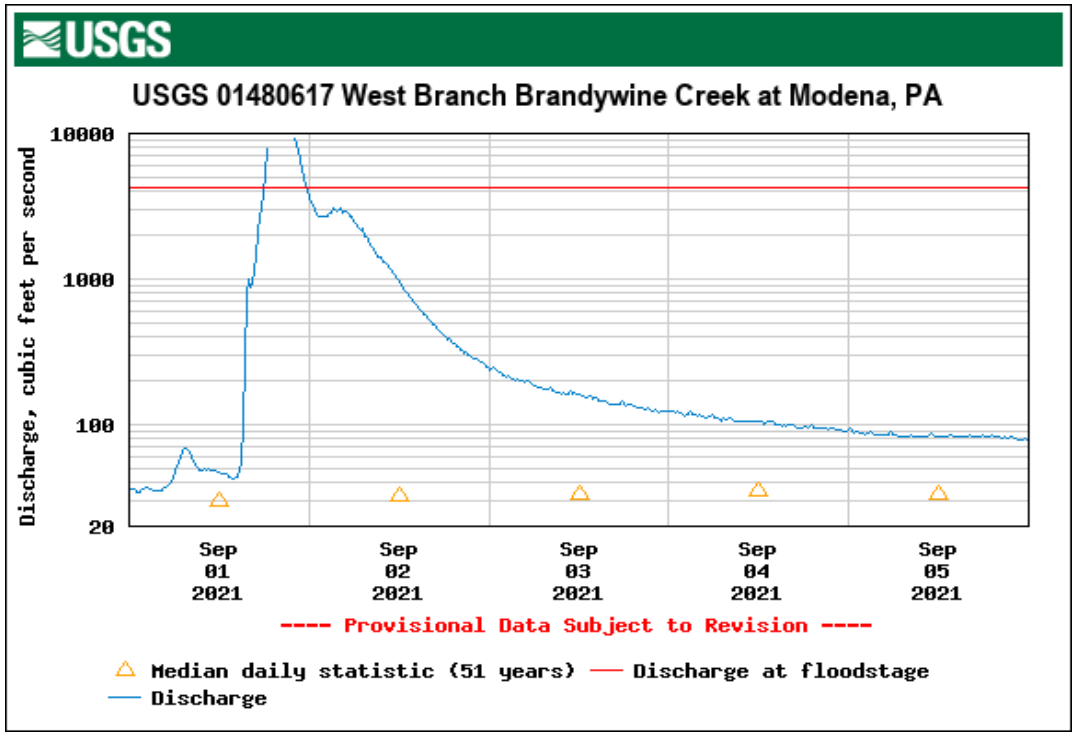
According to USGS, the 100-yr flood (1% chance) discharge at Brandywine Creek at Chadds Ford, PA is 31,380 cfs.



Ida peak discharge recorded at Brandywine Creek at Chadds Ford, PA > 33,000 cfs (>100-yr) at 2 am on Sep 2, 2021.

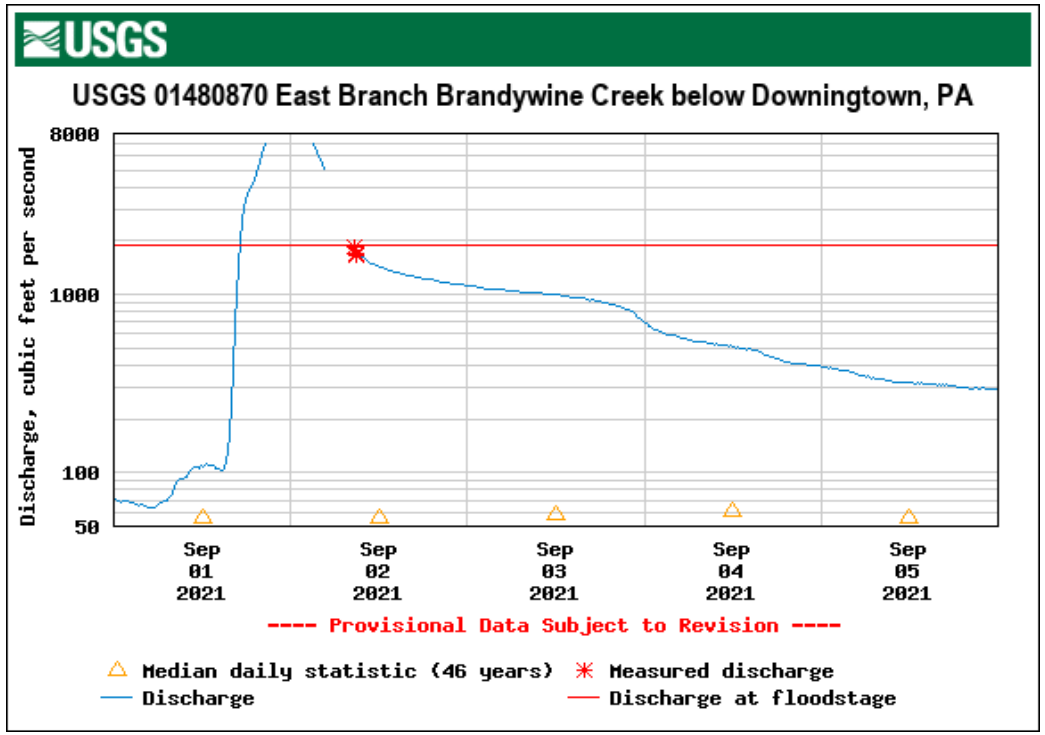


Ida peak stage at Brandywine Cr. at Chadds Ford, Pa = 21.75 ft at 2 am on Sep 2, 2021. Datum of gage is 150.45 ft (NGVD 1929) therefore Ida peak = 172.20 ft.

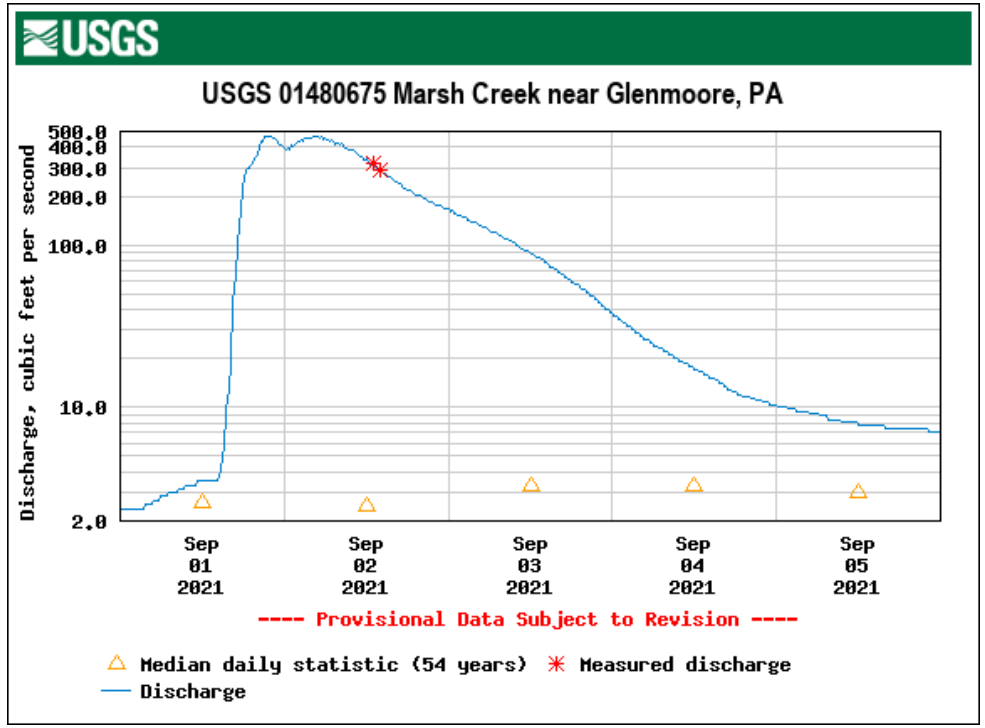


Ida peak discharge West Branch Brandywine Creek at Modena, Pa > 10,000 cfs at 8 pm Sep 1, 2021.

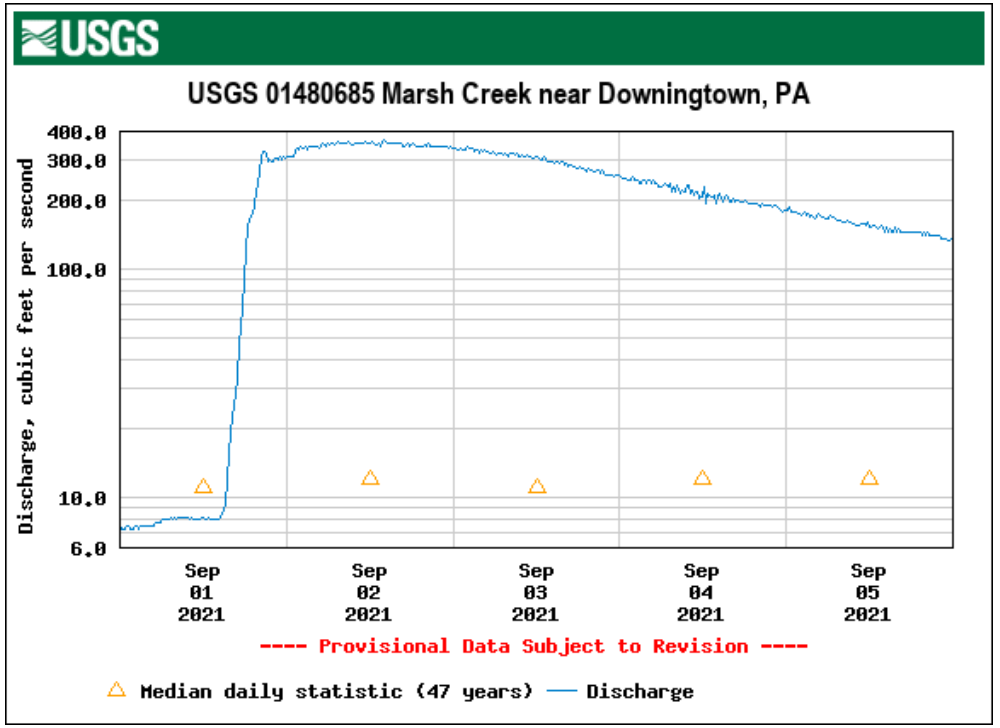
Travel time of peak from Modena to Chadds Ford, Pa was 6 hours.



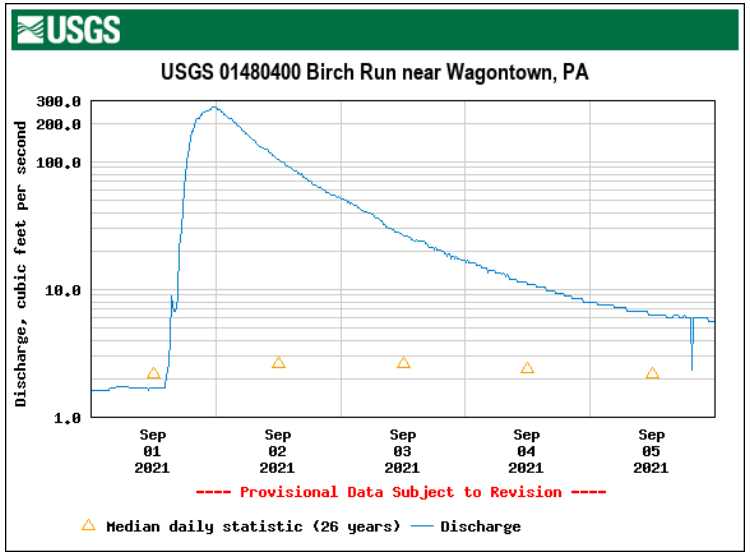
Ida peak discharge East Br. Brandywine Creek below Downington, Pa > 8,000 cfs at 11 pm Sep 1, 2021.



Peak inflow to Marsh Creek Reservoir 500 cfs midnight Sep 1, 2021.



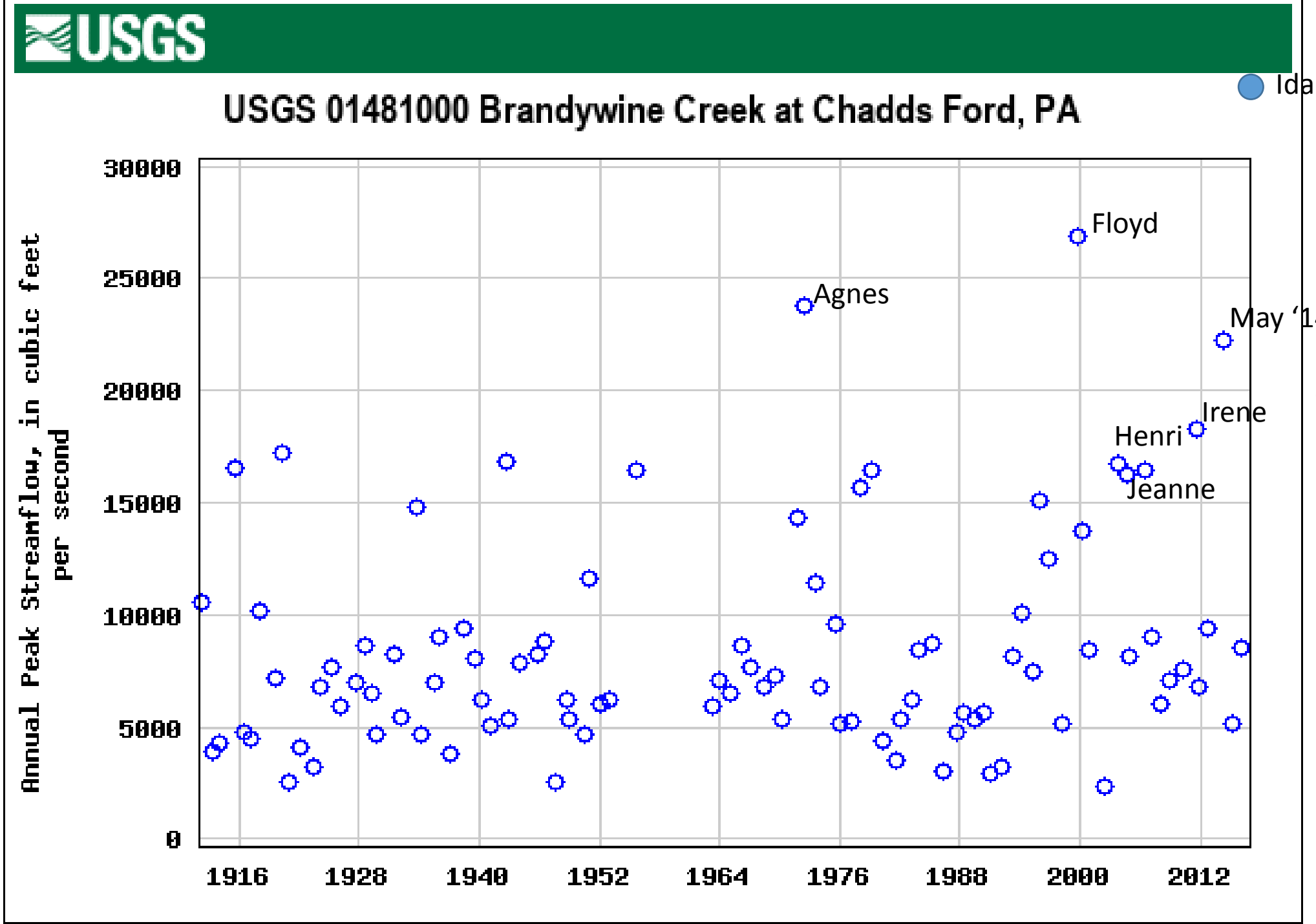
Peak outflow from reservoir < 400 cfs.



Peak outflow from Chambers Lake = 280 cfs along Birch Run above Coatesville, Pa.

USGS Gage	Date	Storm	Peak Flows[1] (cfs)	Return Interval[2]
Shellpot Creek at Wilmington, Del.	7/05/89	4th of July	8,040	100 yr
01477800	9/13/71		6,850	50 yr
	10/1/10		5,760	25-yr
1945-present	8/27/67		4,650	>10 yr
	9/16/99	Floyd	4,460	25 yr
	8/28/11	Irene	4,400	10-yr
	8/7/20		3,250	5-yr
Christina River at Cooches Bridge, Del.	8/4/20	Isaias	8,780	>100 yr
01478000	8/28/11	Irene	7,780	>100 yr
1943-present	9/16/99	Floyd	7,050	>100 yr
	7/05/89	4th of July	5,530	>50 yr
	9/28/04	Jeanne	5,430	>50 yr
	5/01/47		4,330	25-yr
	6/22/72	Agnes	3,320	10 yr
White Clay Creek near Newark, Del.	9/16/99	Floyd	19,500	>200 yr
01479000	8/28/11	Irene	17,000	>100-yr
1943-present	5/01/14		14,600	<100-yr
	9/15/03	Henri	13,900	>50-yr
	8/4/20	Isaias	12,100	50-yr
	7/05/89	4th of July	11,600	>25 yr
	1/19/96		9,150	25 yr
	6/22/72	Agnes	9,080	25 yr
	9/2/21	Ida	8,500	>10-yr
Red Clay Creek at Wooddale, Del.	9/15/03	Henri	15,600	>500 yr
01480000	9/28/04	Jeanne	8,280	>50 yr
1943-present	8/28/11	Irene	7,680	50-yr
	9/16/99	Floyd	7,650	50 yr
	8/7/20		6,730	>25-yr
	4/30/14		5,840	>10 yr
	6/28/06		5,490	>10 yr
	8/4/20	Isaias	5,280	>10 yr
Brandywine Creek at Wilmington, Del.	9/2/21	Ida	33,700	>100-yr
01481500	6/23/72	Agnes	29,000	100 yr
1946-present	9/17/99	Floyd	28,700	>50 yr
	5/01/14		22,800	>25-yr
	1/25/79		22,400	>25 yr
	9/13/71		21,300	25-yr
	9/29/04	Jeanne	20,800	25 yr
	8/19/55	Diane	17,800	>10-yr
	1/26/78		17,200	>10-yr
	8/28/11	Irene	16,800	>10-yr
	8/5/20	Isaias	16,100	10-yr

Ida peak flood **33,700 cfs** (100-yr) on Sep 2, 2021 highest on record along Brandywine Creek at Wilmington dating to 1946 surpassing Hurricane Agnes of **29,000 cfs** on Jun 23, 1972 and Hurricane Floyd of **28,700 cfs** on Sep 17, 1999..



Since 1911, Brandywine Cr. at Chadds Ford, Pa never exceeded 25,000 cfs until Floyd in 1999 (27,000 cfs) then Ida in 2021 (33,000 cfs).

DELAWARE RIVER BASIN, NEW YORK, NEW JERSEY, PENNSYLVANIA, AND DELAWARE

LETTER

FROM

THE SECRETARY OF THE ARMY

TRANSMITTING

A LETTER FROM THE CHIEF OF ENGINEERS, DEPARTMENT OF THE ARMY, DATED APRIL 2, 1962, SUBMITTING A REPORT, TOGETHER WITH ACCOMPANYING PAPERS AND ILLUSTRATIONS, ON A REVIEW OF THE DELAWARE RIVER AND TRIBUTARIES, REQUESTED BY A RESOLUTION OF THE COMMITTEE ON PUBLIC WORKS, UNITED STATES SENATE, ADOPTED APRIL 13, 1950, AND OTHER RESOLUTIONS OF THAT COMMITTEE AND OF THE COMMITTEE ON PUBLIC WORKS, HOUSE OF REPRESENTATIVES, LISTED IN THE REPORT

IN ELEVEN VOLUMES

VOLUME VI

AUGUST 16, 1962.—Referred to the Committee on Public Works and ordered to be printed with illustrations

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U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON : 1962

88197 O

37. Flood of January 1839. After a period of unusually low temperatures during January, a warm rain commenced on the night of 25 January and increased to a violent intensity. The rain continued until the afternoon of 26 January when the weather again became cold. The total quantity of rainfall was about 3-1/2 inches. Schuylkill River at Philadelphia experienced an estimated peak flow of approximately 114,000 c.f.s., with a crest stage above Fairmount Dam of more than 10 feet. The streams were swollen with rushing water carrying immense masses of ice. Bridges and property fell under the combined force of ice and current. Wharves along the Schuylkill from Fairmount to Grays Ferry were damaged, and large quantities of coal and wood were swept off by the flood. On the Delaware River all the bridges from Easton to Trenton were carried away. The ice in Lehigh River came down in a mass tearing away 75 feet of the embankment of the basin of the Pennsylvania Canal. The water rose about 15 feet above low watermark. The water in Brandywine Creek rose from 20 to 22 feet and all the bridges on the stream, except one highway bridge and one railroad bridge, were swept off. All dams were broken, and all mills and factories for many miles up the Brandywine were damaged.

38. Flood of January 1841. The flood of 8 January occurred after a period of intense low temperatures throughout the basin. All streams throughout the area were frozen over, including Delaware River at Philadelphia. The temperature at Philadelphia averaged about 6° above zero for the period 2-6 January. On 6 January the temperature increased rapidly to about 40°F., accompanied by heavy rains which lasted for two days. The persistent rain and thaw quickly broke up the ice in the rivers and the onrush of runoff from upstream areas produced the largest flood experienced on Delaware River to that time. (Estimated peak discharge - 256,000 c.f.s. at Trenton, over 35 feet above low water.) The heavy ice blocks and rushing water did tremendous damage to bridges and dams. Not a bridge was left on Lehigh River, and destruction of property was great. Extensive bridge and property damage occurred on the Schuylkill between Reading and Philadelphia. At Fairmount Dam water reached a height of eight feet above the dam.

39. Flood of September 1850. A violent rainstorm accompanied by heavy thunder occurred on 2 September over the Schuylkill and Lehigh River basins. The rain that fell amounted to about 3-3/4 inches which was somewhat less than the amount that occurred during a storm the preceding July, but the September rainfall occurred in less than half the duration of the earlier storm. The resulting flood was the highest ever known up to that time with an estimated peak of 125,000 c.f.s. on Schuylkill River at Philadelphia. Eleven highway bridges were swept away on the Schuylkill within a short distance of 41 miles between Phoenixville and Mohrsville. The flood rose to the height of 11 feet above Fairmount Dam. Every bridge on the Schuylkill from Tamaqua to Port Clinton was swept away and approximately 50 persons

The USACOE published a 1963 report on the Delaware River Basin that describes a Jan 26, 1839 flood along the Brandywine to height of 20 to 22 ft where all bridges except for a highway and RR bridge were swept away. On Schuylkill crest was 114,000 cfs so by ratio of drainage areas (peak flow 1839/peak flow Ida = 114,000/125,000 = x/33,000) estimated Jan 1839 flood on Brandywine = 30,100 cfs second only to Ida and above Sep 1999 Floyd of 27,000 cfs. Ida was highest flood in two centuries.

lost their lives in that area. The Schuylkill canal was damaged, which caused stoppage of coal shipments for four weeks. The flood on Lehigh River caused considerable damage mainly to bridges and to the Lehigh canal near Allentown, Pennsylvania. Lehigh River at Bethlehem rose to a height of about 17 feet. Delaware River at Easton rose to between 17 and 18 feet above normal.

40. Flood of June 1862. The flood of 5-8 June 1862 was the most severe in the Lehigh River basin recorded up to that time. It was caused by the greatest storm on the Lehigh since 1841 which produced an estimated 78,600 c.f.s. peak discharge at Bethlehem, Pennsylvania. At Easton, the lower portion of the city, bordering on Lehigh and Delaware Rivers, was inundated and the floodwater reached the second story levels of the dwellings. All highway bridges on the Lehigh between Easton and Jim Thorpe (formerly Mauch Chunk) were swept away. The whole town of Weissport was washed away with but three houses left out of about 300. Loss of life was high. Much damage was done on Brodhead Creek and McMichaels Creek, and Stroudsburg suffered severely. All the bridges on Brodhead Creek except the railroad bridge were destroyed and some damage occurred to the Delaware, Lackawanna and Western Railroad. Delaware River at Delaware Water Gap was three feet lower than the previous record high stages in the flood of 1841. The water was 27 feet high on Lehigh River at the dam at Jim Thorpe, six feet higher than in the flood of 1841. The headwaters area of Schuylkill River sustained some damage, though small in comparison to that in the Lehigh basin. Three bridges of the Reading Railway between Port Clinton and Schuylkill Haven were destroyed, and navigation on Schuylkill River was interrupted temporarily.

41. Flood of October 1869. The "Northeaster" flood of 4-6 October caused considerable damage on Schuylkill River and remains the flood of record with an estimated 135,000 c.f.s. peak discharge at Philadelphia, Pennsylvania. An unparalleled drought of so serious a character that the water supply of the city of Philadelphia was greatly diminished was followed closely by a freshet of unprecedented violence. Bridges were carried away, factories and dwellings were inundated, and Fairmount, Flat Rock and other dams, which a few days previously had been high and dry, were completely submerged by the waters that dashed over them with terrific violence. The flood was caused by rain that fell during 2 and 3 October. The amount that fell during this period was one-tenth as much as had fallen for one year previously, or 4.7 inches, at Philadelphia, Pennsylvania. The total storm rainfall over the basin reached approximately 6-3/4 inches. On 5 October crest stage over Fairmount Dam, Philadelphia, reached 11-1/2 feet, or 1/2 foot higher than ever previously recorded. Schuylkill River at Reading, Pennsylvania, rose 22 feet above normal level, or three feet less than during the 1850 flood. Delaware River at Philadelphia rose 20 feet above normal level. Lehigh River at Bethlehem rose 20 feet above low watermark, 15 inches short of the 1862 flood

height. At Wilmington, Delaware, it was the greatest flood on the Brandywine River since 1839.

42. Flood of October 1903. The flood of 7-11 October occurred as a result of a hurricane associated storm which centered east of the upper Delaware River basin. Most of the basin above Trenton was in severe flood and records were established that remained unbroken until 52 years later in August 1955 when flood crests several feet higher were recorded in much of the Delaware River. Flood flows in the upper basin were exceedingly high in 1903 and flood stages reached on the East and West Branches of Delaware River at Fishs Eddy and Hale Eddy, respectively, still remain the maximum of record.

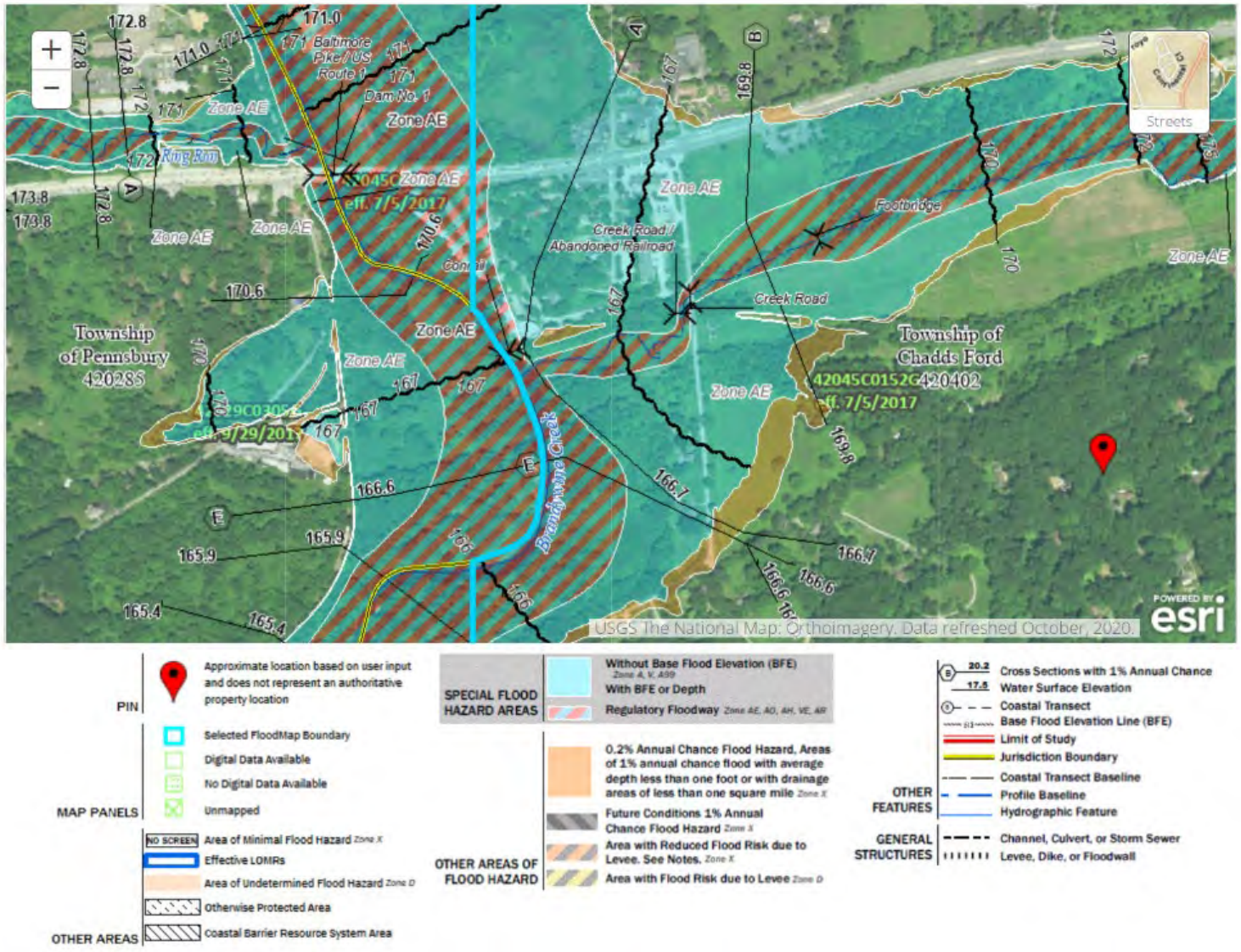
43. Flood of August 1933. The storm of 21-25 August was of the tropical hurricane type which came inland at Norfolk, Virginia, crossed the length of the Susquehanna River basin, and continued northeastward across New York State. The storm produced high runoff causing serious flooding on various streams along the western and northern portions of the Delaware River basin. Schuylkill River at Reading reached a stage of 21.4 on 24 August which is slightly below the alltime record of 22.17 feet on 23 May 1942. A large area was flooded in the southern portion of the city. Basements were filled and the first floors of hundreds of homes and business places were inundated by flood waters. All of the towns along the river from Reading to Philadelphia suffered some degree of flood damage. In the upper portion of the basin major flooding was confined to Neversink River and East Branch of Delaware River. At Fishs Eddy, on the East Branch of Delaware River, flood stage reached 20.6 feet, which is the second highest in 45 years of record.

44. Flood of July 1935. The flooding was caused by several severe localized thunderstorms which occurred during the period 6 to 9 July. Torrential rains on the 7th and 8th of July, centered along the divide of the Susquehanna and Delaware Rivers in southern New York, caused considerable flooding along several minor tributary streams of the West Branch of Delaware River. Heavy thunderstorms occurred in eastern Pennsylvania on 9 July and flooded the Lehigh and Schuylkill Rivers, causing considerable damage when these streams rose as much as 20 feet above bank-full stage during the night of 9 and 10 July. Perkiomen Creek, a tributary of Schuylkill River, rose as much as 20 feet in some places, causing considerable damage to summer cottages along the banks.

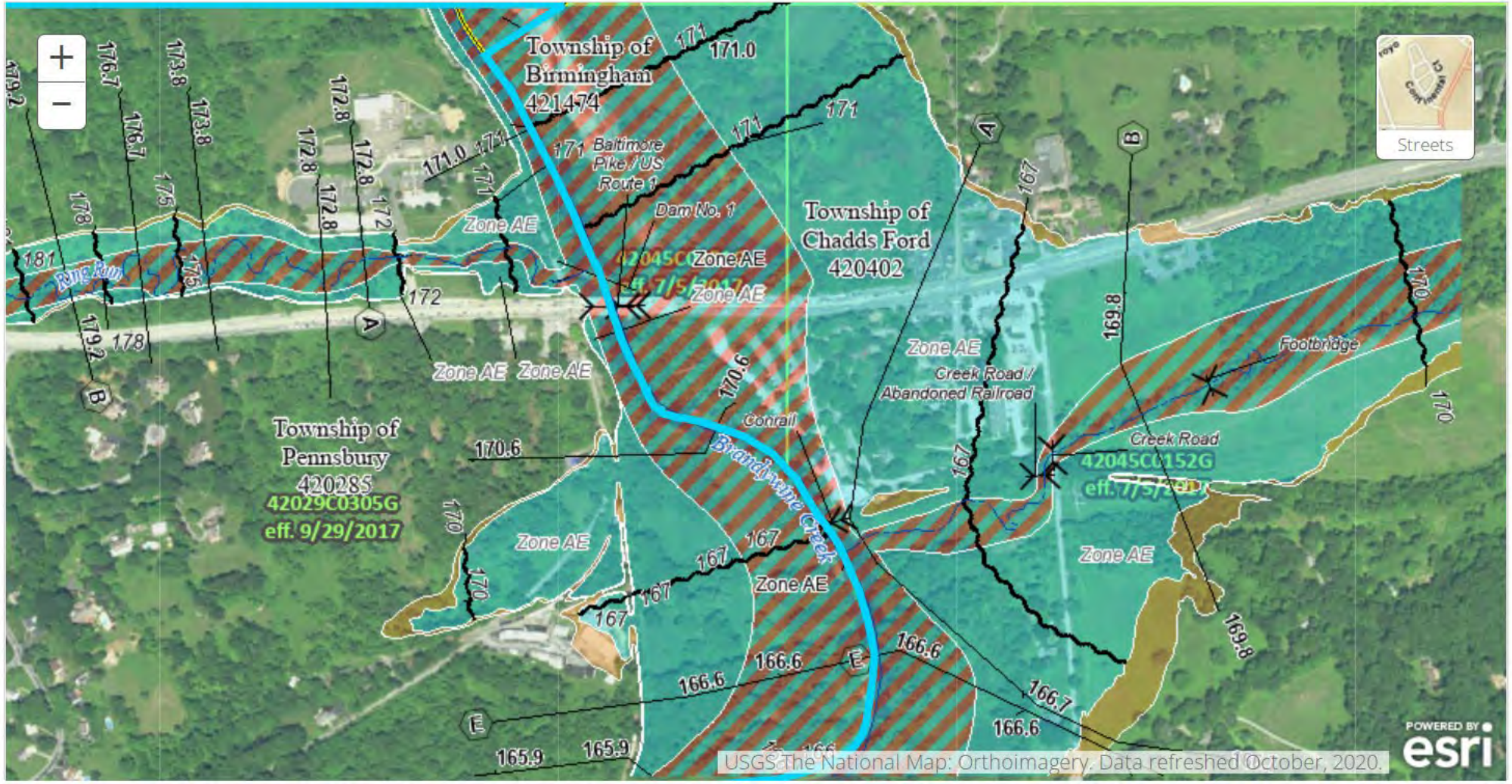
45. Flood of March 1936. Until 25 February the season was typical of winter, the temperature was low and streamflow at the minimum for the season. On 25 February there was a marked rise in temperature, with but little precipitation throughout the basin. The thaw extending from 25 February to 10 March was moderate and discontinuous in upstream areas in New York and Pennsylvania, but somewhat more

https://www.chesco.org/3458/FEMA-Floodplains
https://msc.fema.gov/portal/search#searchresultsanchor

https://www.chesco.org/2198/ChescoViews
https://map1.msc.fema.gov/data/FRP/FRR_42029C_20170801.pdf?LOC=63b372ffb95a0c84d9c3c0abff461a0a



100-yr flood elev. = 167.0 ft below RR trestle, 170.6 ft upstream from trestle, and 171.0 ft at Rte 1 bridge. The USGS stream gage recorded peak stage 172.20 at RR trestle or 1.2 ft > 100-yr flood elev. 171.0 ft. The RR trestle and embankment to east causes at least 3.6 ft rise in flood elevation at the museum and more if debris clogged the RR bridge.



PIN
Approximate location based on user input and does not represent an authoritative property location

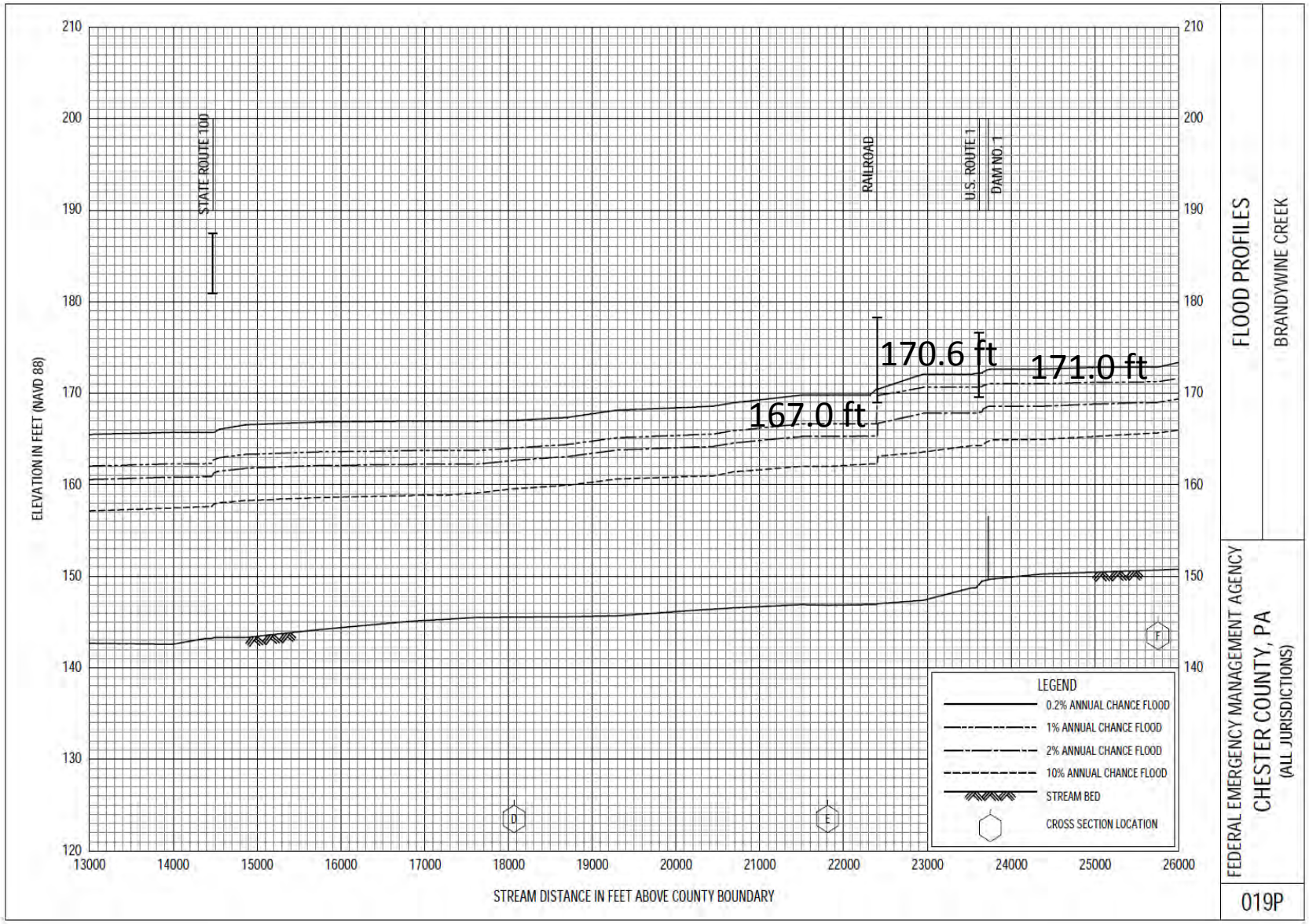
MAP PANELS
Selected FloodMap Boundary
Digital Data Available
No Digital Data Available
Unmapped
NO SCREEN Area of Minimal Flood Hazard Zone X
Effective LOMRs

SPECIAL FLOOD HAZARD AREAS
Without Base Flood Elevation (BFE) Zone A, V, A99
With BFE or Depth
Regulatory Floodway Zone AE, AO, AH, VE, AR

OTHER AREAS OF
0.2% Annual Chance Flood Hazard. Areas of 1% annual chance flood with average depth less than one foot or with drainage areas of less than one square mile Zone X
Future Conditions 1% Annual Chance Flood Hazard Zone X
Area with Reduced Flood Risk due to Levee. See Notes. Zone X

OTHER FEATURES
20.2 Cross Sections with 1% Annual Chance
17.5 Water Surface Elevation
Coastal Transect
Base Flood Elevation Line (BFE)
Limit of Study
Jurisdiction Boundary
Coastal Transect Baseline
Profile Baseline
Hydrographic Feature

GENERAL STRUCTURES
Channel, Culvert, or Storm Sewer
Levee, Dike, or Floodwall



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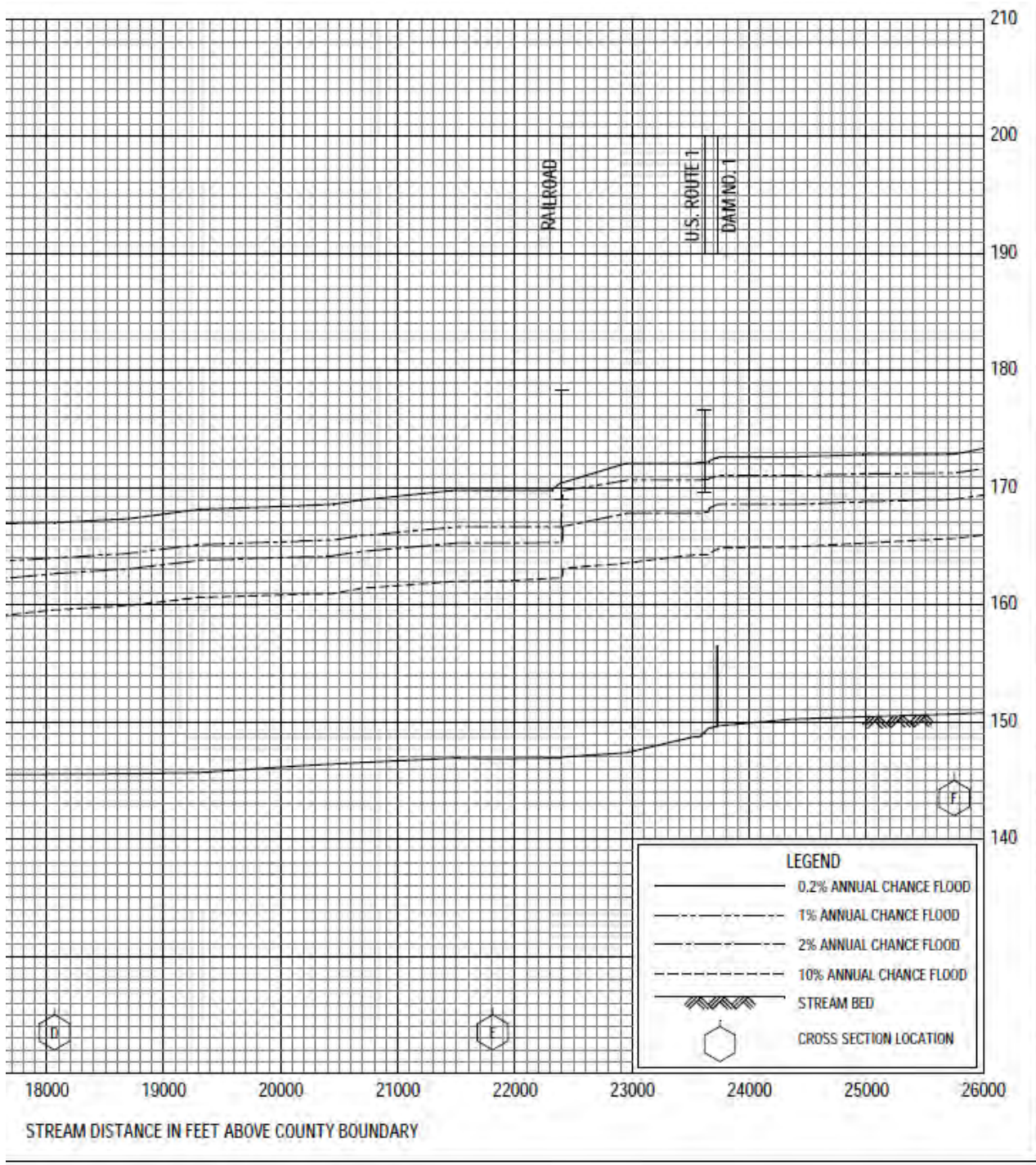

FLOOD PROFILES

BRANDYWINE CREEK

FEDERAL EMERGENCY MANAGEMENT AGENCY

CHESTER COUNTY, PA

(ALL JURISDICTIONS)

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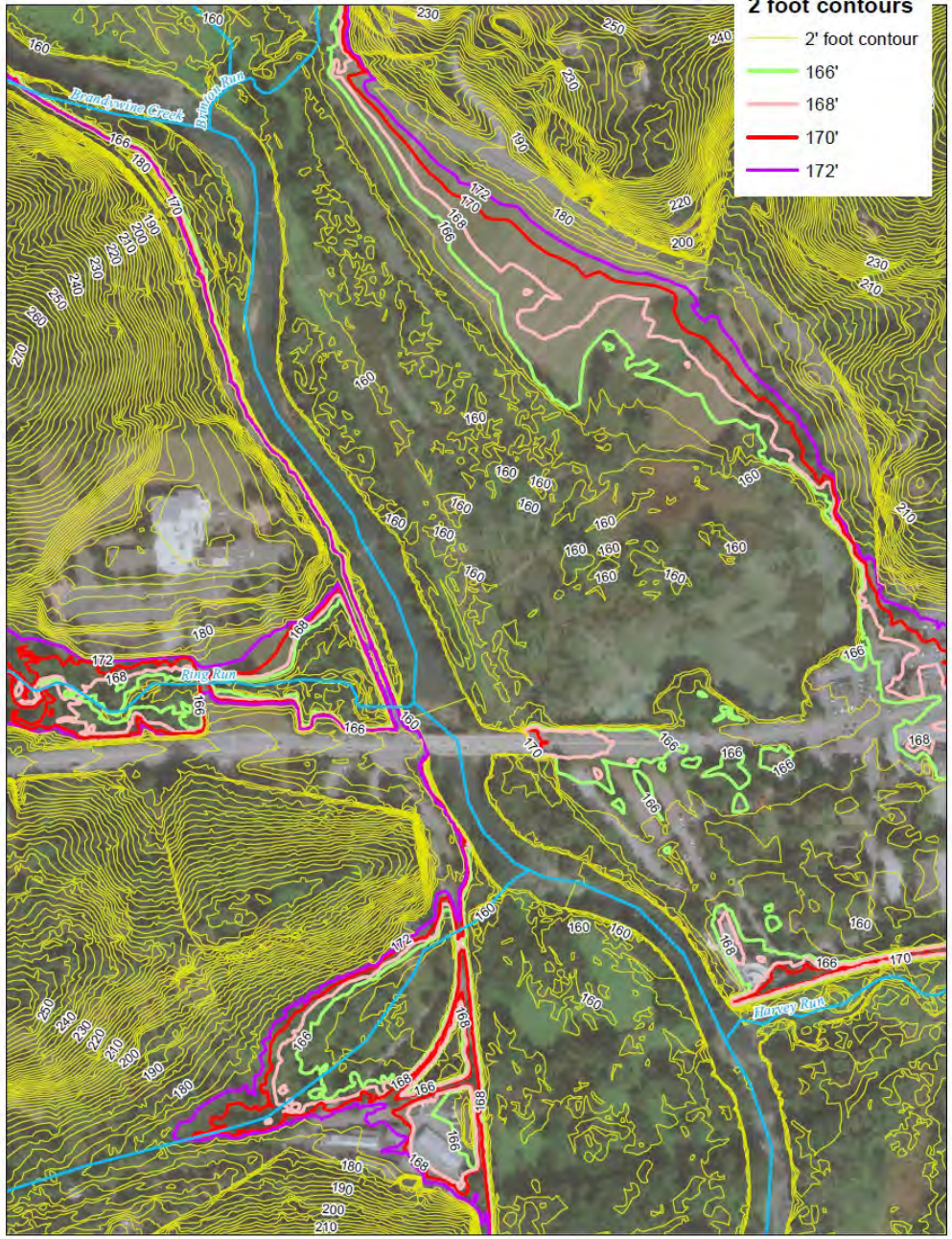

LIDAR map at 2 ft contour interval (UDWRC). Elev 166 ft (green) and 168 ft (salmon) are Ida high water marks below RR trestle. Elev. 170 ft (red) and 172 ft (purple) are high water marks upstream from RR trestle and at/above Rte 1 bridge.

Railroad trestle and embankment to east causes at least 3.6 rise in flood elevation to 170.6 ft at museum.
If all/part of RR embankment to east were removed to grade it would reduce 100-yr flood elev to Elev 167 ft (green and salmon).
RR trestle to west is elevated allowing floodwater to pass unimpeded on the floodplain.

RR trestle looking downstream embankment to east and trestle to west note debris from Ida.

Ida highwater mark (elev. 172 ft) at Rte 1 bridge looking east at 8 am Sep 2, 2021 (BCMA).

The Brandywine Museum, which sits along the banks of the Brandywine, remains closed 10 weeks after the flood as repairs are made. All the Wyeth paintings and other artworks were spared, but the museum complex suffered at least $6 million in damage.

As the River Runs

Ida brought a 1,000-year downpour, and an art museum took a big hit.

By Anthony R. Wood
STAFF WRITER

After terrorizing neighborhoods from Coatesville to Downingtown, the Brandywine's floodwaters reached a crescendo at Chadds Ford. By then, they were two stories high and rampaging at an incredible 33,000 cubic feet per second, a ferocity beyond anything in the period of record.

The waters crashed into the Brandywine River Museum — home of some of the region's most significant artworks, including Andrew Wyeth paintings that famously captured the valley's tranquil and mystical sides — filling the lower level to the ceiling and damaging all 10 buildings in the complex.

Ten weeks after the historic floods incited by the remnants of Ida, and with the peak holiday season now imminent, the museum remains closed and it is unclear when it will reopen.

Although no one was injured and all the Wyeth paintings and other artworks were spared, the museum complex suffered at least $6 million in structural and equipment damage and counting, said Virginia A. Logan, executive director of the Brandywine Conservancy & Museum of Art.

"We've never seen anything like this," she said.

No one else has, either, according to a hydraulic analysis of the Brandywine at Chadds Ford completed last week by Gerald Kauffman Jr., director of the University of Delaware's Water Resources Center. The U.S. Geological Survey "never anticipated this extreme of flooding," nor had any other government agency, he said.

A wave of floodwater two stories high — triple

See **MUSEUM** on B2

Floodwaters filled the lower level to the ceiling and damaged all 10 buildings. Above, the ground-floor museum offices. JOSE F. MORENO / Staff

Another building at the Brandywine River Museum. "We've never seen anything like this," says Virginia A. Logan, executive director of the Brandywine Conservancy & Museum of Art. Several issues contributed to the flooding.

Museum

Continued from B1

the depth of the creek at Chadds Ford — overwhelmed the stream banks, and of all the record Ida-related crests verified by the National Weather Service, that one evidently was No. 1 in terms of exceeding the previous record.

What was captured at the USGS gauge right at the museum was a dramatic encapsulation of the ferocity and unprecedented nature of the Ida-related flooding. The conspirators identified by experts included topography, enhanced rains associated with climate change, a once-in-1,000-years downpour 18 miles upstream, a cascade of water from 1,000 feet above sea level, and a fateful 19th-century engineering decision.

This probably wasn't what Wyeth had in mind when he said: "I don't think that there is anything that is really magical unless it has a terrifying quality."

About the Brandywine

The Brandywine watershed covers 38% of Chester County and all or part of 41 towns, according to the Stroud Water Research Center's Return on Environment report. In a tuning-fork shape, the West and East Branches of the Brandywine Creek in western Chester County join the main stem near Lenape, and it becomes seriously pinched as it approaches Chadds Ford.

The banks at the museum site are about 80 feet apart, less than half the separation just a few hundred yards upstream, says Kauffman.

Population in the watershed has risen 10% this century, and with it paving and other hard surfaces have increased, according to his analysis. Between 1996 and 2010, the watershed added nine square miles of developed land, or about 300 football fields' worth.

Perhaps surprising given that the Brandywine flows through both the Routes 30 and 1 corridors, just under 6% of the watershed is hard-covered, according to Kauffman's report. That's because so much of the acreage is "protected."

Development did make some contribution to Ida's havoc, said Seung Ah Byun, executive director of the Chester County Water Resources Authority.

Nevertheless, Stroud Center director Charles Dow believes Ida's rains probably trumped everything else. When rain overwhelms even a meadow, he said, it can take on the character of a paved surface in that additional rains run right off of it.

The Brandywine River Museum remains closed as the peak holiday season approaches. JOSE F. MORENO / Staff Photographer

And while the overall rain amounts in Chester County were prodigious, the speed with which they came was catastrophic.

At Modena, on the Brandywine's West Branch, 7.02 inches of the 8.18 total fell in a six-hour period ending at 8 p.m. Sept. 1 — a downpour that would be expected only once every 1,000 years — according to a Chester County Water Resources Authority analysis.

"My grandmother used to say, 'It's raining cats and dogs,' " Kauffman said. "This is higher than that."

Six hours later, the consequences had rippled to Chadds Ford, 18 miles downstream.

About Chadds Ford

The museum has a standing disadvantage in its battle with nature, said Dow: "It was built in a floodplain."

Occupying a building that housed a mill dating to 1859, it opened in 1971. A year later, it endured what was then a record flood from the remnants of Agnes, a record topped when Floyd visited in 1999 and the Chadds Ford gauge reached 17.15 feet. Ida, at 21.04 was a full 20% higher.

The museum is still tallying the damage, Logan said. She added that neither insurance nor disaster assistance will come close to covering the costs. The Brandywine Conservancy has set up a relief fund.

Kauffman says the museum's flooding woes have a whole lot to do with human activity, and not just increases in greenhouse gases or development.

At some point in the 19th century, a decision was made to "channelize" the Brandywine's banks from Route 1, near the current site of the museum, for several hundred yards eastward to make way for a railroad bridge, he said. Shrinking the banks provided land for planting the trestle supports.

"I think that's the choke point," he said.

The future

Kauffman is confident that can be fixed, federal money willing, adding it would cost about $500,000 to widen the banks. He is part of a bistate, intergovernmental task force that is looking at the basin and what can be done to mitigate the flood hazards.

"This group, I'm hoping, is going to move quickly, so that malaise doesn't set in, and we're not ready for the next big one," he said. "We're trying to avert that.

"We call this the hydro-illogical cycle," he said, "not the hydrologic cycle."

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Conclusions

1. Based on instrumental record to 1911 Ida was a truly historic event only two floods > 25,000 cfs and not until 1999 then 20 yrs later in 2021.

2. There looks like there could be a fix here involving earthwork with the RR embankment to the east. We have a USGS map showing the RR in 1896 and looking at the history realize the mill buildings and RR are circa Civil War.

3. This began a century and a half ago and if we had computer hydraulic models in the 19th century the code to protect the riparian rights of the mill would have specified the RR build a trestle to east out to Rte 100 to span the floodplain ala the short trestle to west that does the job job.

4. At high 50-yr floods and over like Ida, the RR trestle can't adequately pass flood without backwater and serves as dam with debris jams, this insufficient hydraulic capacity increased Ida flood elevations at museum and Rte 1 by 4 ft which is difference between water damage and not.

5.The museum is also at the confluence of the Brandywine itself and 2 incoming tributaries Ring Run and Harvey Run.

6. Ida at 33,000 cfs far exceeded Floyd (1999) at 27,000 cfs. Ida at 33,000 cfs > USGS 100 yr flood discharge 31,380 cfs.

7. From USACOE 1963 report, Jan 26, 1839 flood on Brandywine rose to 22 ft all bridges except for highway and RR bridge swept away. Estimate Jan 1839 Brandywine flood = 30,100 cfs second only to Ida and above Sep 1999 Floyd of 27,000 cfs. Ida was highest flood in two centuries.

8. Ida peak flood wave travel time from Modena (8 pm Sep 1, 2021) to Chadds Ford (2 am Sep 2, 2021) = 6 hours.

9. PADCNR & CCWRA reservoirs attenuated flood. Marsh Cr. reservoir release 100 cfs < than inflow. Just 300 cfs release Chambers Lake reservoir.

10. Chadds Ford USGS gage recorded Ida peak flood elevation 172.2 ft msl upstream from the RR trestle.

11. FEMA HECRAS flood profile: RR trestle and embankment causes 3.6 ft rise in 100-yr flood elevation (170.6 ft US – 167.0 ft DS).

12. Removing part of RR embankment to east to grade could reduce 100-yr flood and historic Ida elevations by 4 ft at museum and campus buildings which could flood proof these facilities and leaves Rte 1 unflooded so businesses at Rte 100 intersection/PENNDOT benefit too

13. The elevated RR trestle to west spans the floodplain providing effective flood storage there.