Brandywine Flood Study

Full Technical Report

Draft Release - January 2025

PREPARED BY

Brandywine Conservancy

University of Delaware Water Resources Center

Chester County Water Resources Authority

Acknowledgements

The Brandywine Conservancy, Chester County Water Resources Authority and University of Delaware Water Resources Center would like to acknowledge the following organizations for their partnership in preparing the Brandywine Flood Study report. The following organizations have contributed to the data and content provided in this report as well as participated in the flood studies technical committee and outreach:

- Arcadis
- Chester County, Pennsylvania
- City of Wilmington, Delaware
- Delaware County, Pennsylvania
- Gannett Fleming
- Geodesy, Inc.
- Meliora Design
- New Castle County, Delaware
- Stroud Water Research Center
- United States Geological Survey
- West Chester University

It is important to recognize there are a multitude of projects being conducted in the Brandywine watershed throughout Delaware and Pennsylvania through a variety of nonprofit, government, academic and private organizations. The Brandywine Flood Study is an important piece of a broader and multi-faceted effort to reduce flooding and its impact on the communities in the Brandywine River Watershed.

The report team would like to acknowledge Chester County, Delaware County, Federal Emergency Management Agency (FEMA), National Oceanic and Atmospheric Administration (NOAA) and Pennsylvania Emergency Management Agency (PEMA) for its funding support of the Brandywine Flood Study.

Table of Contents

List of Tables

List of Figures

Chapter 1 Flooding in the Brandywine – A Call to Action

1.1. Introduction

The Brandywine Creek, which traverses through southeastern Pennsylvania and northern Delaware, has always had an incredible impact on the local landscapes and communities. Hundreds of years ago, industries established themselves along the banks of the Brandywine and its tributaries to harness its power. Townships and cities settled around those industrial hubs and continued to grow and expand even as the use of hydropower declined. Today, these streams provide natural character and numerous ecosystem services to their communities. Yet, flooding along these waterways has the potential to endanger lives, disrupt economic activities, and cause extensive damage.

Communities along the Brandywine Creek and its tributaries are no stranger to the threat of rising waters. Many residents across the region can vividly recall hurricanes, tropical storms, and other major rain events that disrupted their lives in one way or another. The devastation caused by Hurricane Ida in 2021 brought renewed attention to flood mitigation efforts in the Brandywine watershed. That storm served as the main catalyst for this study to better understand the factors that contribute to and exacerbate flooding in the watershed, as well as identify actionable steps communities can take to reduce flood risks.

Planning for flooding along the Brandywine Creek and its tributaries has been an ongoing exercise for decades. Major floods in 1920, 1933, 1942, 1955, 1972, and 1973 were referenced in plans that ultimately resulted in the construction of five regional flood control facilities within the upper portions of the watershed. These include:

- Robert G. Struble, Sr. Dam and Regional Flood Control Facility - built in 1971 on the East Branch Brandywine Creek in Honey Brook Township.
- Marsh Creek Reservoir and State Park - built in 1973 on Marsh Creek in the East Branch Brandywine watershed in Upper Uwchlan Township.
- Beaver Creek Regional Flood Control Facility - built in 1975 on Beaver Creek in the East Branch Brandywine watershed in East Brandywine Township.
- Barneston Regional Flood Control Facility - built in 1983 on the East Branch Brandywine Creek in Wallace Township.
- Hibernia Regional Flood Control Facility - built in 1994 on Birch Run in the West Branch Brandywine Creek watershed in West Caln Township.

Together, these structures provide 5.5 billion gallons of total flood storage capacity to protect thousands of lives and properties downstream. This amount of water could fill the entire Lincoln Financial Field stadium, home of the Philadelphia Eagles, seven times.

Struble Lake and Dam in Chester County, PA

However, as storms become more frequent and intense and development continues throughout the watershed, the challenge of flooding continues. According to the National Oceanic and Atmospheric Administration (NOAA) Storm Events Database, since 1996 (two years after the construction of the final regional flood control facility), flood events have resulted in two deaths and more than $56 million in property damage in Chester County, PA. The remnants of Hurricane Ida alone, which occurred September 1-2, 2021, caused nearly $45 million in damage to private property and public infrastructure in southeastern Pennsylvania and northern Delaware. Several communities within the watershed are still actively recovering from Ida.

To address these longstanding challenges, the Chester County Water Resources Authority (CCWRA), Brandywine Conservancy & Museum of Art (BC), University of Delaware Water Resources Center (UDWRC), and Delaware County, PA have conducted a flood study of the Brandywine Creek and its tributaries in Chester County, PA and the state of Delaware. This study builds upon the 2017 Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRMs) updates and flood zone maps revisions for the region by incorporating updated land use data and climate model projections with hydrologic and hydraulic computer modeling.

The project analyzes the Brandywine Creek during intense storm and flooding events in order to produce an actionable suite of flood mitigation recommendations. This report provides a summary of the research and community outreach conducted, along with proposed implementation strategies to address future intense storm events and flooding throughout the watershed.

The Brandywine Flood Study included the following key elements:

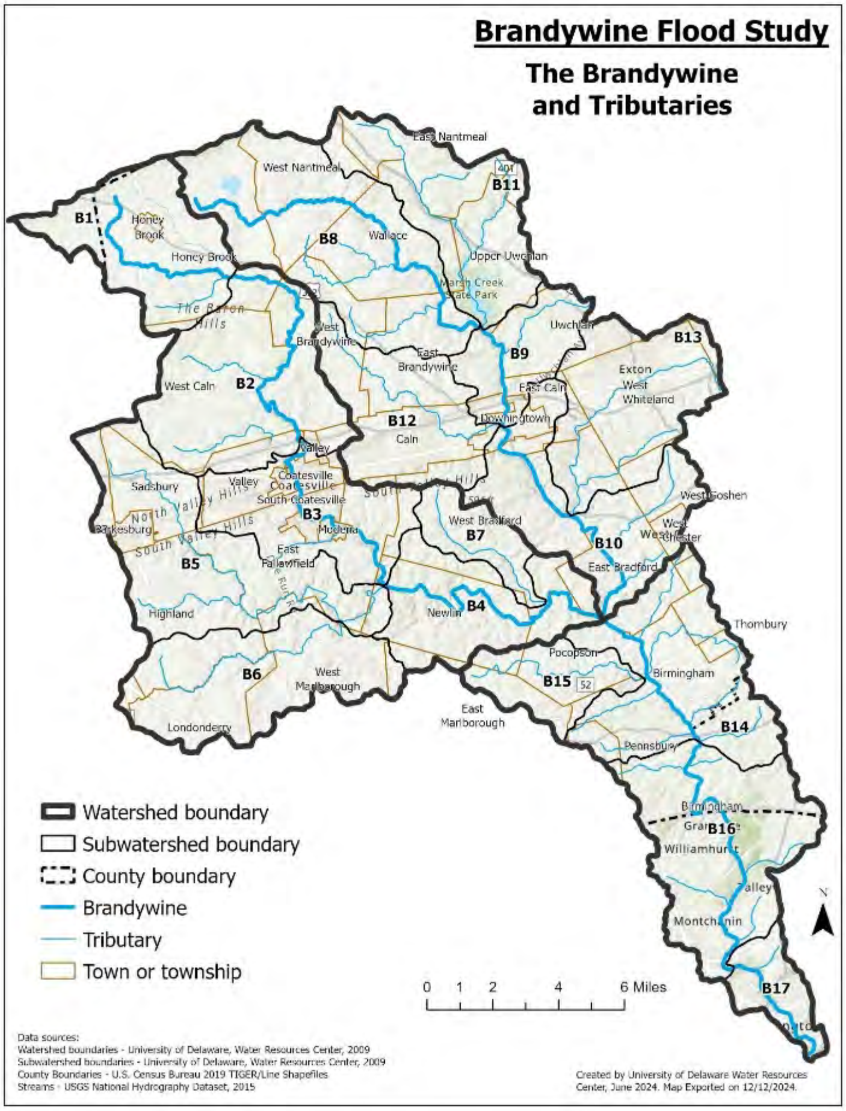
1) *Flood Working Group:* Identify representatives from the public (focus on municipal governments), private, and nonprofit entities to serve on a Flood Working Group to inform and advise on the initiative. Conduct public outreach meetings. Develop a website to organize and distribute GIS data.
2) *Flood Identification:* Identify and map chronic flooding areas through the review of literature from FEMA, US Army Corps of Engineers (USACOE), U.S. Geological Survey (USGS), Delaware Department of Natural Resources and Environmental Control (DNREC), Pennsylvania Department of Environmental Protection (PADEP), CCWRA, and the media. Conduct field reconnaissance to field survey and map flood areas.
3) *Storm Event Analysis:* Develop a series of storm events using historical records at precipitation gages in Chester County to analyze hydrologic and hydraulic models. Use historical storm event analysis to develop storm events representing potential increases in intensity and duration of future events for the models.
4) *Hydrologic Model:* Utilize U.S. Department of Agriculture (USDA) Technical Release 55 (TR-55) hydrologic models and ArcView GIS to delineate watersheds/subwatersheds, incorporate USGS stream gages, stream/storage routing, and conduct existing/proposed (i.e., with flood solutions) conditions modeling for the 2-, 10-, 50-, 100-, 500-, 1000-year, and storm of record flood frequency scenarios. The scenarios incorporated projections related to climate change and the potential effects of future development throughout the watershed.
5) *Hydraulic Model:* Conduct field survey and utilize existing USACOE HEC-RAS hydraulic models and FEMA flood profiles for the mainstem, east and west branches, and tributaries of the Brandywine Creek to evaluate existing flooding conditions and perform proposed future conditions modeling.
6) *Flood Relief Analysis:* For areas with chronic flooding or significant obstructions, perform flood control analysis using hydrologic/hydraulic models and assess opportunities for structural and non-structural mitigation projects.
7) *Public Engagement:* Solicit public input on flooding hot spots, areas of concern, and ideas for future solutions through multiple avenues, including live and pre-recorded presentations, web-based surveys, an interactive flood mapping tool, and community listening sessions in key areas throughout the watershed.
8) *Municipal Outreach:* Meet with staff and officials from each municipality in the watershed to gather feedback on localized flooding challenges as well as ongoing/planned efforts to address them.

This study was funded through grants from FEMA, and Chester and Delaware Counties in Pennsylvania. The primary authors of this report are CCWRA, BC, and UDWRC. Multiple project partners have contributed significantly to the report by providing data, feedback, mapping support, written content, and technical review at all stages of the project. In addition to the primary authors, the Brandywine Flood Study partners include the Stroud Water Research Center, West Chester University, and Meliora Design. The Brandywine Flood Study Technical Advisory Committee includes government officials, nonprofit organizations, and private entities who provided continuous feedback and expertise throughout the project. Community members throughout the Brandywine provided the project team with meaningful input and have contributed significantly to inform and advise the project. This report was made possible by the robust support of this broad network of engaged stakeholders.

1.2. Current Watershed Conditions

The Brandywine watershed is one of the most historic small watersheds in the nation. It is part of the ancestral homelands of the Lenni Lenape, nestled within two of the original thirteen U.S. colonies. The area boasts a rich agricultural heritage and is home to early mills which helped to power the American Industrial Revolution. The watershed spans 325 square miles (sq. mi.), of which 303 sq. mi. (93%) are in Pennsylvania and 23 sq. mi. (7%) are in Delaware. It is currently home to more than 265,000 people (U.S. Census 2020).

The Brandywine watershed is made up of 17 subwatersheds and more than a dozen tributaries (Figure 1.1 and Table 1.1). This network of waterways includes a total of approximately 183 stream miles. The headwaters of the Brandywine lie in the hilly farmland around Honey Brook, Pennsylvania, near the northern border of Chester and Lancaster Counties. The terrain flattens out around the Pocopson area where the two primary tributaries, the East and West Branch Brandywine Creek, come together to form the Main Stem Brandywine Creek. As the creek flows south, the watershed narrows into a funnel shape below Chadds Ford, and elevation changes rapidly after the creek enters the State of Delaware (Figure 1.2). The Brandywine ultimately flows into the Christina River in Wilmington, the state's largest city. The section of the Brandywine Creek in Wilmington from the Market Street bridge to the confluence with the Christina River is tidally influenced and historically was used for navigation.



Data sources:
Watershed boundaries - University of Delaware, Water Resources Center, 2009
Subwatershed boundaries - University of Delaware, Water Resources Center, 2009
County Boundaries - U.S. Census Bureau 2019 TIGER/Line Shapefiles
Streams - USGS National Hydrography Dataset, 2015

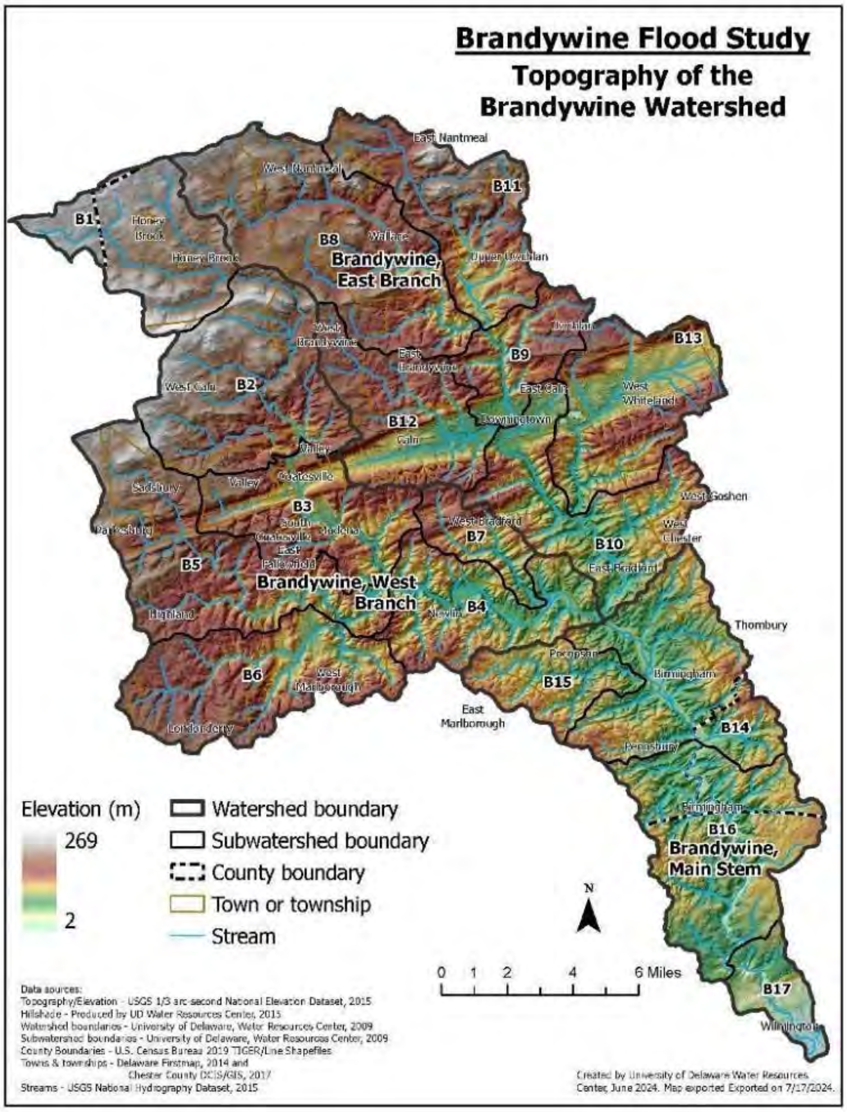
Created by University of Delaware Water Resources Center, June 2024. Map Exported on 12/12/2024.

Figure 1.1 Subwatersheds of the Brandywine Creek

Table 1.1 Streams in the Brandywine Watershed

Reach ID	Stream	Length (mi)	Length (ft)	Drainage Area (mi^2)	Q10 (cfs)	Q50 (cfs)	Q100 (cfs)	Q500 (cfs)
TY1	Beaver Creek	9.5	50,138	18.2	2,528	3,952	4,645	6,494
TY2	Bennetts Run	3.4	18,068	2.8	989	1,740	2,129	3,236
	Birch Run	3.6	18,940	4.6	1,700	2,905	3,480	4,870
TY3	Broad Run	5.6	29,568	6.4	1,700	2,850	3,420	4,960
	Buck Run	17.3	91,227	24.4	3,750	6,302	7,595	11,200
	Colebrook Run	2.5	13,045	1.7	565	881	1,035	1,443
TY4	Copeland Run	1.8	9,547	1.0	470	819	999	1,560
	Cossart Run	1.0	5,384	2.0	776	1,402	1,732	2,689
	Craigs Mill Run	2.6	13,465	1.8	671	1,198	1,474	2,271
	Doe Run	9.4	49,619	21.7	3,236	5,527	6,702	10,019
TY5	Harvey Run	2.8	14,718	3.8	1,340	2,270	2,720	3,960
	Indian King Run	2.1	10,843	1.0	484	771	915	1,302
TY6	Little Buck Run	3.5	18,566	2.6	827	1,383	1,663	2,439
TY7	Parke Run	1.6	8,501	1.8	529	765	876	1,157
TY8	Pocopson Creek	7.3	38,494	9.1	2,082	3,599	4,378	6,580
	Radley Run	5.6	29,590	0.4	295	449	538	820
TY9	Ring Run	3.5	18,278	2.1	859	1,474	1,786	2,662
	Rock Run	2.1	11,201	8.1	2,005	3,382	4,078	6,011
	Shamona Creek	3.9	20,390	4.0	815	1,516	1,851	2,701
TY10	Sucker Run	3.4	18,045	4.8	1,246	2,004	2,378	3,391
	Taylor Run	4.7	24,724	3.6	1,257	2,058	2,453	3,225
TY11	West Valley Creek	9.8	51,775	12.0	2,026	3,011	3,477	4,682
TY12	Valley Run	2.9	15,371	4.7	1,678	3,023	3,666	5,260
BW	Brandywine at Wilm.	10.0	52,800	314.0	16,100	25,700	30,400	50,032
BC	Brandywine at Chadds Ford	9.7	51,216	300.0	17,137	27,593	32,711	46,326
EB	East Br. Brandywine	25.7	135,696	123.0	8,417	11,403	12,605	15,287
WB	West Br. Brandywine	27.7	146,256	134.0	11,395	18,437	21,941	31,505
	Total	**138.0**	**965,465**	**1014.0**				

Note: Q10, Q50, Q100, and Q500 are the peak flood flows the USGS defines as likely to occur once every 10, 50, 100, and 500 years, respectively, or more precisely have a 10%, 2%, 1%, and 0.2% annual chance of occurring in any given year, respectively.



Data sources:
Topography/Elevation - USGS 1/3 arc-second National Elevation Dataset, 2015
Hillshade - Produced by UD Water Resources Center, 2015
Watershed boundaries - University of Delaware, Water Resources Center, 2009
Subwatershed boundaries - University of Delaware, Water Resources Center, 2009
County Boundaries - U.S. Census Bureau 2019 TIGER/Line Shapefiles
Towns & townships - Delaware Firstmap, 2014 and
Chester County DCIS/GIS, 2017
Streams - USGS National Hydrography Dataset, 2015

Created by University of Delaware Water Resources Center, June 2024. Map exported Exported on 7/17/2024.

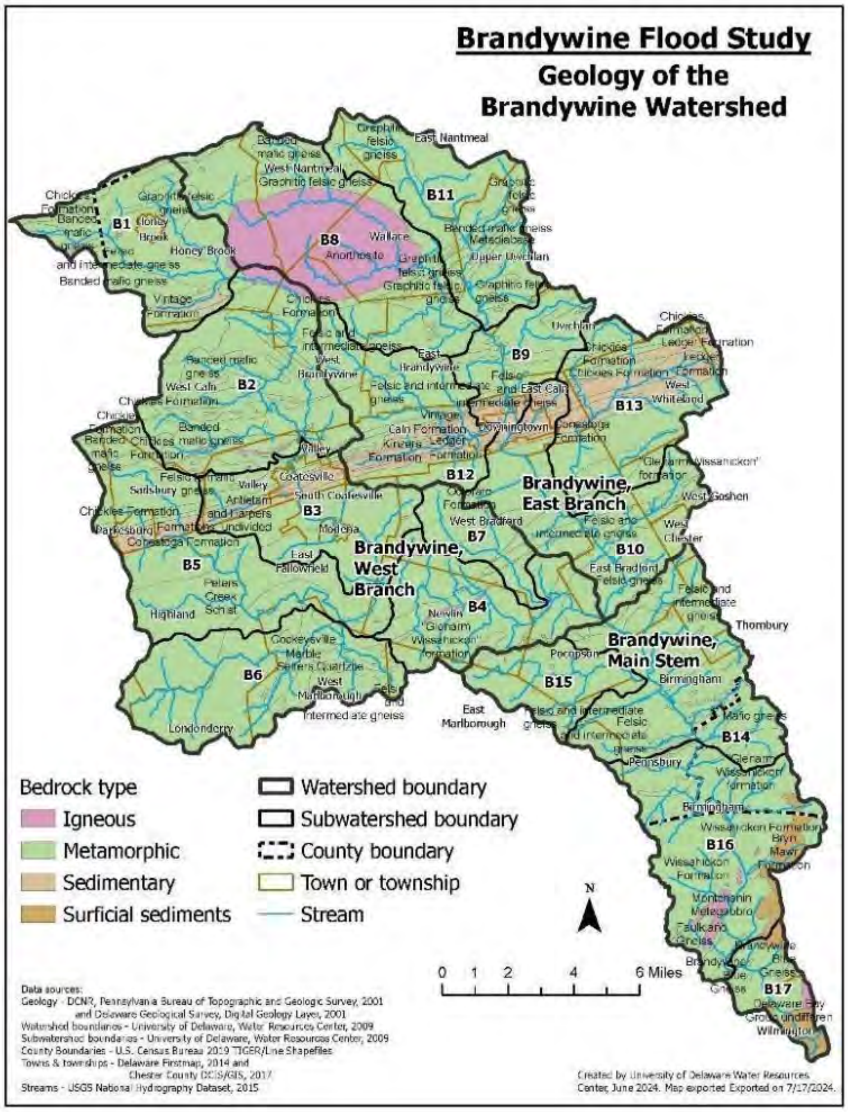
Figure 1.2 Topography of the Brandywine Watershed

Topography, Geology and Soils

The Brandywine Creek passes through a diverse lithology from its headwaters near Honey Brook Township to the confluence and eventual endpoint in Wilmington (Figure 1.3). Most of the watershed is underlain by metamorphic rocks. The northernmost portion is predominantly gneiss, with the East Branch traversing an outcropping of igneous rock (anorthosite). Both branches pass through a significant depression running east-west in the central portion of the watershed, characterized by sedimentary rock (limestone and dolomite). This feature, known as the Chester Valley or Great Valley, is noteworthy for its karst geology and steep slopes to the north and south. The long straight valley lent itself to the development of road and rail systems, accommodating both the U.S. Route 30 highway and

Southeastern Pennsylvania Transportation Authority (SEPTA) rail lines. Along this corridor lies the most intensive urban development within the Pennsylvania portion of the watershed.

South of this valley lie schist formations, which predominate until the creek flows past Chadds Ford, where the bedrock consists of gneisses, with some outcrops of igneous gabbro, and significant areas of Brandywine Blue gneiss, the so-called “Wilmington Blue Rock.” As the creek flows through Wilmington, it enters the Coastal Plain, which is characterized by unconsolidated silt and sediment.

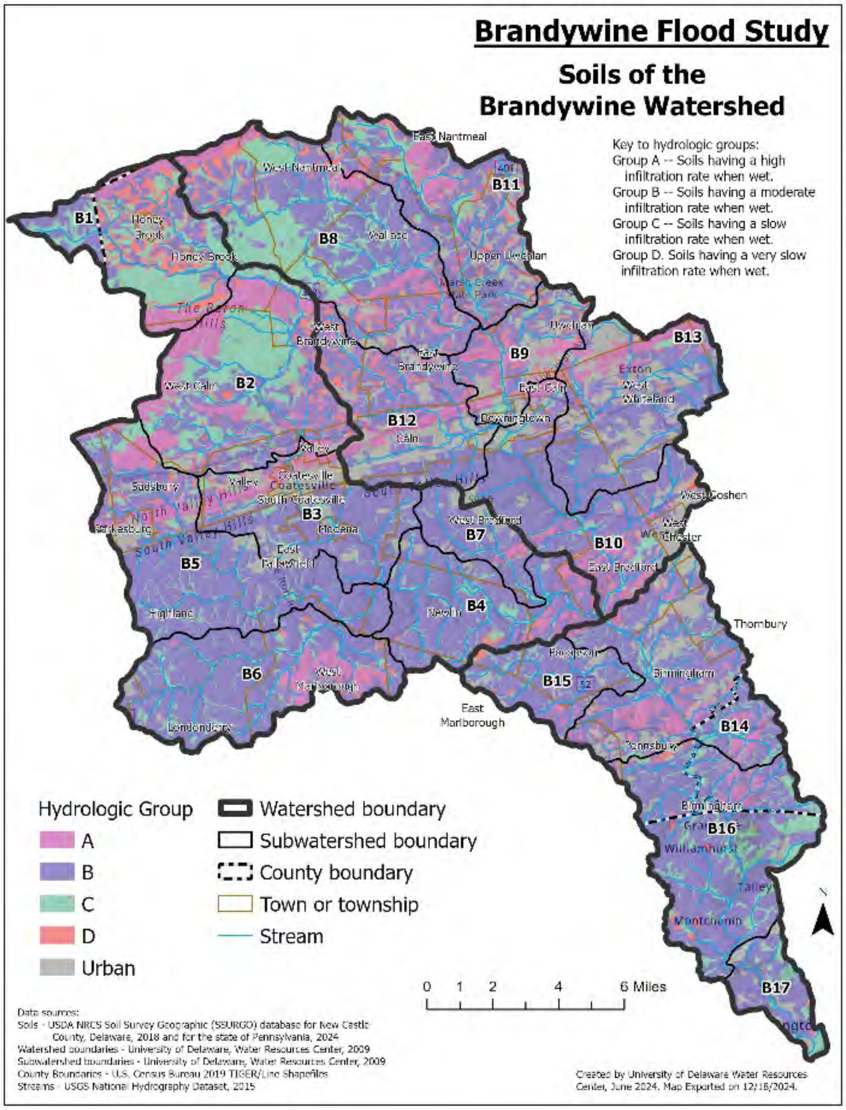


Data sources:
Geology - DCNR, Pennsylvania Bureau of Topographic and Geologic Survey, 2001
and Delaware Geological Survey, Digital Geology Layer, 2001
Watershed boundaries - University of Delaware, Water Resources Center, 2009
Subwatershed boundaries - University of Delaware, Water Resources Center, 2009
County Boundaries - U.S. Census Bureau 2019 TIGER/Line Shapefiles
Towns & townships - Delaware Firstmap, 2014 and
Chester County DCIS/GIS, 2017
Streams - USGS National Hydrography Dataset, 2015

Created by University of Delaware Water Resources Center, June 2024. Map exported Exported on 7/17/2024.

Figure 1.3 Geology of the Brandywine Watershed

Soils in the Brandywine Watershed are predominantly well-drained loams (Hydrologic Group B). These soils are relatively transmissive to runoff water, allowing infiltration of excess precipitation. The upper East Branch has extensive areas of Hydrologic Group C/D soils, which are moderately well-drained, as well as the watershed’s most extensive areas of poorly drained soils (Hydrologic Group D). The portion of the watershed drained by the West Branch has the greatest extent of Hydrologic Group A soils, which are the most well-drained soils, allowing the highest amount of infiltration. The mainstem of the Brandywine, from Pocopson south into Wilmington, is characterized by generally well-drained (Hydrologic Group B) soils, with some areas of less well drained Hydrologic Group C/D soils adjacent to the creek and its lower tributaries (Figure 1.4).



Data sources:
Soils - USDA NRCS Soil Survey Geographic (SSURGO) database for New Castle County, Delaware, 2018 and for the state of Pennsylvania, 2024
Watershed boundaries - University of Delaware, Water Resources Center, 2009
Subwatershed boundaries - University of Delaware, Water Resources Center, 2009
County Boundaries - U.S. Census Bureau 2019 TIGER/Line Shapefiles
Streams - USGS National Hydrography Dataset, 2015

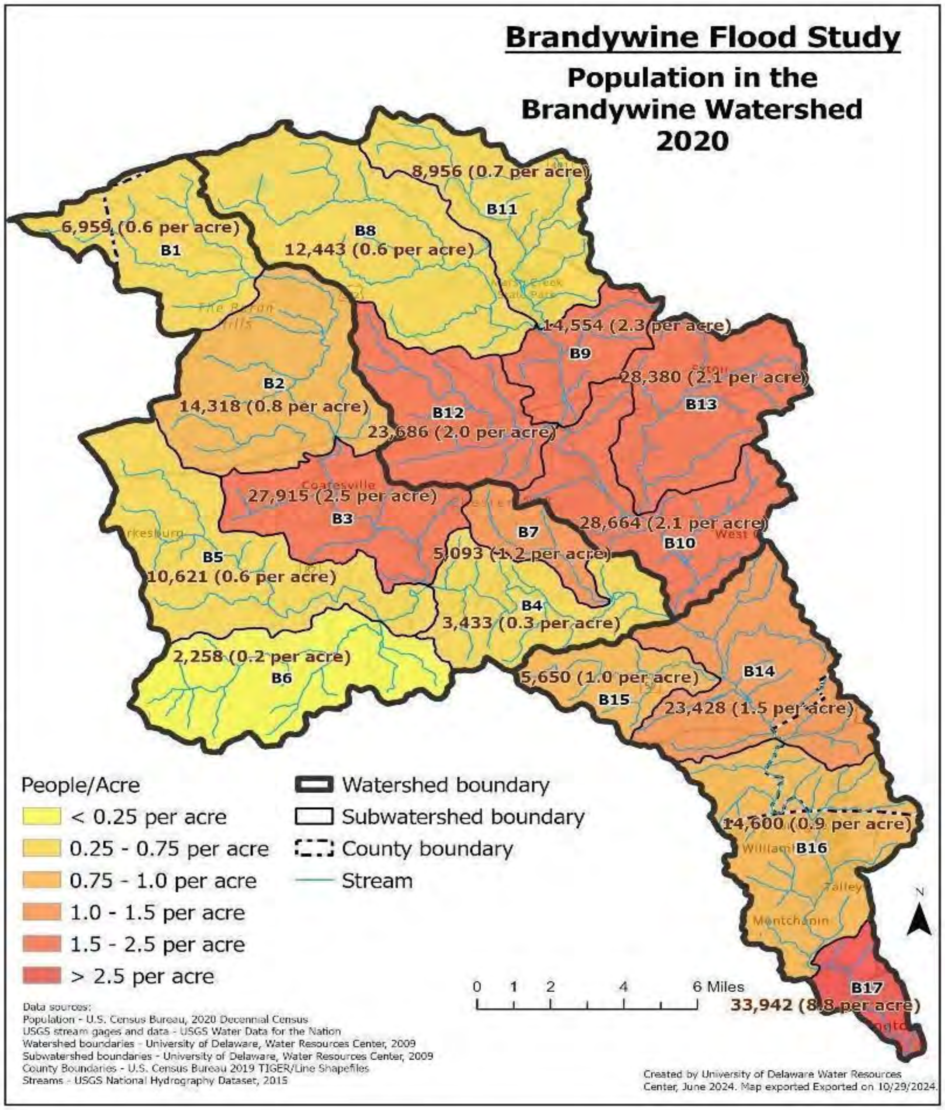
Created by University of Delaware Water Resources Center, June 2024. Map Exported on 12/16/2024.

Figure 1.4 Soils of the Brandywine Watershed

Population

The Brandywine Creek watershed is characterized by areas of relatively sparse population in the agricultural region in the northern portion of the watershed and the lower sections of the West Branch, along with fairly densely urbanized areas along major transportation corridors in the central watershed and lower East Branch. The highly urbanized areas are typically surrounded by more extensive, low-density suburban development. Based on the 2020 Decennial Census, there are more than 265,000 inhabitants in the watershed, with roughly 222,000 (84%) in Pennsylvania, and 43,000 (16%) in Delaware (Table 1.2). Figure 1.5 presents the total population by subwatershed in the Brandywine Creek watershed, including total population density in people per acre.

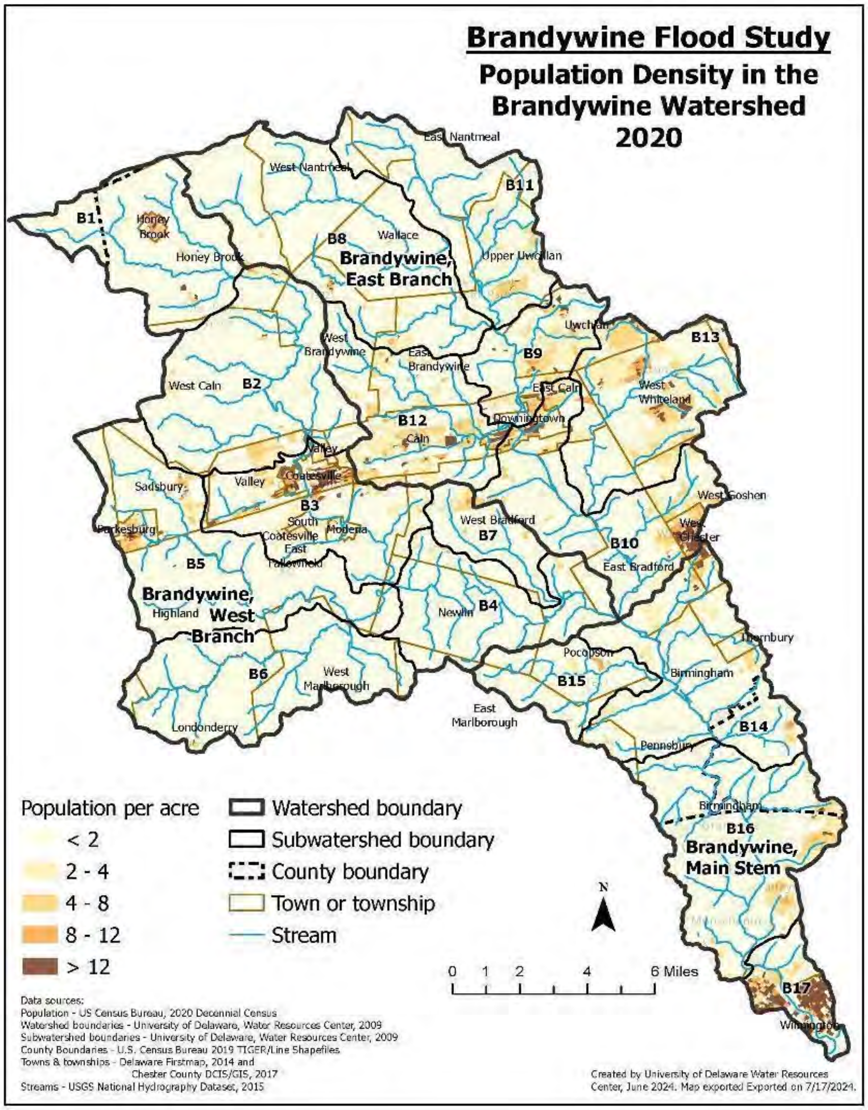
The highest population densities occur in the urbanized areas along the US Route 30 corridor in Chester County, PA, concentrated in and around the City of Coatesville and the Borough of Downingtown, in West Chester Borough, and in the City of Wilmington, DE. Figure 1.6 shows the population density across the watershed. Streams flow through and around many of the more populous communities in the watershed, leaving them more prone to flooding issues.



Data sources:
Population - U.S. Census Bureau, 2020 Decennial Census
USGS stream gages and data - USGS Water Data for the Nation
Watershed boundaries - University of Delaware, Water Resources Center, 2009
Subwatershed boundaries - University of Delaware, Water Resources Center, 2009
County Boundaries - U.S. Census Bureau 2019 TIGER/Line Shapefiles
Streams - USGS National Hydrography Dataset, 2015

Created by University of Delaware Water Resources Center, June 2024. Map exported Exported on 10/29/2024.

Figure 1.5 Population in the Brandywine Watershed, 2020


Brandywine Flood Study

Population Density in the Brandywine Watershed 2020

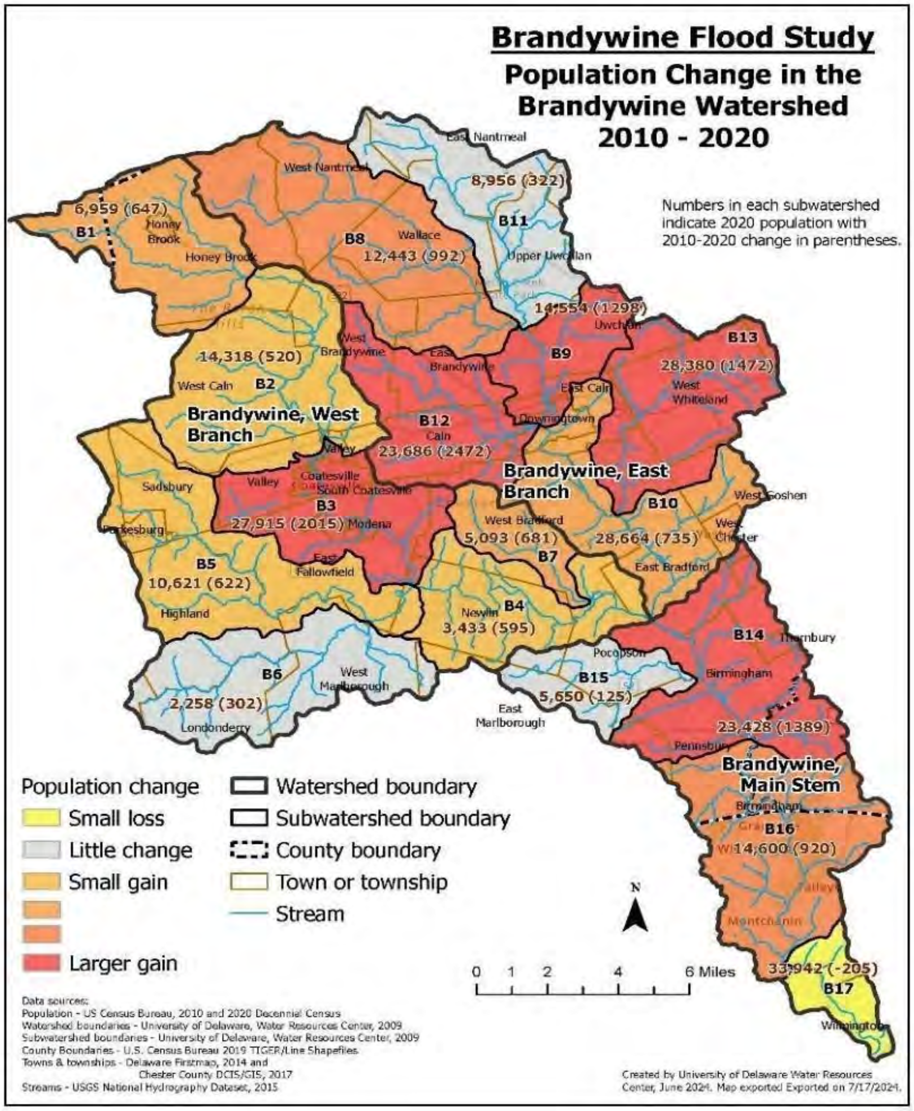
Data sources:
Population - US Census Bureau, 2020 Decennial Census
Watershed boundaries - University of Delaware, Water Resources Center, 2009
Subwatershed boundaries - University of Delaware, Water Resources Center, 2009
County Boundaries - U.S. Census Bureau 2019 TIGER/Line Shapefiles
Towns & townships - Delaware Firstmap, 2014 and
Chester County DCIS/GIS, 2017
Streams - USGS National Hydrography Dataset, 2015

Created by University of Delaware Water Resources Center, June 2024. Map exported Exported on 7/17/2024.

Figure 1.6 Population Density in the Brandywine Watershed, 2020

Figure 1.7 and Table 1.2 show the change in population between 2010 and 2020 by subwatershed in the Brandywine watershed. Darker shades indicate a greater increase in total population over the period. Much of the most intensive growth has occurred in the already urbanized or suburbanized areas of the subwatersheds in central Chester County (subwatersheds B3, B9, B12, and B13), as well as in the southern portion of Chester County between US Route 1 and the confluence of the East and West Branches of the Brandywine Creek (subwatershed B14).

New Castle County Delaware, in the lower portion of the watershed, saw an increase of nearly 700 residents (1.7%) in the ten-year period, while the Pennsylvania portion of the watershed increased by over 14,000 (6.8%). The largest absolute population increase occurred in Chester County (14,024, 7.0%), with Delaware County increasing by only approximately 50 residents. Lancaster County saw an increase of 82 residents (9.5%).



Data sources:
Population - US Census Bureau, 2010 and 2020 Decennial Census
Watershed boundaries - University of Delaware, Water Resources Center, 2009
Subwatershed boundaries - University of Delaware, Water Resources Center, 2009
County Boundaries - U.S. Census Bureau 2019 TIGER/Line Shapefiles
Towns & townships - Delaware Firstmap, 2014 and Chester County DCIS/GIS, 2017
Streams - USGS National Hydrography Dataset, 2015

Created by University of Delaware Water Resources Center, June 2024. Map exported Exported on 7/17/2024.

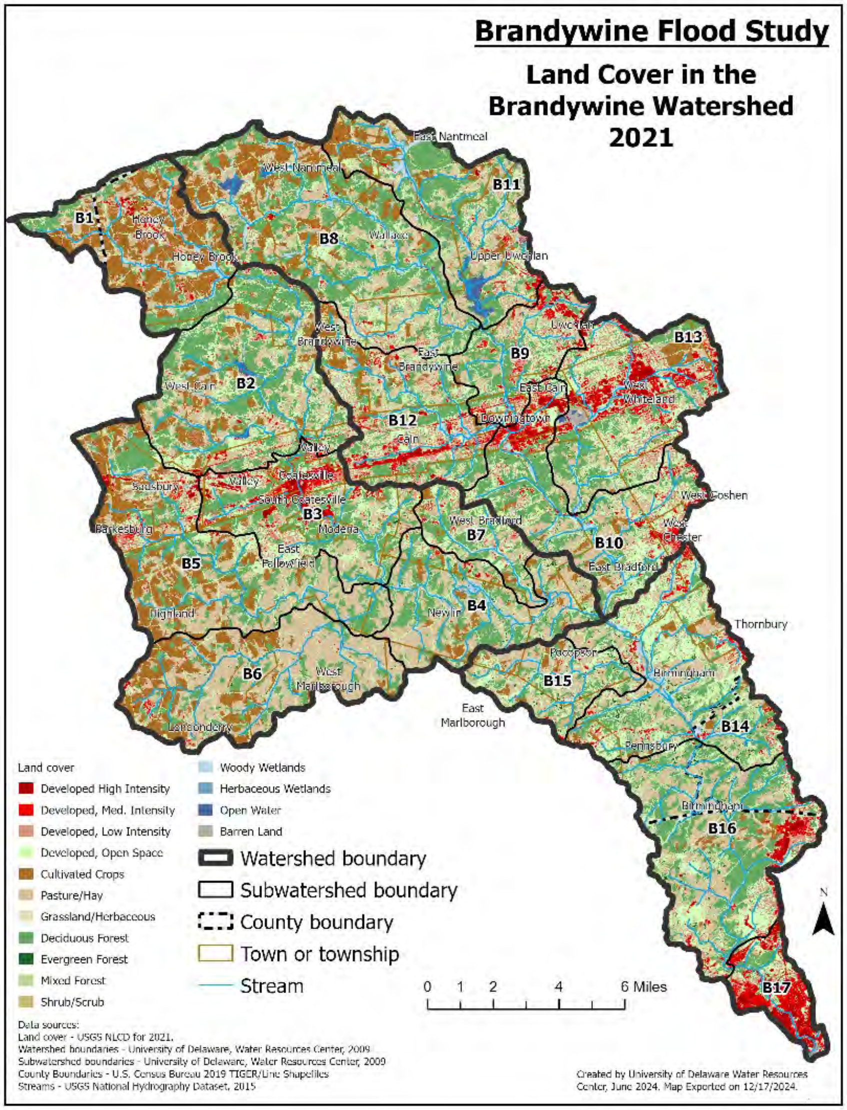
Figure 1.7 Population Change in the Brandywine Watershed by Subwatershed, 2010-2020

Table 1.2 Watershed Population in the Brandywine Creek Watershed by County

Brandywine Creek Watershed	2010	2020	2010 - 2020	% Change
DE Total	42,088	42,785	696	1.7%
New Castle Co.	42,088	42,785	696	1.7%
PA Total	208,626	222,783	14,157	6.8%
Chester Co.	201,473	215,497	14,024	7.0%
Delaware Co.	6,288	6,338	50	0.8%
Lancaster Co.	866	948	82	9.5%
Watershed Total	**250,715**	**265,568**	**14,853**	**5.9%**

Land Cover

Land cover is a key determinant of the quality of watersheds and their water bodies, affecting habitats, ecological functions, and water quality, both on the surface and in groundwater. Land cover in the Brandywine watershed varies geographically, with large extensive areas of agricultural land to the north, bordered by mixed suburban and wooded land that extend south to the high-density urban/suburban development along the US Route 30 corridor in central Chester County (Figure 1.8). Continuing south, the watershed is largely rural again, with scattered pockets of suburban development, until it reaches the greater Wilmington, Delaware area. Generally speaking, land cover in the watershed is divided in thirds, with roughly equal amounts of forested land, agricultural land, and urbanized areas (Figure 1.9).



Data sources:
Land cover - USGS NLCD for 2021.
Watershed boundaries - University of Delaware, Water Resources Center, 2009
Subwatershed boundaries - University of Delaware, Water Resources Center, 2009
County Boundaries - U.S. Census Bureau 2019 TIGER/Line Shapefiles
Streams - USGS National Hydrography Dataset, 2015

Created by University of Delaware Water Resources Center, June 2024. Map Exported on 12/17/2024.

Figure 1.8 Land Cover in the Brandywine Watershed by Subwatershed, 2021

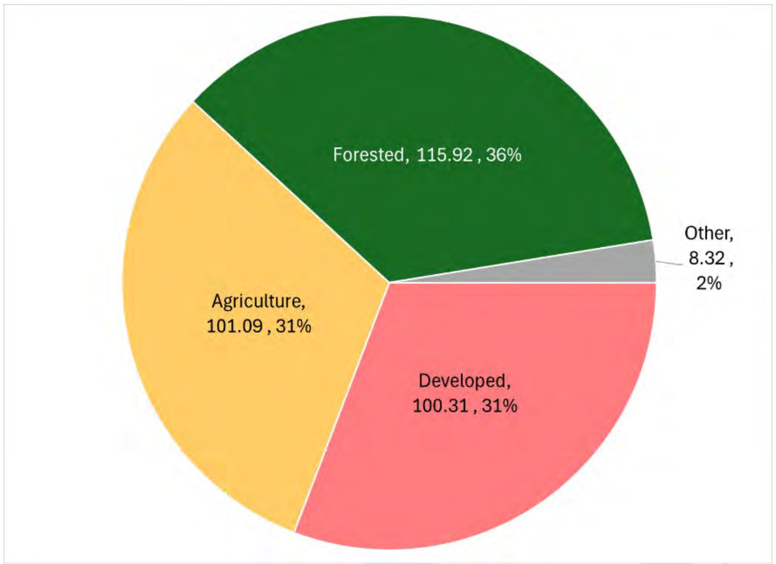


Figure 1.9 Percentage of Major Land Cover Categories in the Brandywine Watershed, 2021

Depending on the subwatershed, there are various proportions of each major land cover type, as shown in Figure 1.10. The East Branch watershed is more urbanized, particularly around Exton, Downingtown, and West Chester, than either the West Branch or Main Stem. In the West Branch, development is concentrated in and around the City of Coatesville, while in the Main Stem watershed, it is centered around the City of Wilmington.

Land cover in the Brandywine watershed has changed significantly over time. What began as a largely forested region gave way in the early colonial period to farms and small villages. As time progressed, industry and transportation innovations shifted the landscape, which allowed for populations to expand. Over the course of the last hundred years, thousands of formerly agricultural or forested acres have been converted into residential or commercial spaces to keep pace with needs of modern communities. These changes in land use have major impacts on the watershed, particularly as it relates to increases in impervious cover. Hard-scaped areas tend to lead to increased stormwater runoff, as water is less able to percolate into the groundwater table during periods of rainfall. Hence, land use changes can cause streams to flood more frequently during storms. The same process may cause low stream flows during dry periods, as the groundwater that feeds those streams are prevented from percolating into the ground. In addition to water quantity, land use change also has the potential to impact water quality. Pollutants such as heavy metals, oils, and bacteria can enter waterways as an area becomes increasingly developed. Sediment, pesticides, and nutrients such as nitrogen and phosphorous, as well as bacteria from animal waste wash off from agricultural uses if they are not contained by good management practices.

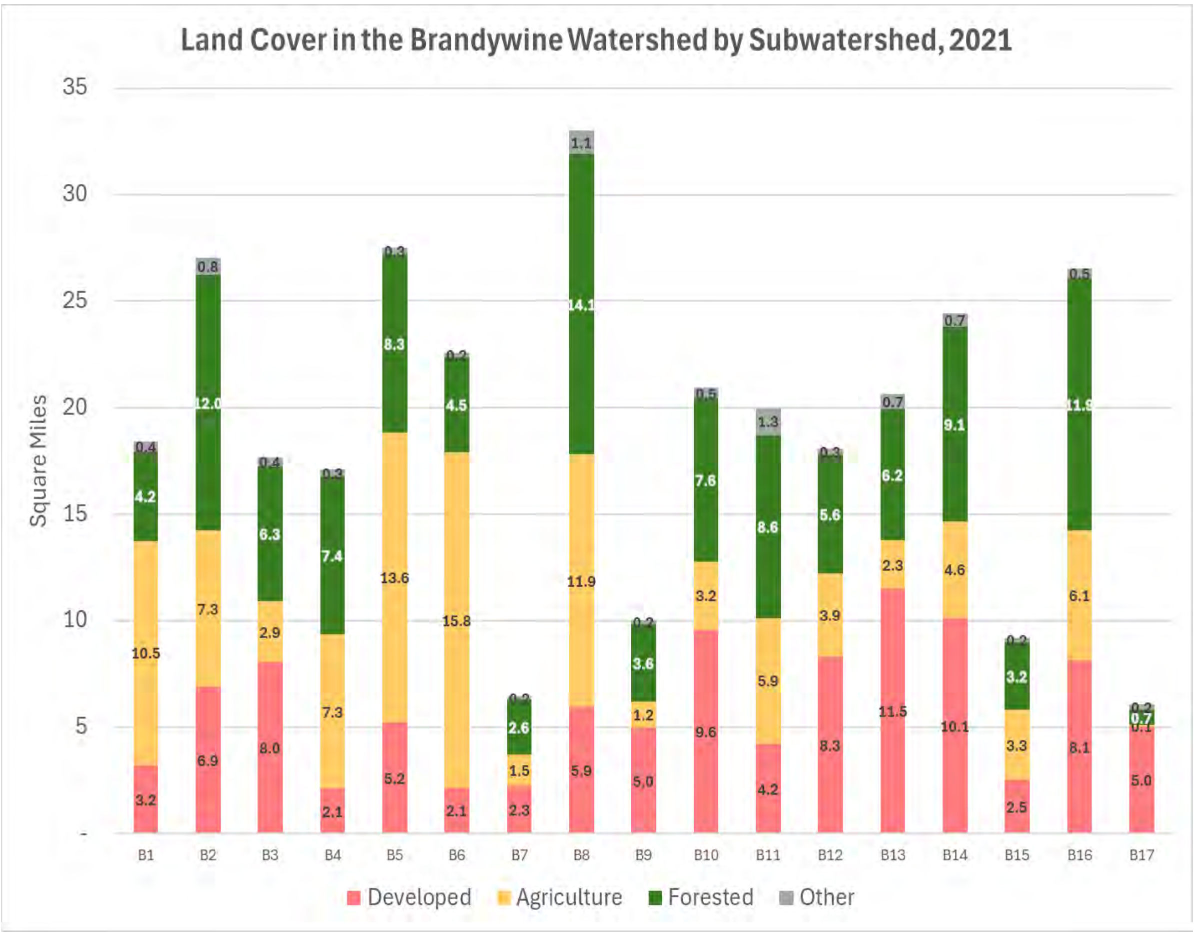


Figure 1.10 Percentage of Major Land Cover Categories in the Brandywine Watershed by Subwatershed, 2021

Over the past twenty years, from 2001 to 2021, the Brandywine watershed has experienced significant development pressure. Meeting this increased demand has resulted in an overall decline of both natural forested areas and agriculture. The graph in Figure 1.11 shows the trend in each five-year period between 2001 and 2021 for each land cover category. Development overall increased, with accompanying decreases in agricultural and, to a slightly lesser extent, forested land.

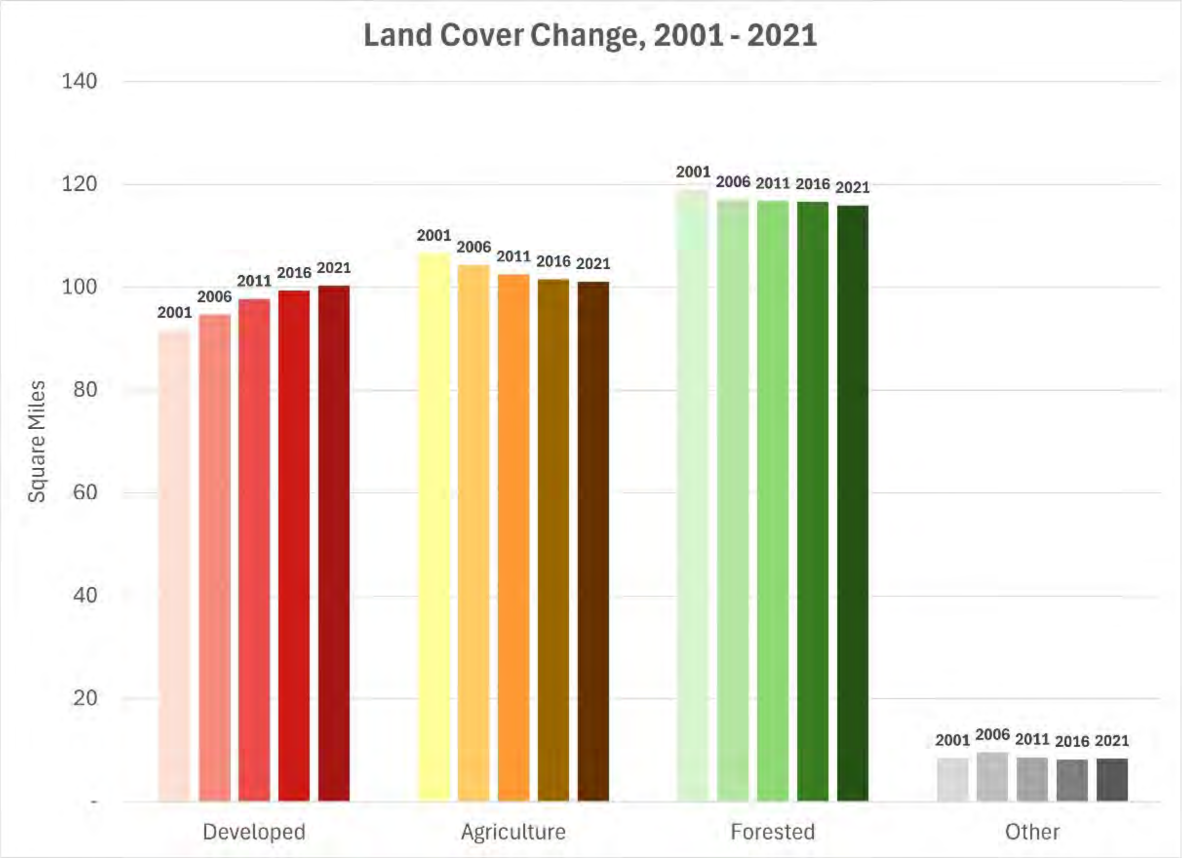
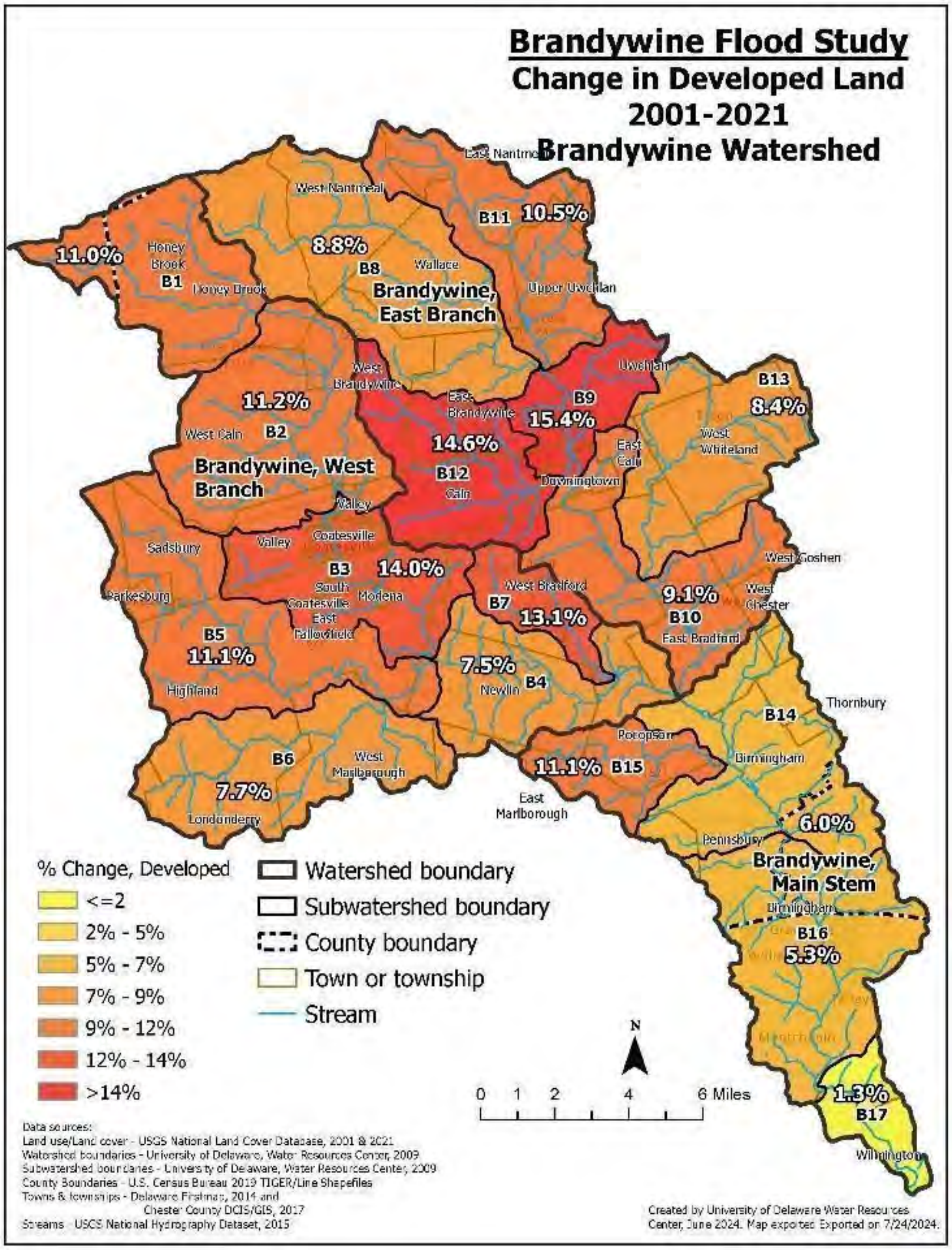


Figure 1.11 Land Cover Change in the Brandywine Watershed, 2001-2021

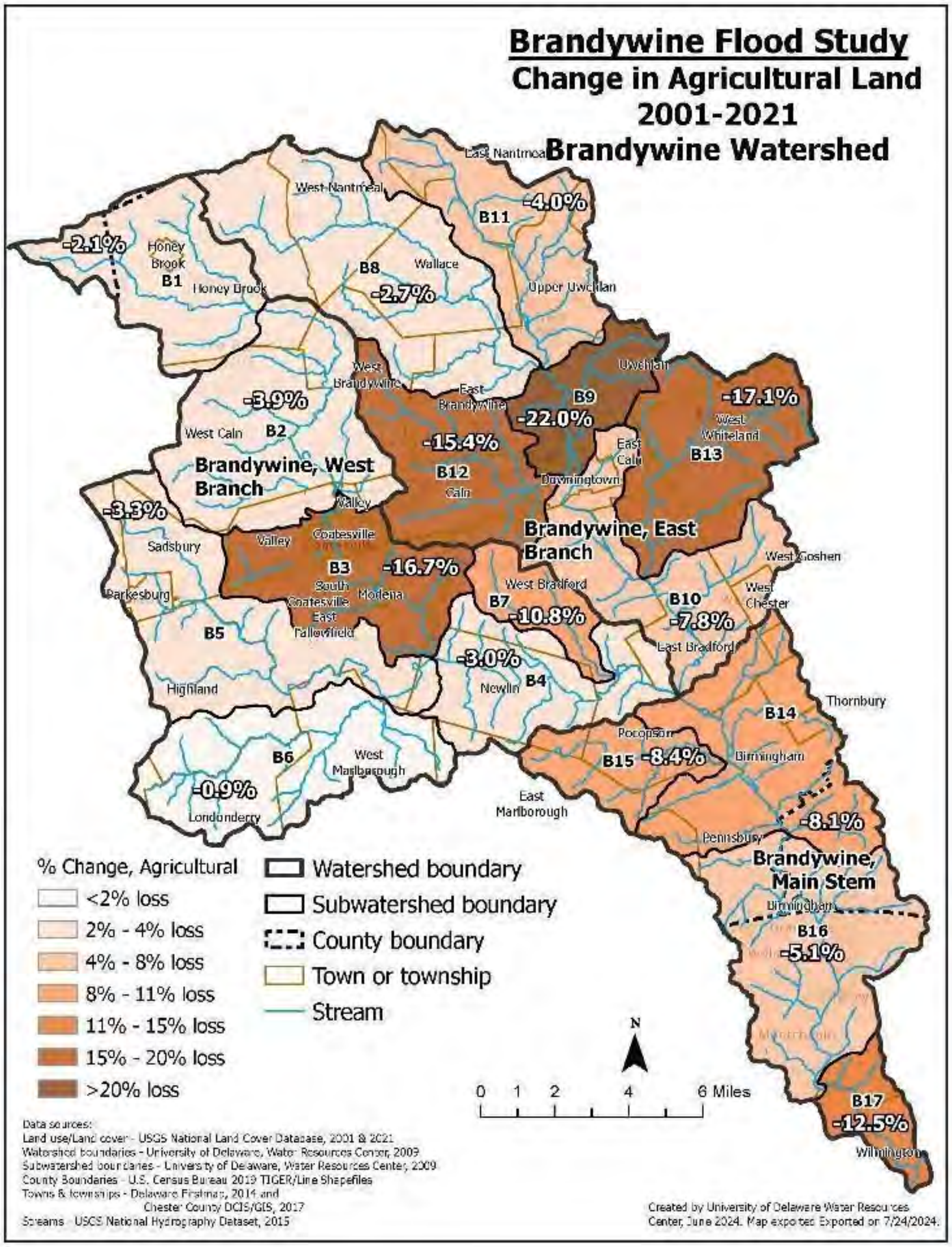
The maps in Figures 1.12 through 1.14 illustrate the percentage change in each major land use category by subwatershed. The central subwatersheds from the confluence of the East and West Branches, particularly in the highly developed East Branch, show the largest percent increase in development. The more northerly subwatersheds in Chester County saw the highest amount of change due to development. During the same period, those subwatersheds also saw a decrease in the amount of forested land and agriculture. The upper and lower West Branch subwatersheds saw the least loss of agricultural lands, while forested land in the lower portion of the West Branch remained relatively stable.



Data sources:
Land use/Land cover - USGS National Land Cover Database, 2001 & 2021
Watershed boundaries - University of Delaware, Water Resources Center, 2009
Subwatershed boundaries - University of Delaware, Water Resources Center, 2009
County Boundaries - U.S. Census Bureau 2019 TIGER/Line Shapefiles
Towns & townships - Delaware Fishnet, 2014 and
Chester County DCIS/GIS, 2017
Streams - USGS National Hydrography Dataset, 2015

Created by University of Delaware Water Resources Center, June 2024. Map exported Exported on 7/24/2024.

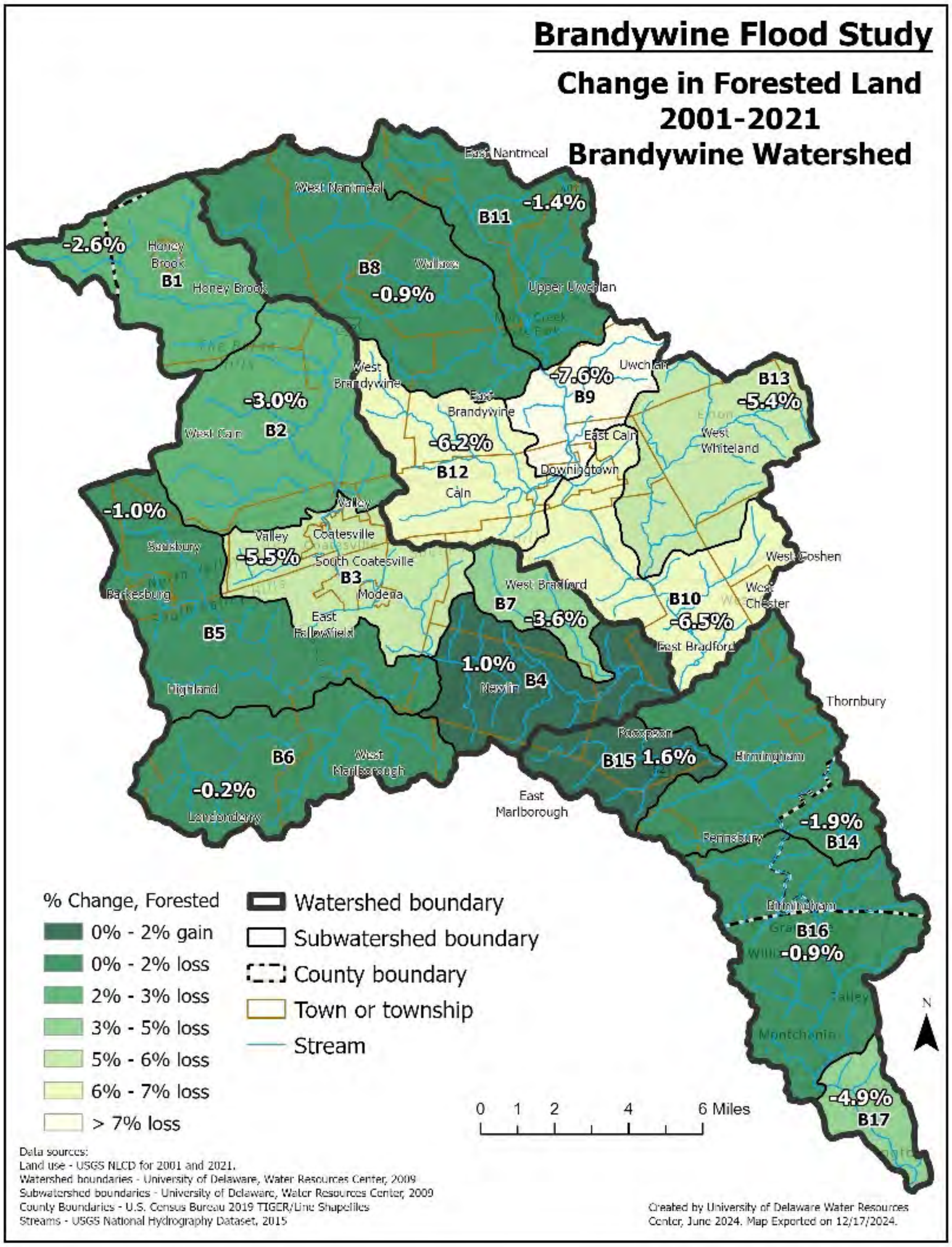
Figure 1.12 Change in Developed land, 2011-2021



Data sources:
Land use/Land cover - USGS National Land Cover Database, 2001 & 2021
Watershed boundaries - University of Delaware, Water Resources Center, 2009
Subwatershed boundaries - University of Delaware, Water Resources Center, 2009
County Boundaries - U.S. Census Bureau 2019 TIGER/Line Shapefiles
Towns & townships - Delaware Firstmap, 2014 and
Chester County DCIS/GIS, 2017
Streams - USGS National Hydrography Dataset, 2015

Created by University of Delaware Water Resources Center, June 2024. Map exported Exported on 7/24/2024.

Figure 1.13 Change in Agricultural land, 2001-2021



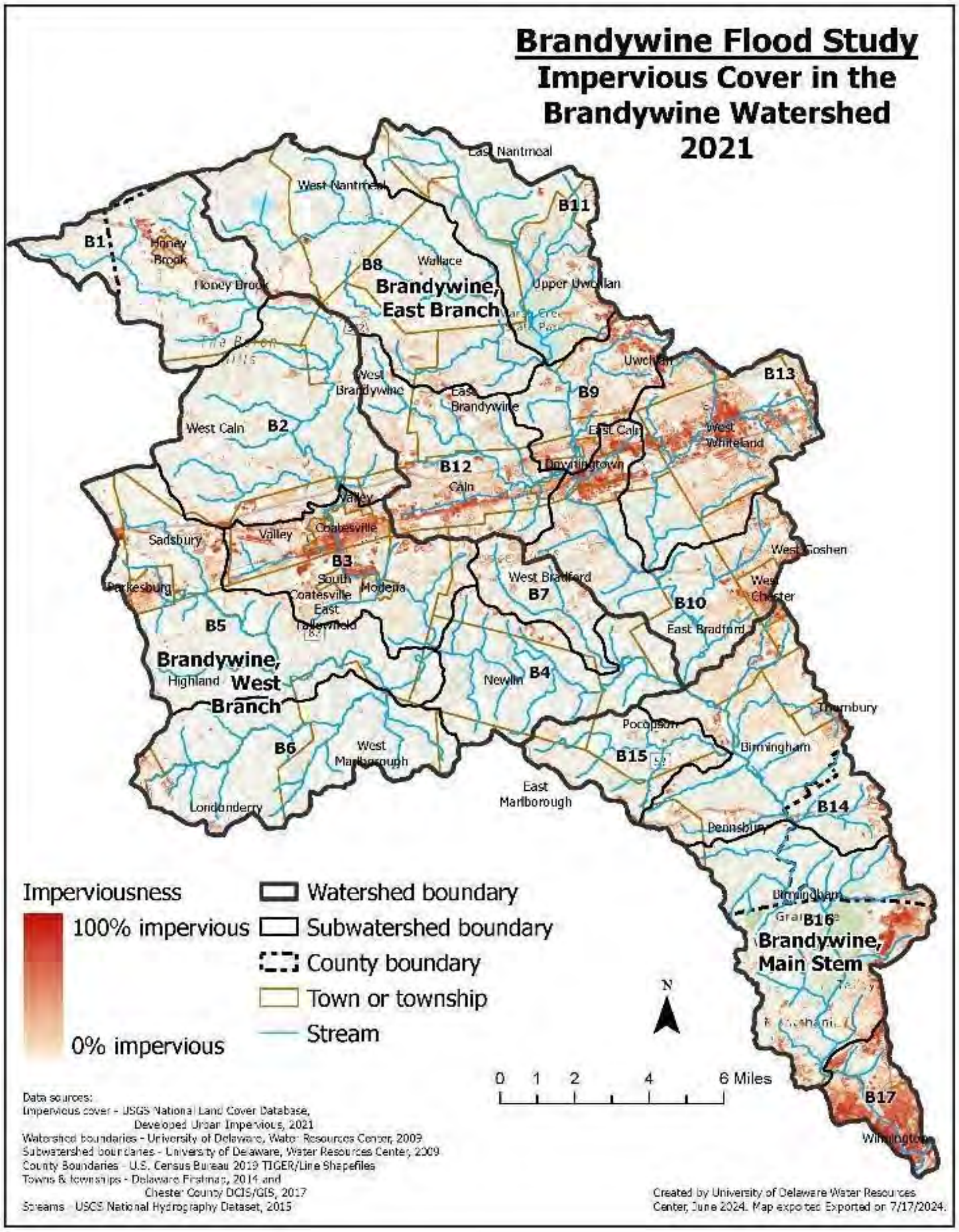
Data sources:
Land use - USGS NLCD for 2001 and 2021.
Watershed boundaries - University of Delaware, Water Resources Center, 2009
Subwatershed boundaries - University of Delaware, Water Resources Center, 2009
County Boundaries - U.S. Census Bureau 2019 TIGER/Line Shapefiles
Streams - USGS National Hydrography Dataset, 2015

Created by University of Delaware Water Resources Center, June 2024. Map Exported on 12/17/2024.

Figure 1.14 Change in Forested land, 2001-2021

Impervious Cover

As previously discussed, the amount of impervious surface (typically dictated by the amount of development) in a watershed can have a significant impact on both water quality and quantity. In the Brandywine watershed, the areas of highest imperviousness are in the most urbanized areas, including the US Route 30 corridor in central Chester County, the US Route 202 corridor, and in the Wilmington metropolitan region. The map in Figure 1.15 illustrates the distribution and intensity of imperviousness across the watershed, based on 2021 data. Darker red areas have a higher percentage of impervious land cover.

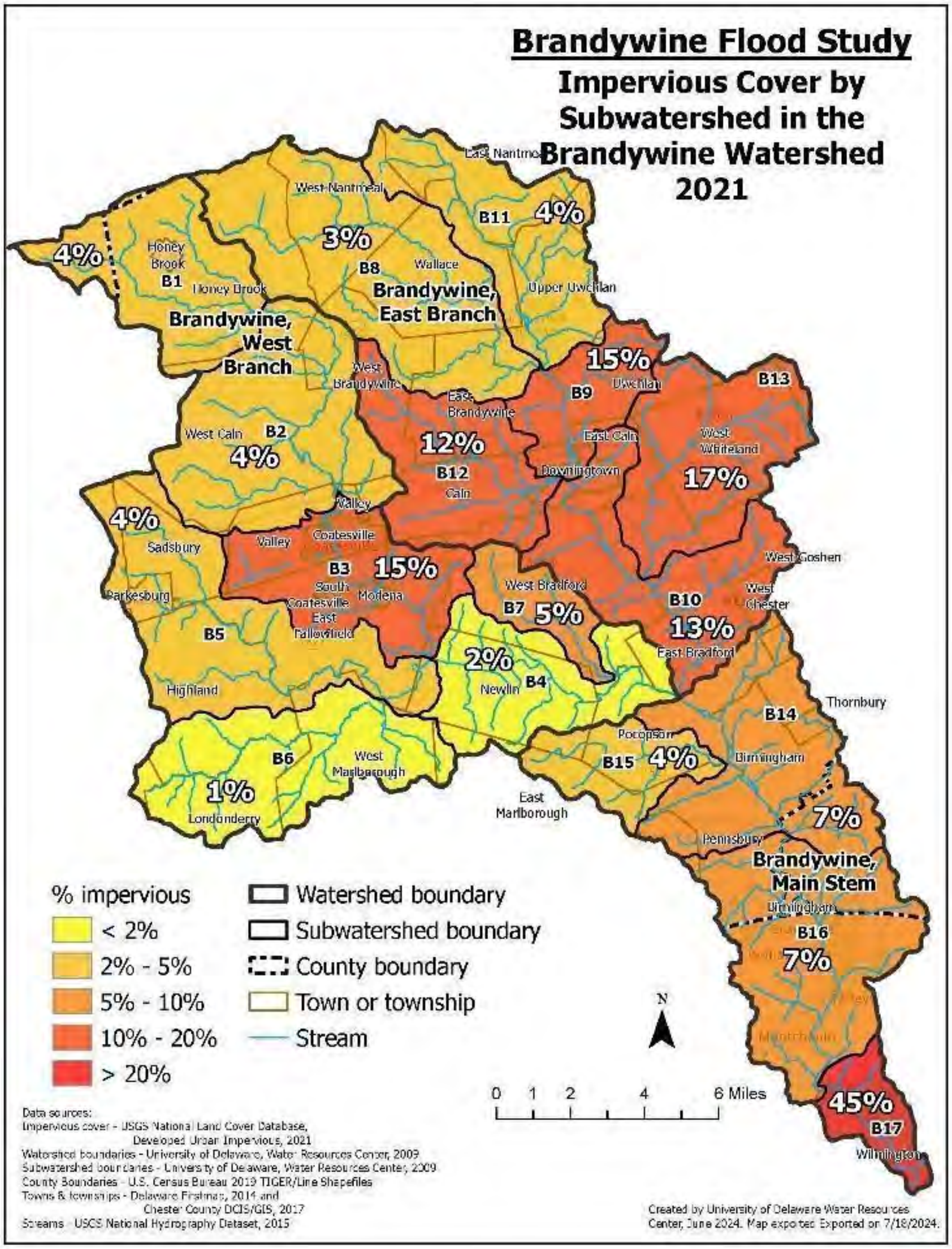


Data sources:
Impervious cover - USGS National Land Cover Database, Developed Urban Impervious, 2021
Watershed boundaries - University of Delaware, Water Resources Center, 2009
Subwatershed boundaries - University of Delaware, Water Resources Center, 2009
County Boundaries - U.S. Census Bureau 2019 TIGER/Line Shapefiles
Towns & townships - Delaware Firstmap, 2014 and Chester County DCIS/GIS, 2017
Streams - USGS National Hydrography Dataset, 2015

Created by University of Delaware Water Resources Center, June 2024. Map exported Exported on 7/17/2024.

Figure 1.15 Impervious cover in the Brandywine Watershed, 2021

Figure 1.16 shows the overall percentage of impervious cover in each subwatershed. Wilmington has the highest percentage imperviousness, at 45%, followed by the urbanized areas around Exton and Coatesville, at 17% and 15% respectively.



Data sources:
Impervious cover - USGS National Land Cover Database, Developed Urban Impervious, 2021
Watershed boundaries - University of Delaware, Water Resources Center, 2009
Subwatershed boundaries - University of Delaware, Water Resources Center, 2009
County Boundaries - U.S. Census Bureau 2019 TIGER/Line Shapefiles
Towns & townships - Delaware Firstmap, 2014 and Chester County DCIS/GIS, 2017
Streams - USGS National Hydrography Dataset, 2015

Created by University of Delaware Water Resources Center, June 2024. Map exported Exported on 7/18/2024.

Figure 1.16 Impervious Cover in the Brandywine Watershed by Subwatershed, 2021

The change in impervious cover over time may indicate where potential flooding may be exacerbated by land use change. The type and pattern of development has a large influence on the degree to which imperviousness may have negative impacts on the watershed. Hard surfaces on steep slopes or without adequate stormwater controls for instance, will have a greater negative impact than other types of impervious cover. Between 2001 and 2021, the greatest increases in impervious cover generally occurred in and around areas with the most intensive existing development. Many of those areas are also characterized by relatively steep slopes and existing flooding problems.

While increasing impervious cover over the past few decades does have an impact on the total volume of stormwater runoff generated in the watershed, it is worth noting that development during this timeframe was done in accordance with modern stormwater management regulations. Therefore, assuming its associated stormwater infrastructure is functioning as designed, a new development is less likely to exacerbate localized runoff and flooding challenges than one constructed prior to 1990, which may not have any meaningful stormwater infrastructure installed site.

Chapter 2 Historic Flooding Challenges

2.1. History of Major Floods

The Brandywine Creek and its tributaries have a long history of flooding along the mainstem of the river in Delaware and Pennsylvania, the east and west branches, and dozens of tributaries. These flood events have endangered lives, disrupted economic activities, and caused extensive damage. This section summarizes numerous reports and studies which have captured flood events over the last two centuries, including:

- U.S. Army Corps of Engineers, 1962. Delaware River Basin, New York, New York, New Jersey, Pennsylvania, and Delaware. Letter from the Secretary of the Army. Volume VI.
- U.S. Army Corps of Engineers, 1973. Floodplain Information, Brandywine Creek, New Castle County, Delaware. Prepared for the New Castle County Department of Planning.
- Chester County Hazard Mitigation Plan, 2010.
- Federal Emergency Management Agency, 2015. Flood Insurance Study, New Castle County, Delaware.
- Federal Emergency Management Agency, 2017. Flood Insurance Study, Chester County, Pennsylvania.
- Federal Emergency Management Agency, 2017. Flood Risk Report, Chester County, Brandywine Christina Watershed, 02-040205. Report No. 01.

Records of flooding in the Brandywine Valley date back to January 1839 (USACOE, 1963). During that winter storm, the main stem of the Brandywine rose dramatically and all but two of the bridges across the creek were swept away. Since then, dozens of flood events have impacted communities across the watershed. Tropical Storm Agnes produced over seven inches of rain on the area between June 20-25, 1972 and resulted in a flood crest elevation of 167.0 feet in Brandywine Creek at Chadds Ford, PA. Prior to Agnes, the previous flood of record at that location was a flood crest elevation of 165.5 ft on March 5, 1920. Other major floods that impacted the Brandywine watershed in the 20th century include events in August 1915, August 1933, August 1942, August 1955 (Hurricanes Connie and Diane), September 1971, and July 1979. The impacts of these floods were distributed differently across each of the subwatersheds depending on the nature of their associated storms, but each caused significant damage in at least one community.

Beginning in the 1950s, the impacts of severe storms (as well as growing water supply demands and drought concerns) led local, state, and federal partners active in the watershed to collaborate on the development of the Brandywine Watershed Work Plan. The most significant outcomes of the plan's implementation include the construction of five major flood control structures in the upper reaches of the watershed, identified in Table 2.1. These facilities were completed between 1971 and 1996. As mentioned in Chapter 1, these structures provide a combined 5.5 billion gallons of total flood storage capacity.

Table 2.1 Major flood control structures in the Brandywine watershed in Chester County, PA

Structure	Stream	Type	Built	Dam Height (ft)	Storage (ac ft)	Storage (MG)	Purpose
R G Struble Lake	East Branch Brandywine Creek	Impoundment	1971	31	2,880	940	Flood Control/ Recreation
Marsh Creek Reservoir	Marsh Creek (East Branch Brandywine Creek)	Impoundment	1973	90	24,000	7,800	Flood Control/ Recreation/ Water Supply
Beaver Creek Dam	Beaver Creek	Dry Dam	1975	36	1,410	460	Flood Control
Barneston Dam	East Branch Brandywine Creek	Dry Dam	1983	43	3,700	1,205	Flood Control
Hibernia Dam/ Chambers Lake	Birch Run	Impoundment	1994	65	3,300	1,075	Flood Control/ Recreation/ Water Supply

Source: U. S. Army Corps of Engineers National Inventory of Dams (https://nid.sec.usace.army.mil/#/)

While these structures provide significant protection for downstream communities during storms, they are not a cure-all, particularly as they only manage water from the drainage area above the structure itself. Since the final flood control structure was built in the mid-1990s, numerous floods have negatively impacted communities across the watershed. These include, but are not limited to:

- Hurricane Floyd in September 1999
- Multiple severe storms in July 2003
- Tropical Storm Henri in September 2003
- Tropical Depression Ivan in September 2004
- Tropical Depression Frances in September 2004
- Hurricane Jeanne in September 2004
- Hurricane Katrina in September 2005
- Severe storms in June 2006
- Hurricane Irene in August 2011
- Tropical Storm Lee in September 2011
- Hurricane Sandy in October 2012
- Hurricane Ida in September 2021

Table 2.2 identifies the most significant flood events (in terms of peak discharge) along the mainstem of the Brandywine at the USGS gage in Wilmington, DE for the period of record (1946-present).

Table 2.2 Peak floods along the Brandywine River at Wilmington USGS Gage 01481500 (1946-present)

Date	Storm	Peak Discharge (cfs)	Return Interval
Sep 2, 2021	Ida	33,700	>100-yr
Jun 23, 1972	Agnes	29,000	100-yr
Sep 17, 1999	Floyd	28,700	>50-yr
May 1, 2014	[Unnamed]	22,800	>25-yr
Jan 25, 1979	[Unnamed]	22,400	>25-yr
Sep 13, 1971	[Unnamed]	21,300	>25-yr
Sep 29, 2004	Jeanne	20,800	>25-yr
Aug 19,1955	Diane	17,800	>10-yr
Jan 26, 1978	[Unnamed]	17,200	>10-yr
Aug 28, 2011	Irene	16,800	>10-yr
Aug 5, 2020	Isaias	16,100	>10-yr

What does the term “100-year flood” really mean?

It doesn’t actually refer to a flood that can happen only once every 100 years.

Instead, it is the level of flooding that has a 1% chance (or once out of 100 times) of occurring in any given year.

Sometimes, this is referred to as the “1% Annual Chance” flood. This term can be used interchangeably with the “100-year” flood or “100-year return interval.”

2.2. Hurricane Ida

Hurricane Ida made landfall in Louisiana on Sunday August 29, 2021, with winds of up to 150 miles per hour (mph). The storm’s remnants reached the Brandywine watershed three days later on Wednesday, September 1, 2021.

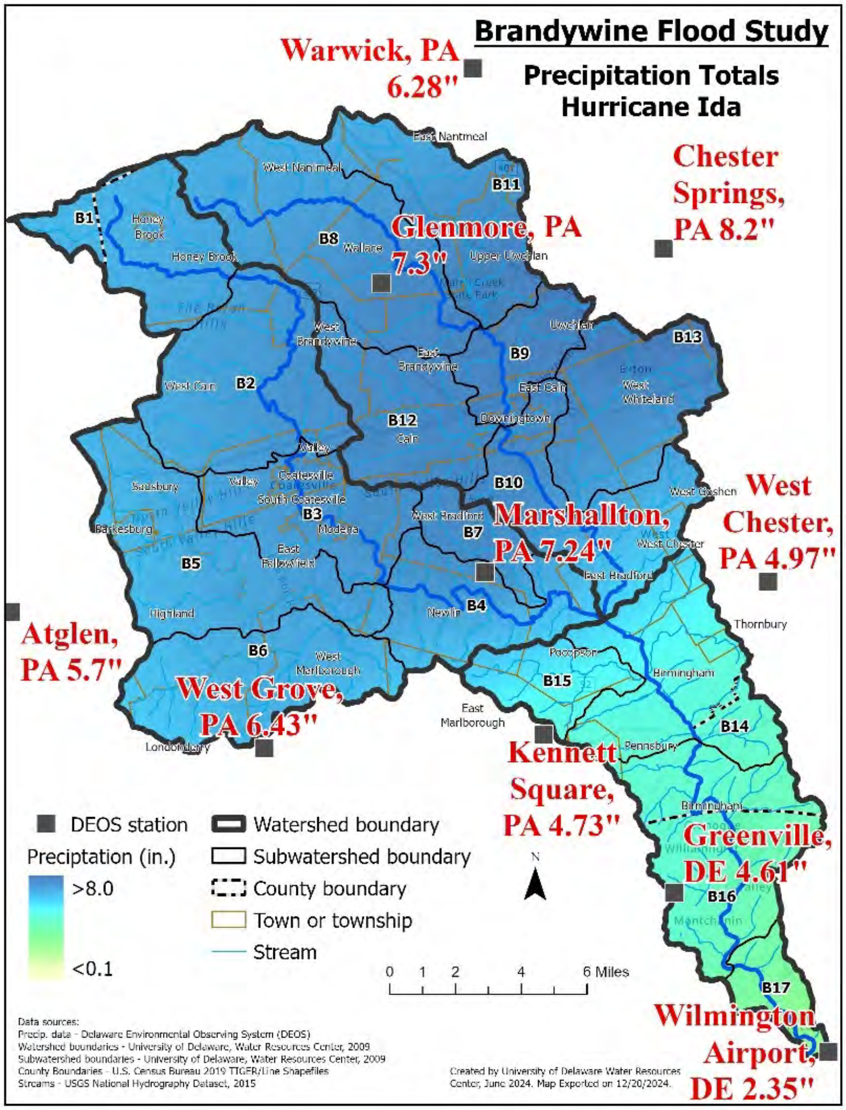
Rainfall intensity varied throughout the watershed as well as over the course of the day when Hurricane Ida passed over the Brandywine Creek watershed. Ida dropped 7.3 inches of rain at Coatesville and 8.2 inches at Downingtown over the duration of the storm. However, most of the rainfall occurred in a 6-hour window. As noted in Table 2.3. the rainfall totals recorded in the 6-hour timeframe at the USGS gage in Modena Borough exceeded NOAA’s estimate for the 1,000-year storm of 6.93 inches. Most other sites in the upper Brandywine Creek watershed also exceeded the 200-year event.

Hurricane Ida made landfall in Louisiana on Sunday August 29, 2021, with winds of up to 150 miles per hour (mph). The storm’s remnants reached the Brandywine watershed three days later on Wednesday, September 1, 2021. Rainfall intensity varied throughout the watershed as well as over the course of the day as Hurricane Ida passed over the watershed. Ida dropped 7.3 inches of rain at the City of Coatesville and 8.2 inches at Downingtown Borough over the duration of the storm. However, most of the rainfall occurred in a 6-hour window. As noted in Table 2.5, the maximum rainfall recorded in the 6-hour timeframe at the USGS gage in Modena Borough exceeded NOAA’s estimate for the 1,000-year storm (6.93 inches in 6 hours). Most other sites in the upper Brandywine Creek watershed exceeded the 200-year event.

Table 2.3 Maximum rainfall (in) and Associated Recurrence Intervals During Hurricane Ida

Precip. Gage Network	Precip. Gage Location	1 Hour Max	NOAA Frequency Range	6 Hour Max	NOAA Frequency Range	24 Hour Max	NOAA Frequency Range
USGS	Chambers Lake near Wagontown	2.05	10-yr	5.82	200-yr	6.68	50-yr
	West Branch Brandywine Creek at Modena	2.27	10-yr	7.02	1,000-yr	8.18	100-yr
	East Branch Brandywine Creek below Downingtown	1.49	2-yr	5.83	200-yr	6.93	50-yr
	Brandywine Creek at Chadds Ford	1.83	5-yr	3.28	5-yr	5.12	10-yr
UDel DEOS	Chester Springs, PA	1.58	2-yr	6.18	200-yr	8.2	100-yr
	Glenmoore, PA at Springton Manor Farm	1.88	5-yr	4.99	100-yr	7.29	50-yr
	Marshallton in West Bradford, PA	1.69	2-yr	5.25	100-yr	7.24	50-yr
	Wilmington, DE	0.49	< 1-yr	1.67	< 1-yr	2.35	< 1-yr

Further, NOAA Atlas 14 reports that the 100-year, 24-hour storm for this region is considered to be 7.7 inches of precipitation over a 24-hour period. As recorded at USGS gages in Modena and Chadds Ford, precipitation totals were 8.2 inches and 5.1 inches, respectively. The maximum rainfall intensity was observed at 5pm in Glenmoore and Chadds Ford at 1.88 inches per hour and 1.54 inches per hour, respectively. Both readings exceed the 100-year rainfall intensity for a 3-hour storm duration (1.3 inches/hour). By precipitation volume (inches) and intensity (inches/hour), Ida was greater than a 100-year storm in central Chester County (Figure 2.1).

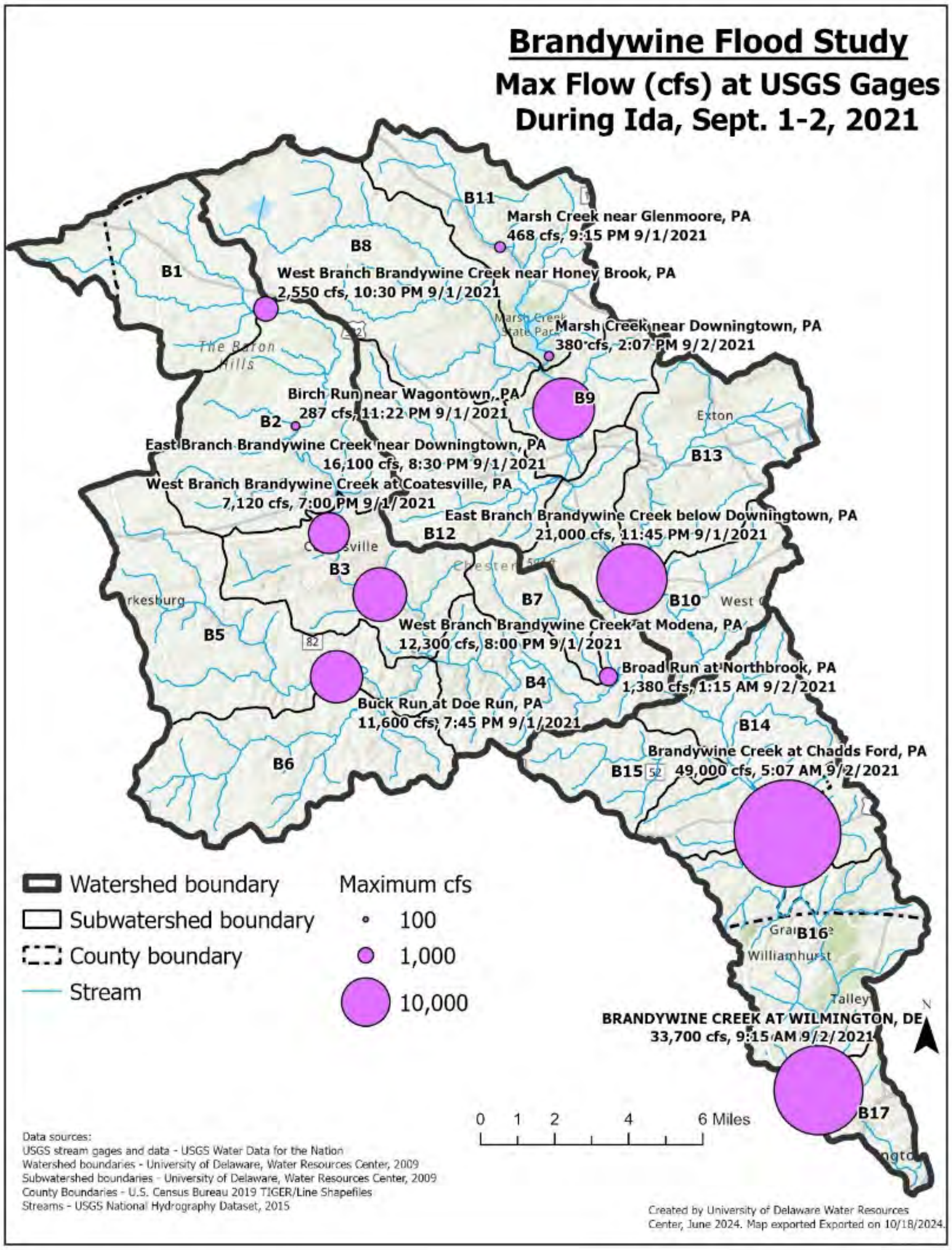


Data sources:
Precip. data - Delaware Environmental Observing System (DEOS)
Watershed boundaries - University of Delaware, Water Resources Center, 2009
Subwatershed boundaries - University of Delaware, Water Resources Center, 2009
County Boundaries - U.S. Census Bureau 2019 TIGER/Line Shapefiles
Streams - USGS National Hydrography Dataset, 2015

Created by University of Delaware Water Resources Center, June 2024. Map Exported on 12/20/2024.

Figure 2.1 Precipitation depth (in) during Hurricane Ida in the Brandywine watershed

While rainfall totals during Ida were less in the lower Brandywine watershed, flooding in the upper reaches was exacerbated by the inherently steep Piedmont topography, which creates a funnel-like shape in the watershed closer to the Pennsylvania/Delaware state line. Floodwaters overtopped the USGS gage at Chadds Ford in the early morning hours of September 2, 2021. USGS used high water marks and other data to determine that Ida's peak discharge at that location was roughly 49,000 cfs. Based on this estimate, this would represent approximately an 800-year flood event (Stuckey et.al., 2023) and the highest flood recorded at the site in two centuries. While the wider, flatter floodplains in southern Chester County were able to attenuate some of the flood waters, the peak flow in the City of Wilmington reached 33,700 cfs on September 2, 2021 (Figure 2.2). This is the highest flood discharge on record along the Brandywine Creek at Wilmington dating back to 1946, surpassing Hurricanes Agnes (29,000 cfs) in 1972 and Floyd (28,700 cfs) in 1999 (Figure 2.3).



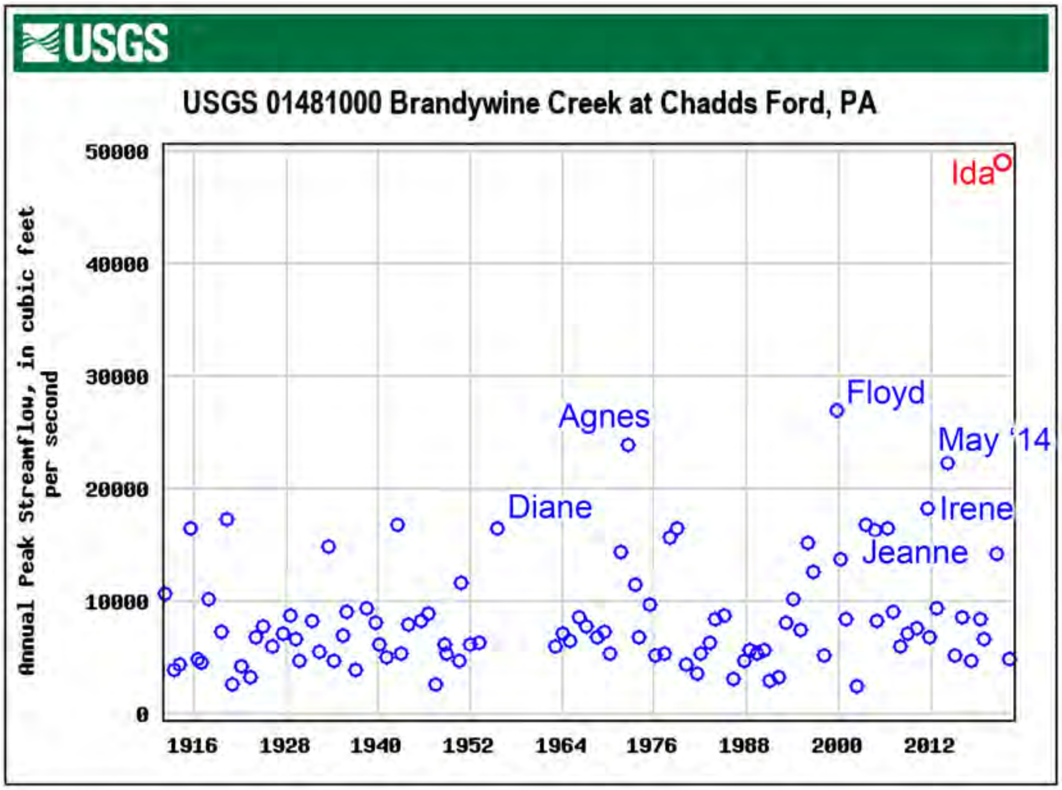
Brandywine Flood Study

Max Flow (cfs) at USGS Gages During Ida, Sept. 1-2, 2021

Data sources:
USGS stream gages and data - USGS Water Data for the Nation
Watershed boundaries - University of Delaware, Water Resources Center, 2009
Subwatershed boundaries - University of Delaware, Water Resources Center, 2009
County Boundaries - U.S. Census Bureau 2019 TIGER/Line Shapefiles
Streams - USGS National Hydrography Dataset, 2015

Created by University of Delaware Water Resources Center, June 2024. Map exported Exported on 10/18/2024.

Figure 2.2 Peak Stream Flows during Ida throughout the Brandywine Watershed



Since 1911, the Brandywine Creek at Chadds Ford, PA never exceeded 25,000 cfs until Tropical Storm Floyd in 1999 which resulted in flood flows of 26,900 cfs. However, flood flows from Hurricane Ida set a new recorded and were esimated by the U. S. Geological Survey to be nearly twice as high at 49,000 cfs.

Source: U. S. Geological Survey, Peak Streamflow for the Nation, USGS 01481000 Brandywine Creek at Chadds Ford, PA
https://nwis.waterdata.usgs.gov/nwis/peak?site_no=01481000&agency_cd=USGS&format=html

Figure 2.3 Flood peaks along the Brandywine River at Chadds Ford, Pennsylvania

The results of this storm were catastrophic for many communities in the central and lower portions of the watershed. In some cases, individual recovery efforts are still ongoing. Figures 2.4 through 2.6 depict high water marks documented in the aftermath of the flooding. The hurricane's impacts were the dominant catalyst for this study, to provide recommendations for communities to be better protected and prepared for future storms.

Figure 2.4 Hurricane Ida high water at the AMTRAK viaduct and NE Blvd. in Wilmington, Del.

Figure 2.5 Hurricane Ida high water mark at Howard High School, the Josephine Fountain, and Brecks Mill (Dam No. 7) on the Brandywine in Wilmington, Del.

Figure 2.6 Hurricane Ida high water mark at US Route 1 (northbound) and US Route 1 (southbound) in Chadds Ford, Pennsylvania

2.3. Chronic Flooding Areas

Chronic flooding areas in the Brandywine Creek watershed in Delaware and Pennsylvania have been identified through examining the FEMA floodplain maps and profiles, news media reports, and published reports by the USCOE, USGS, and others. The analysis identified twenty-two specific flood hazard sites--five along the mainstem of the Brandywine (BR), five along the east branch (EB) and west branch (WB), and twelve sites along the tributaries (TY) and are displayed in Figures 2.7 to 2.9. Additional details about the floodplains at these locations are listed in Table 2.4 and shown in the FEMA maps (Figures 2.10-2.19) for those sites along the mainstem and East and West Branches of the Brandywine and its tributaries.

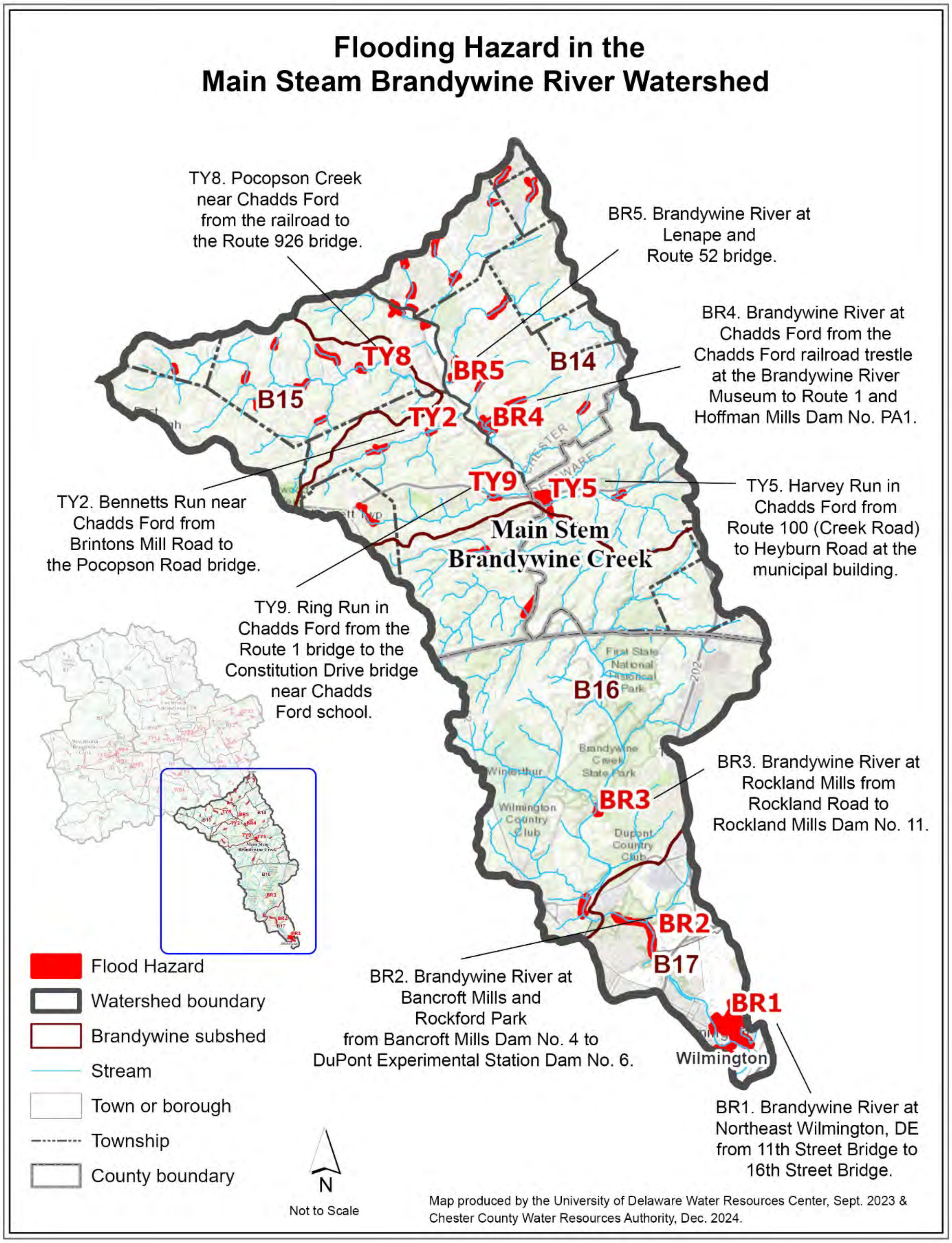
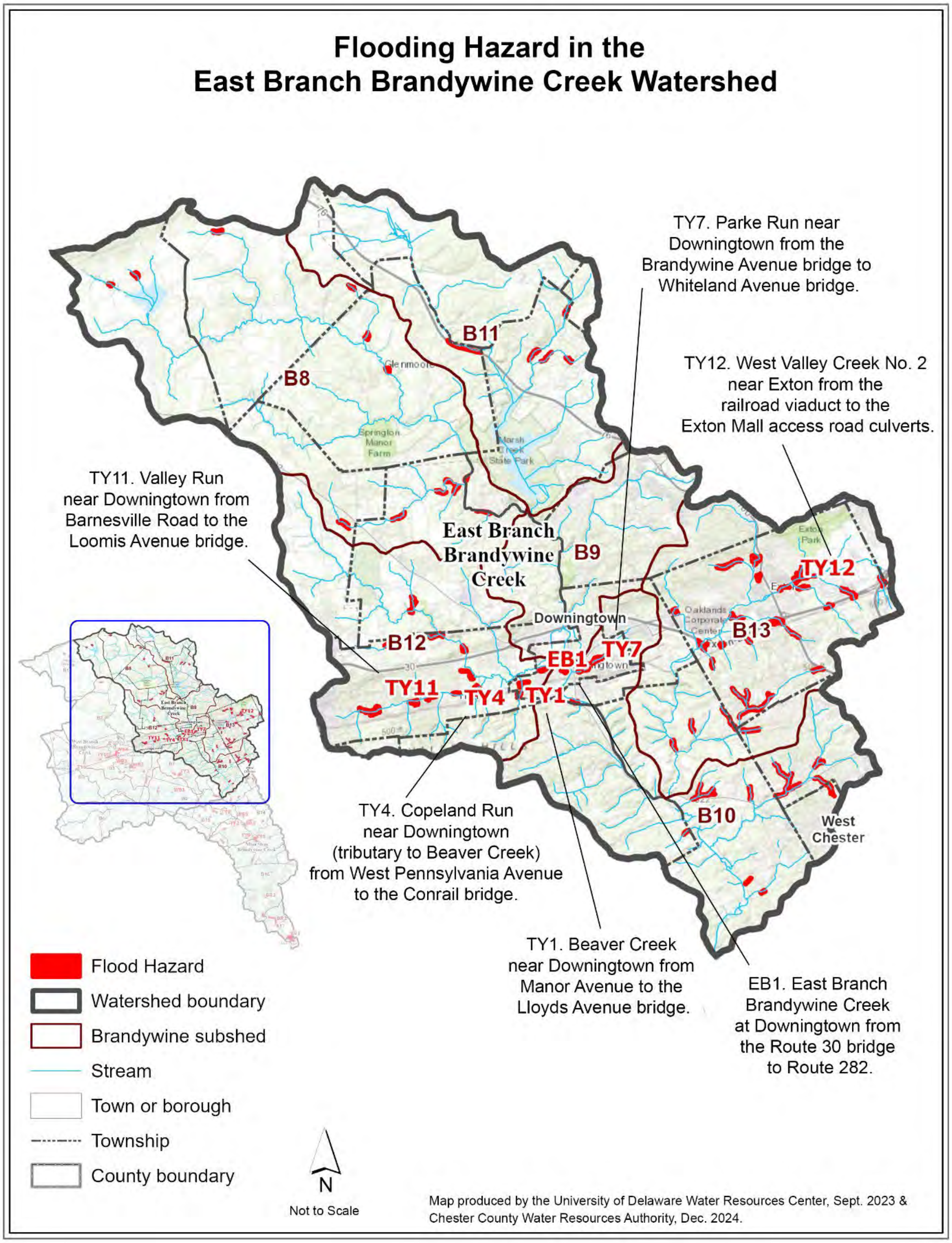
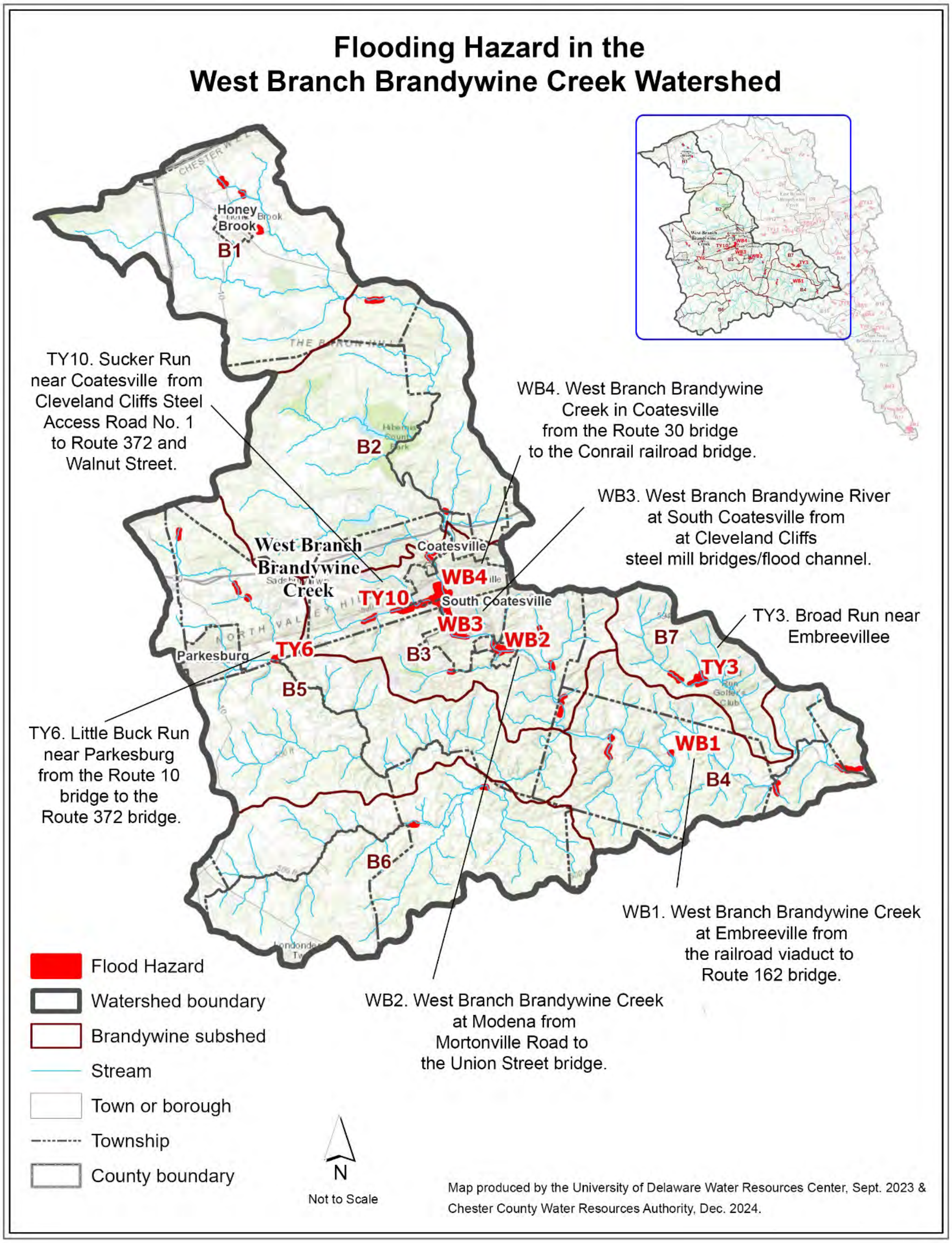


Figure 2.7 Flood Hazard Sites in the Mainstem Brandywine Watershed



Map produced by the University of Delaware Water Resources Center, Sept. 2023 & Chester County Water Resources Authority, Dec. 2024.

Figure 2.8 Flood Hazard Sites in the East Branch Brandywine Watershed



Flooding Hazard in the West Branch Brandywine Creek Watershed

TY10. Sucker Run near Coatesville from Cleveland Cliffs Steel Access Road No. 1 to Route 372 and Walnut Street.

WB4. West Branch Brandywine Creek in Coatesville from the Route 30 bridge to the Conrail railroad bridge.

WB3. West Branch Brandywine River at South Coatesville from at Cleveland Cliffs steel mill bridges/flood channel.

TY3. Broad Run near Embreevillee

TY6. Little Buck Run near Parkesburg from the Route 10 bridge to the Route 372 bridge.

WB1. West Branch Brandywine Creek at Embreeville from the railroad viaduct to Route 162 bridge.

WB2. West Branch Brandywine Creek at Modena from Mortonville Road to the Union Street bridge.

Map produced by the University of Delaware Water Resources Center, Sept. 2023 & Chester County Water Resources Authority, Dec. 2024.

Figure 2.9 Flood Hazard Sites in the West Branch Brandywine Watershed

Table 2.4 Flood-prone Streams in the Brandywine Watershed

Reach ID	Subshed ID	Stream	RM	Floodplain (acre)	100-yr Flood Elev. (feet MSL)
BR1	B17	Brandywine River at Northeast Wilmington, DE from 11th Street Bridge to 16th Street Bridge.	1.5 to 1.9	61	12 to 15
BR2	B17	Brandywine River at Bancroft Mills and Rockford Park from Bancroft Mills Dam No. 4 to DuPont Experimental Station Dam No. 6.	3.7 to 4.6	22	57 to 89
BR3	B17	Brandywine River at Rockland Mills from Rockland Road to Rockland Mills Dam No. 11.	7.2 to 7.4	12	135 to 141
BR4	B16	Brandywine River at Chadds Ford from theChadds Ford railroad trestle at the Brandywine RiverMuseum to Route 1 and Hoffman Mills Dam No. PA1.	23,500 to 24,000	35	167 to 171
BR5	B16	Brandywine River at Lenape and Route 52 bridge.	42,000 to 45,000	104	180 to 182
EB1	B9	East Branch Brandywine Creek at Downingtown from the Route 30 bridge to Route 282.	47,000 to 51,000	92	235 to 246
WB1	B4	West Branch Brandywine Creekat Embreeville fromthe railroad viaduct to Route 162 bridge.	38,500 to 41,000	115	220 to 230
WB2	B3	West Branch Brandywine Creekat Modena fromMortonville Road to the Union Street bridge.	71,000 to 74,000	69	271 to 277
WB3	B3	West Branch Brandywine River at South Coatesville fromat Cleveland Cliffs steel mill bridges/flood channel.	76,000 to 80,000	28	293 to 305
WB4	B3	West Branch Brandywine Creek in Coatesville from the Route 30 bridge to the Conrail railroad bridge.	81,000 to 89,000	184	305 to 330
TY1	B12	Beaver Creek near Downingtown from Manor Avenue to the Lloyds Avenue bridge.	1,500 to 6,500	115	240 to 250
TY2	B14	Bennetts Run near Chadds Ford from Brintons Mill Road to the Pocopson Road bridge.	1,600 to 10,800	41	178 to 200
TY3	B7	Broad Run near Embreeville		46	
TY4	B12	Copeland Run near Downingtown (tributary to Beaver Creek) from West Pennsylvania Avenue to the Conrail bridge.	1,000 to 3,000	14	258 to 300
TY5	B14	Harvey Run in Chadds Ford fromRoute 100 (Creek Road) to Heyburn Road at themunicipal building.	1,200 to 9,600	39	170 to 210
TY6	B5	Little Buck Run near Parkesburg from the Route 10 bridge to the Route 372 bridge.	3,300 to 5,200	14	458 to 510
TY7	B10	Parke Run near Downingtown from the Brandywine Avenue bridge to Whiteland Avenue bridge.	3,090 to 3,500	3	234 to 245
TY8	B15	Pocopson Creek near Chadds Ford from the railroad to the Route 926 bridge.	200 to 3,800	17	178 to 189
TY9	B14	Ring Run in Chadds Ford from theRoute 1 bridge to the Constitution Drive bridge near Chadds Ford school.	1,000 to 5,000	28	170 to 200
TY10	B3	Sucker Run near Coatesville from Cleveland Cliffs Steel Access Road No. 1 to Route 372 and Walnut Street.	3,000 to 10,500	51	320 to 377
TY11	B12	Valley Run near Downingtown from Barnesville Road to the Loomis Avenue bridge.	4,000 to 13,500	65	216 to 320
TY12	B13	West Valley Creek No. 2 near Exton from the railroad viaduct to the Exton Mall access road culverts.	5,500 to 15,500	65	280 to 310
			TOTAL (ac)	**1220**	

Note: River Miles (RM) in the list below are in miles for Delaware stream reaches and in feet for Pennsylvania stream reaches due to differences in reporting by state.

Figure 2.10 Brandywine Creek near northeast Wilmington (BR1)

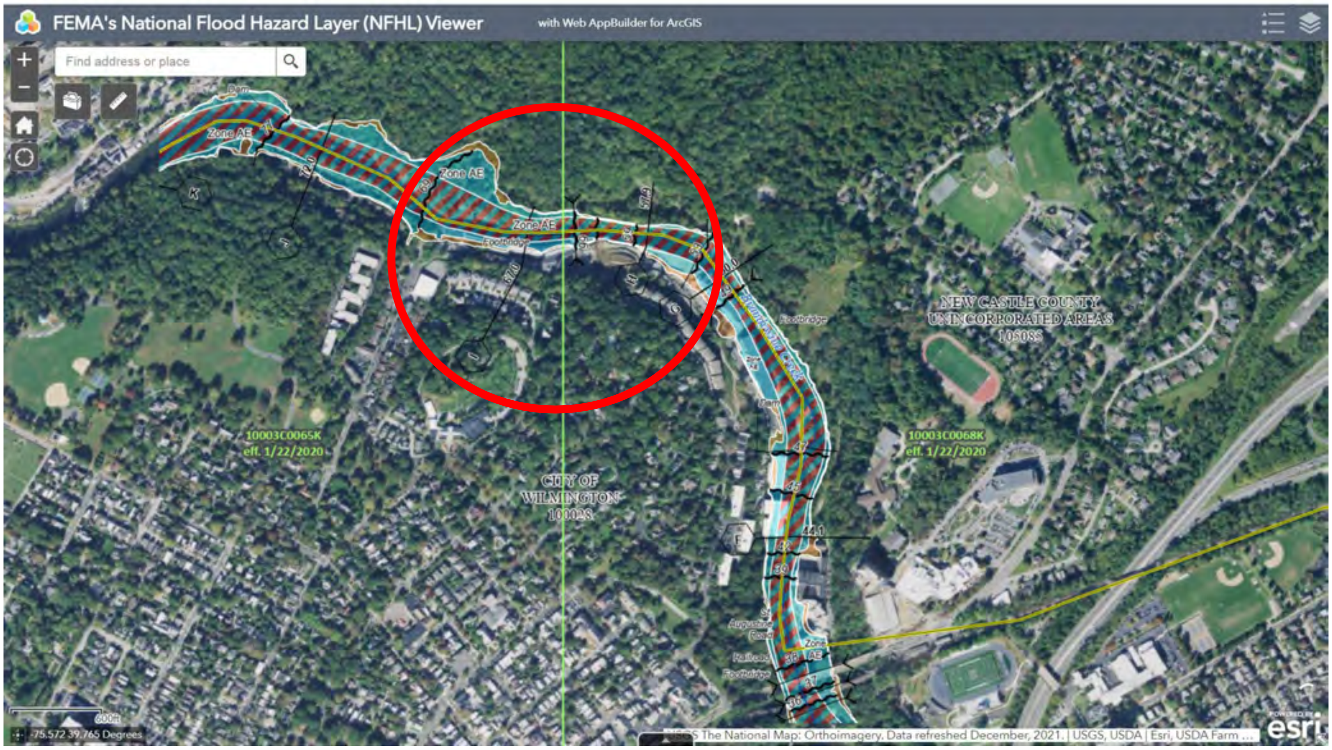


Figure 2.11 Brandywine Creek at Bancroft Mills and Rockford Park (BR2)

Figure 2.12 Brandywine Creek at Rockland (BR3)

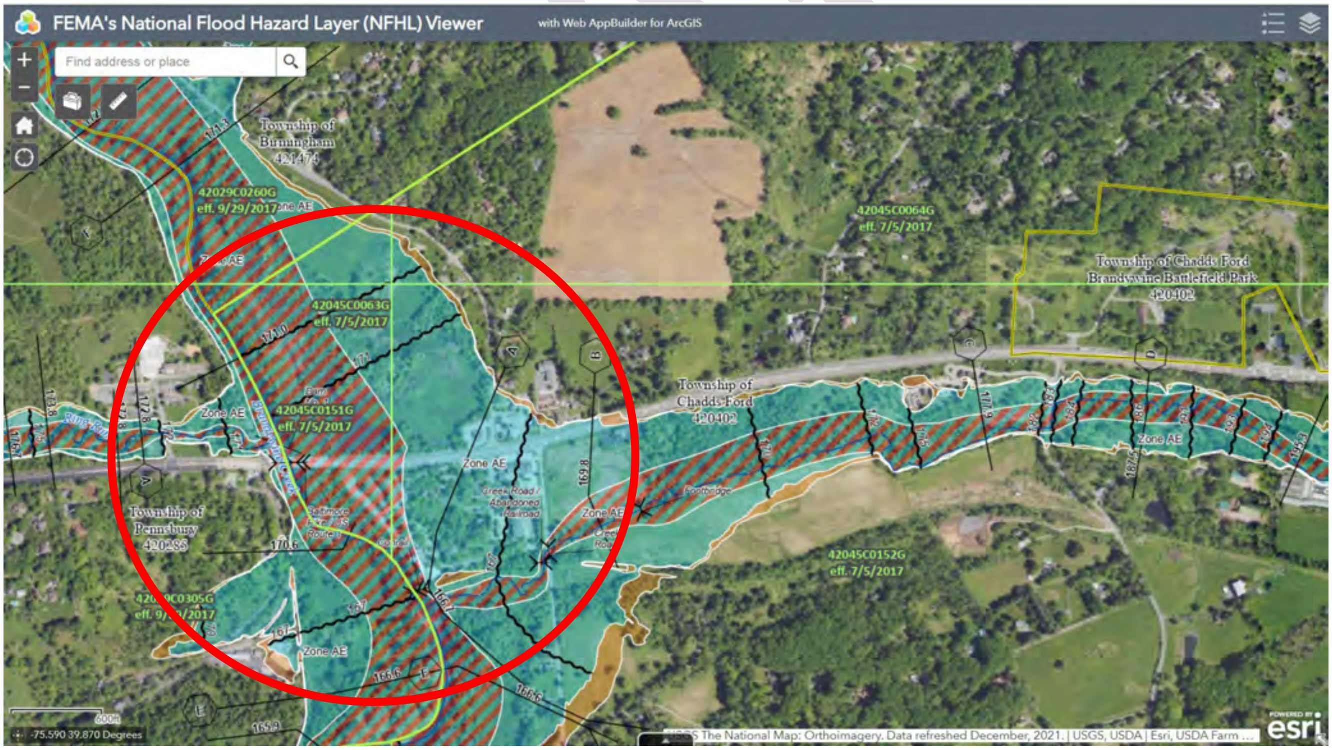


Figure 2.13 Brandywine Creek at Chadds Ford (BR4)

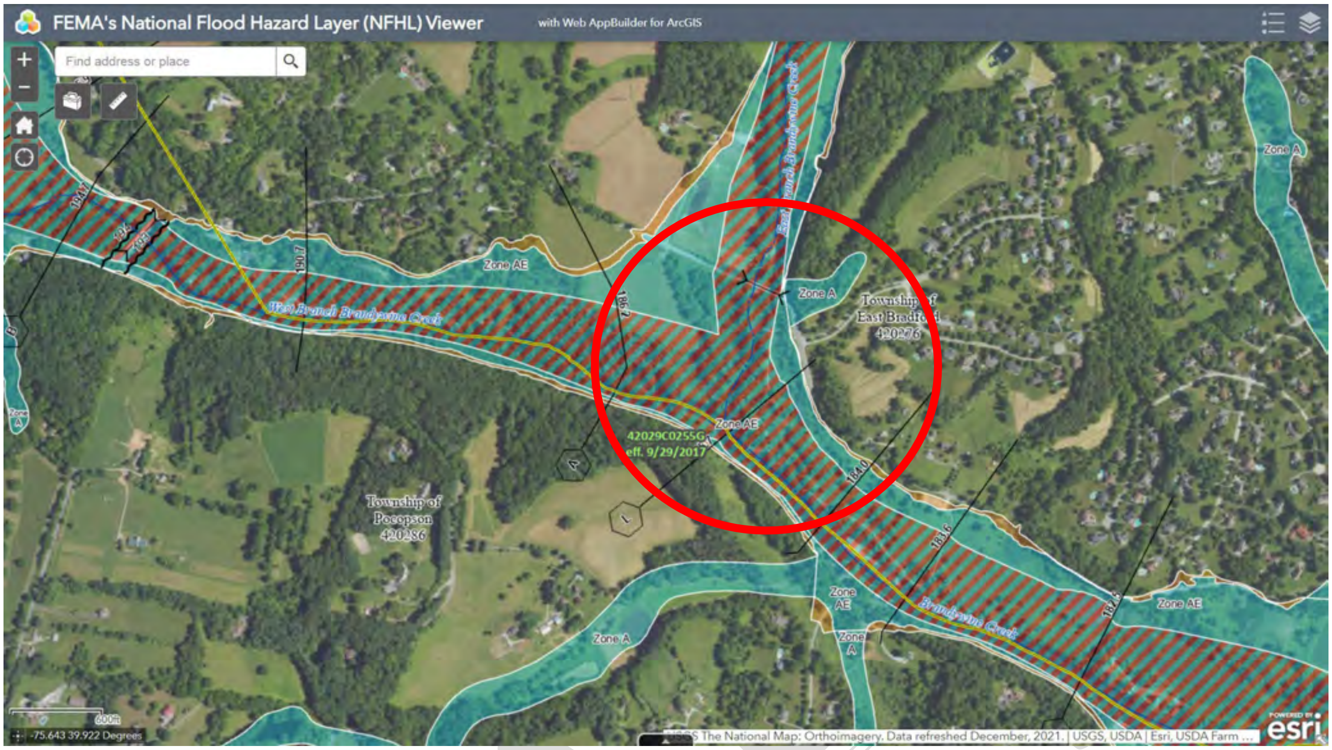


Figure 2.14 Brandywine Creek at Lenape (BR5)

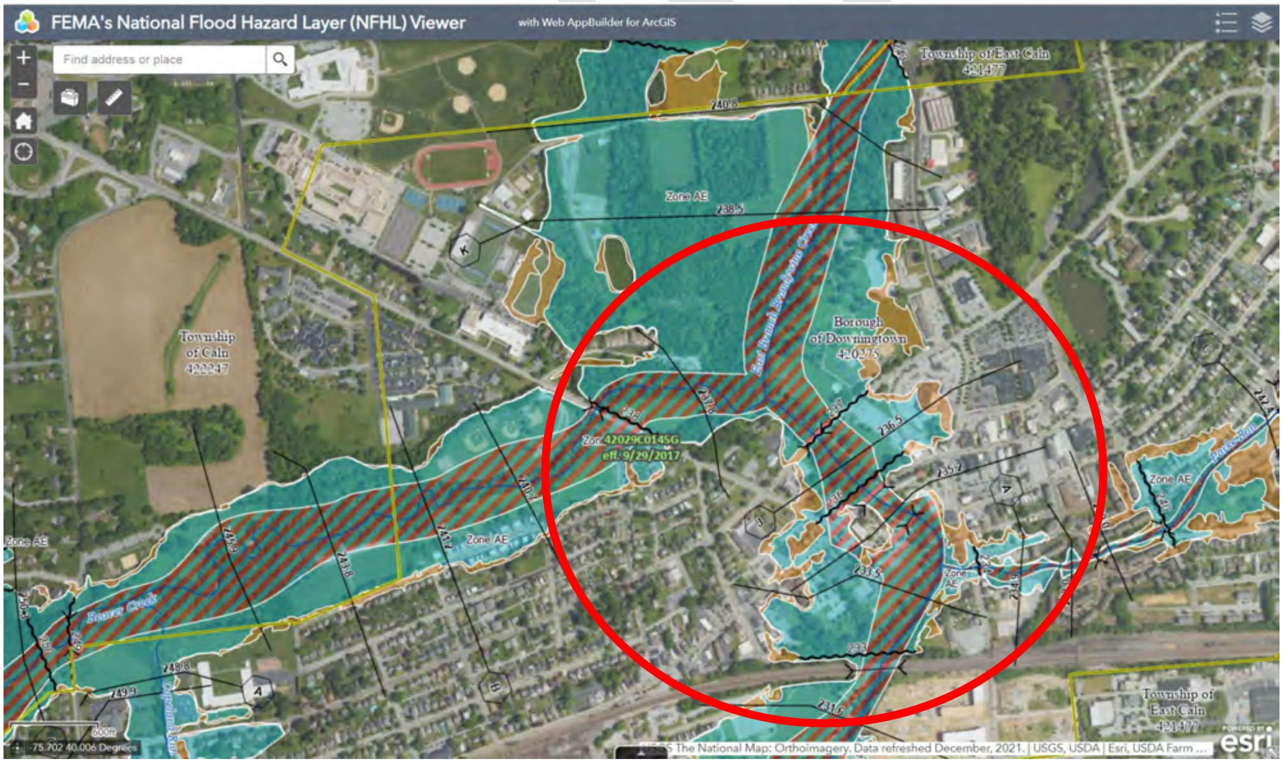


Figure 2.15 East Branch Brandywine Creek at Downingtown (EB1)

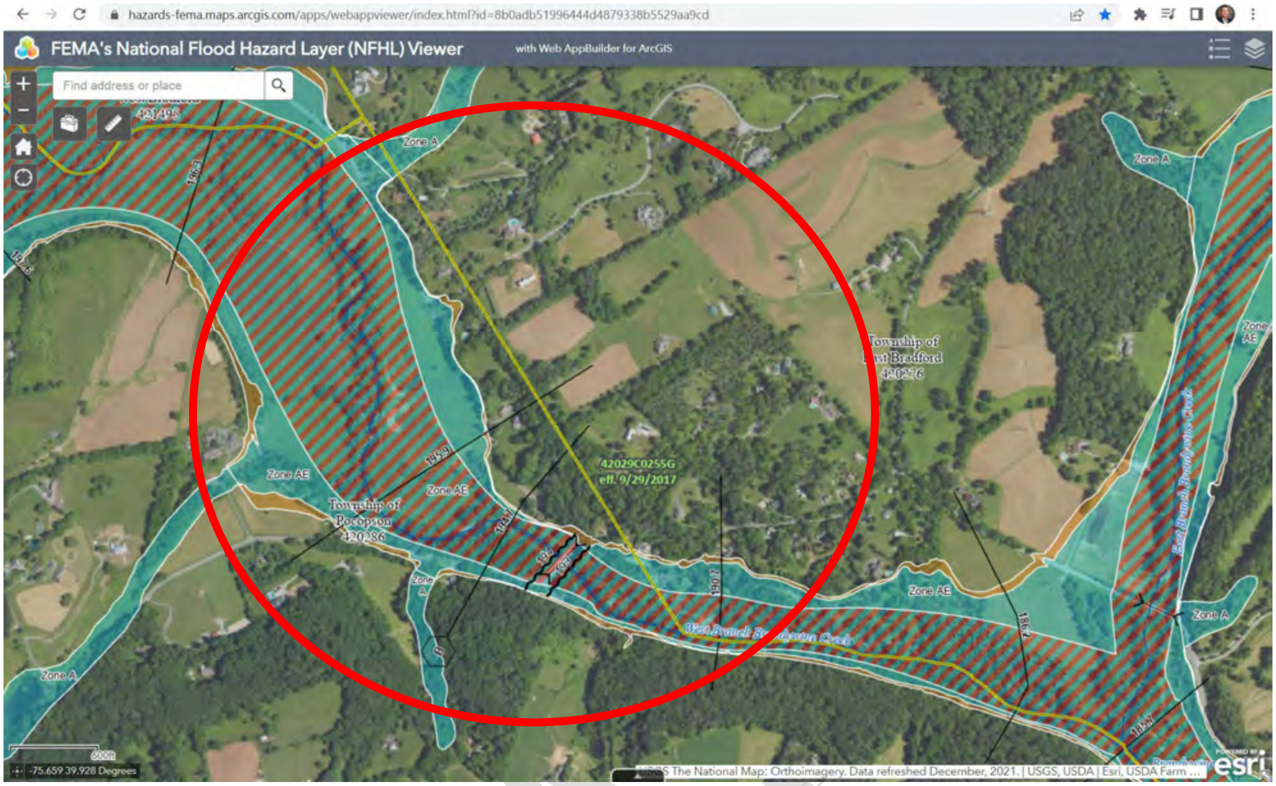


Figure 2.16 West Branch Brandywine Creek at Embreeville (WB1)

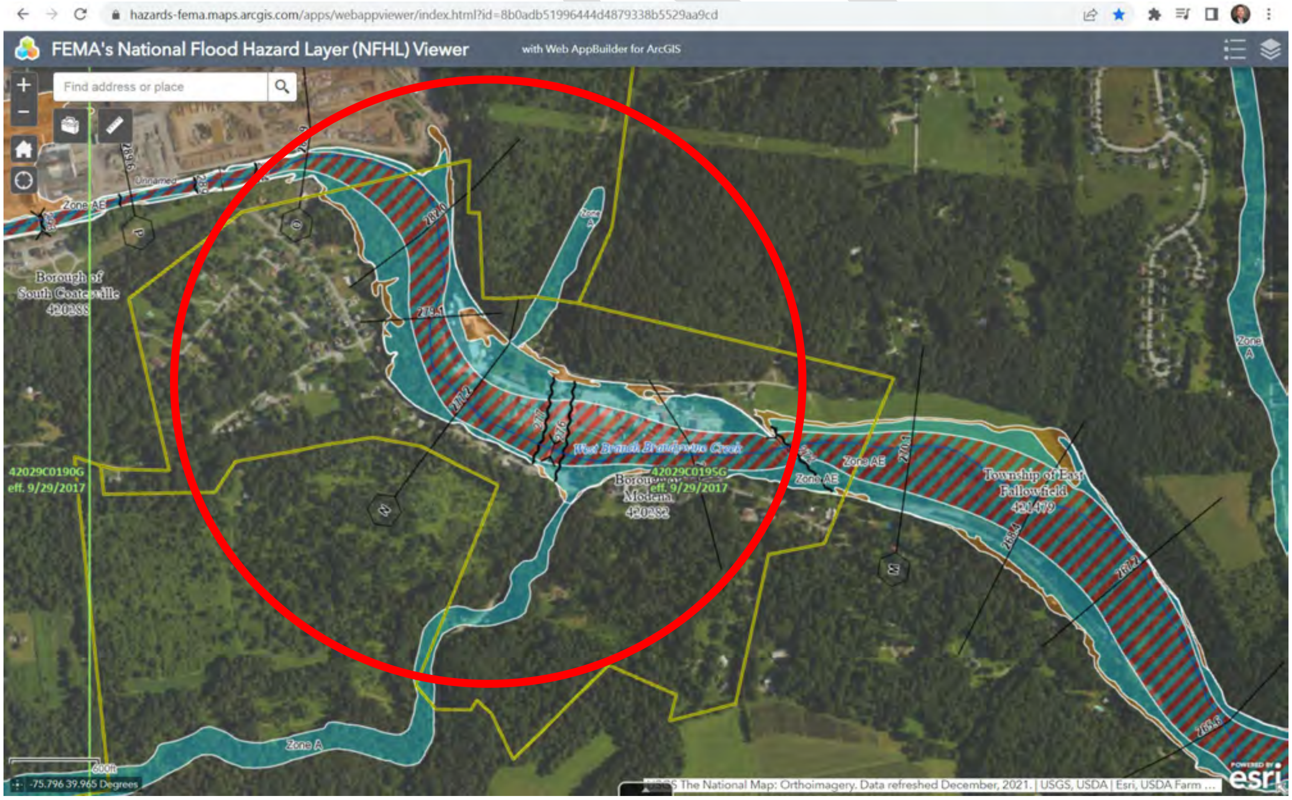


Figure 2.17 West Branch Brandywine Creek at Modena (WB2)

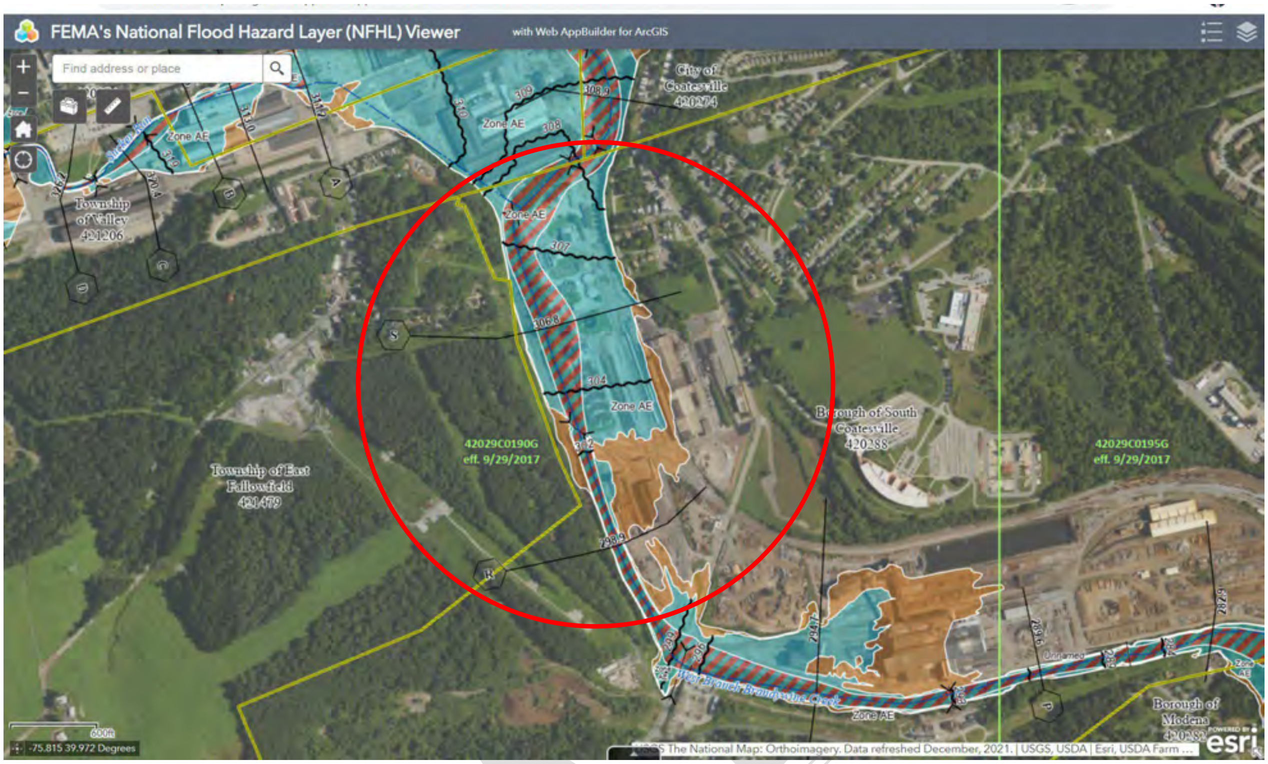


Figure 2.18 West Branch Brandywine Creek in South Coatesville (WB3)

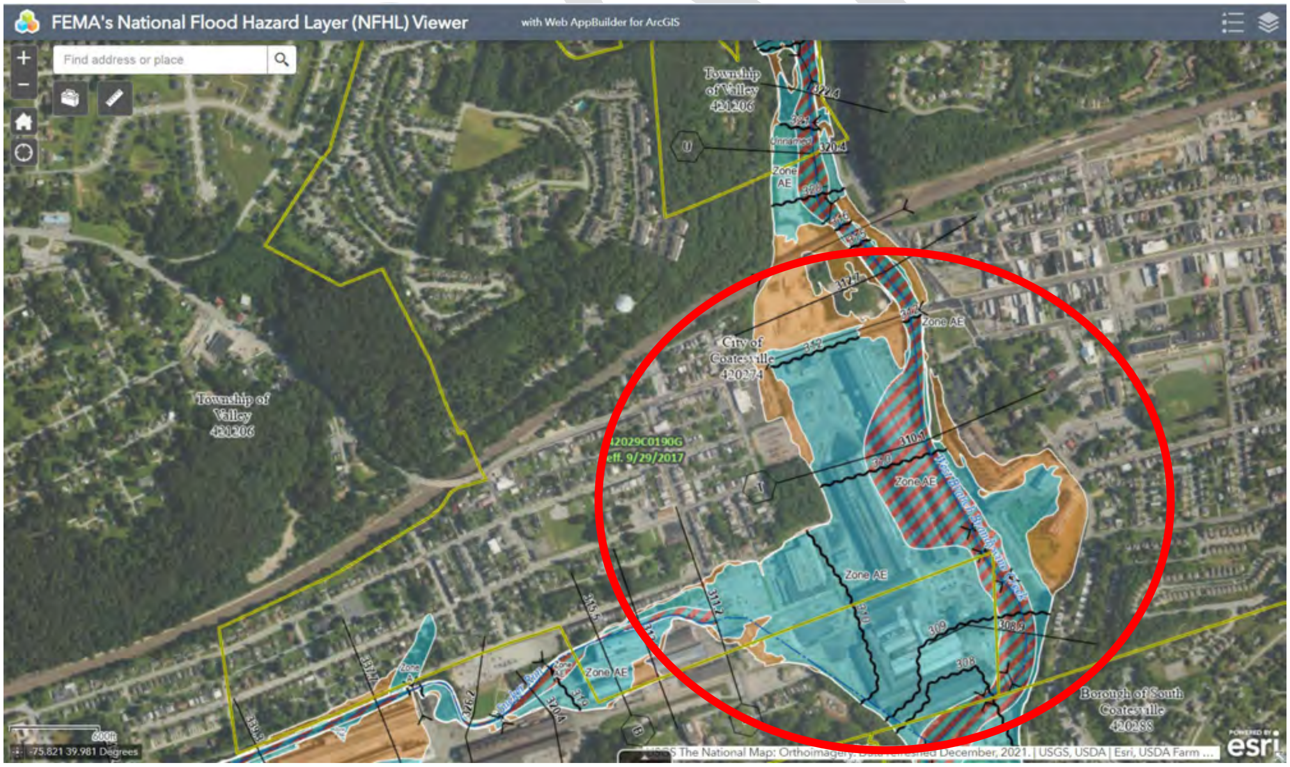


Figure 2.19 West Branch Brandywine Creek in Coatesville (WB4)

Chapter 3 Hydrologic & Hydraulic Models

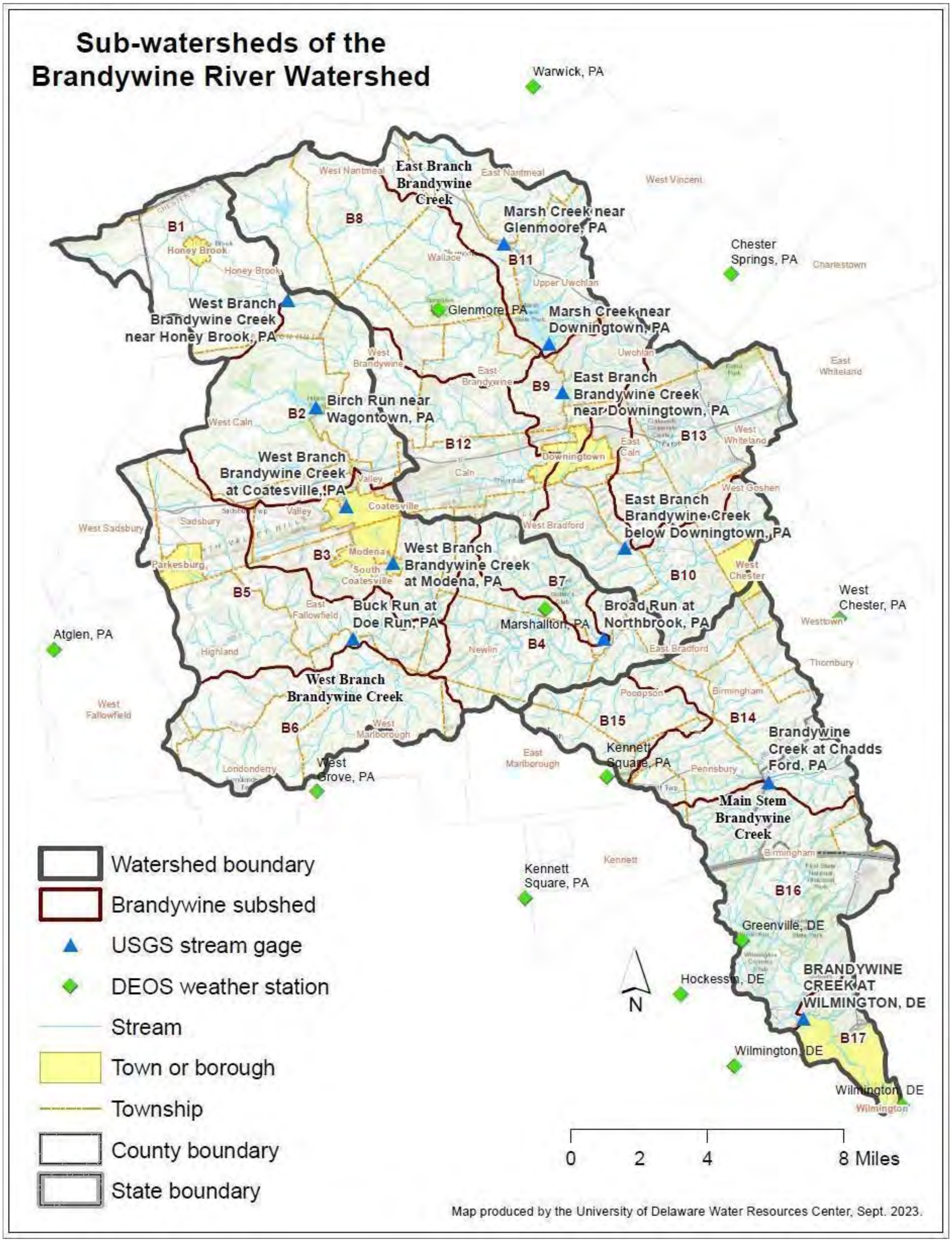
3.1. Overview

To further understand flooding in the Brandywine Watershed, the project team used hydrologic and hydraulic (H&H) computer models. The models were used to characterize existing conditions and future scenarios in the watershed to further identify flood risk areas in the watershed. The future scenarios incorporate impacts from climate change and development to current high-risk flood-prone communities and increased risk to other areas. Combined with information collected from previous studies and municipal and public input, the H&H modeling identifies flood-prone areas and the level of flood risk in years to come.

3.2. Hydrology

The USDA Technical Release 55 (TR-55) hydrologic model and ArcView GIS was used to estimate rainfall-runoff relationships in the 320-square mile Brandywine Watershed in Pennsylvania and Delaware. The modeling was a multi-step process:

- Delineate the watersheds (mainstem, east branch, west branch) and 18 subwatersheds (Figure 3.1 and Table 3.1). Note: For modeling purposes, one of the 17 subbasins, B8 was split into 2 subwatersheds.
- Map land cover, soils, topography, and slopes.
- Develop runoff curve numbers and time of concentration for each of the 18 TR-55 models.
- Incorporate storage routing for 5 reservoirs in the watershed.
- Input precipitation data for the 2-, 10-, 50-, 100-, 500-, 1,000-year frequency storms and Hurricane Ida.
- Validate the TR-55 models by comparing the output (peak flow and hydrograph shape) with the USGS stream gages for Hurricane Ida and other historic storms.
- Perform analysis for existing conditions and four proposed flood scenarios (existing precipitation/2020 land use, climate change precipitation, full buildout, and climate change plus full buildout).



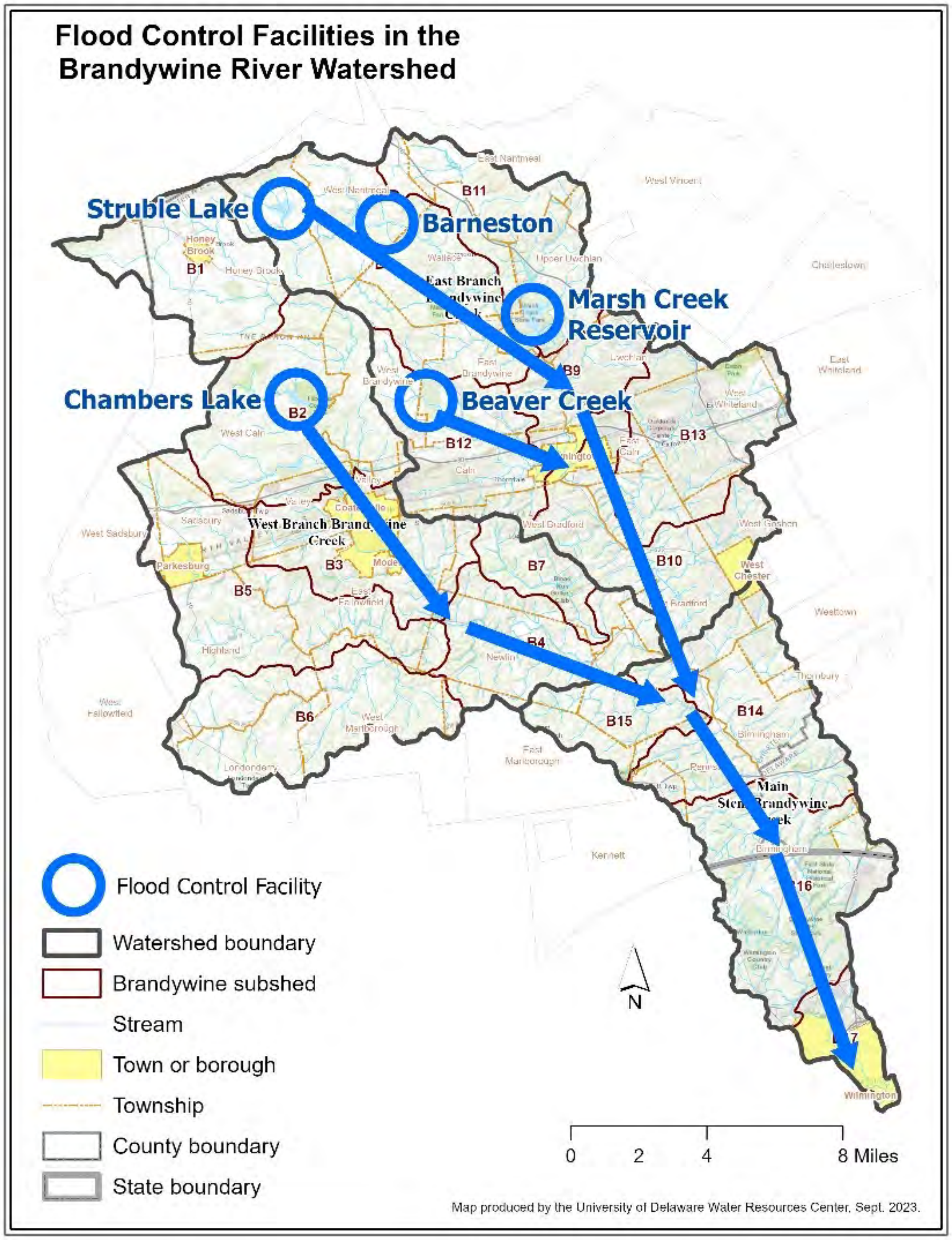
Map produced by the University of Delaware Water Resources Center, Sept. 2023.

Figure 3.1 Subwatersheds in the Brandywine Creek watershed

Table 3.1 Brandywine Creek Subwatersheds

Watershed	Subwatershed	Area (sq.mi.)	State	County	Locality
West Branch					
	B1 UWB Honeybrook	18.5	PA	Chester, Lancaster	Honeybrook Twp., Honeybrook Boro.
	B2 UWB Hibernia	26.0	PA	Chester	West Brandywine, West Caln
	B3 LWB Coatesville	18.6	PA	Chester	Caln, Coatesville, E. Fallowfield, Modena, S. Coatesville, Valley
	B4 LWB Embreeville	17.1	PA	Chester	Newlin, Pocopson, West Bradford
	B5 Buck Run	27.5	PA	Chester	E. Fallowfield, Highland, Parkesburg, Sadsbury
	B6 Doe Run	22.6	PA	Chester	Highland, Londonderry, West Marlborough
East Branch					
	B7 Broad Creek	6.4	PA	Chester	West Bradford
	B8 UEB Struble Lake	33.0	PA	Chester	Honeybrook, Wallace, West Nantmeal
	B9 UEB Shamona Creek	10.0	PA	Chester	East Brandywine, Uwchlan, Downingtown
	B10 Lower East Branch	21.0	PA	Chester	East Bradford, West Chester
	B11 Marsh Creek	20.0	PA	Chester	East Caln, East Nantmeal, U. Uwchlan
	B12 Beaver Creek	18.1	PA	Chester	Caln, Downingtown, E. Fallowfield, West Brandywine
	B13 Valley Creek	20.6	PA	Chester	East Brandywine, East Caln, W. Whiteland
Mainstem					
	B14 above Chadds Ford	24.6	PA	Chester, Delaware	Birmingham, Pennsbury, Pocopson, Chadds Ford,
	B15 Pocopson Creek	9.1	PA	Chester	Chadds Ford, E. Marlborough, Newlin, Pocopson
	B16 Below Chadds Ford	26.5	DE	New Castle, Chester, Delaware	Birmingham, Concord, Pennsbury, Pocopson, Chadds Ford, New Castle Co.
	B17 Through Wilmington	6.1	DE	New Castle	Wilmington, New Castle Co.
	Total	**320**			

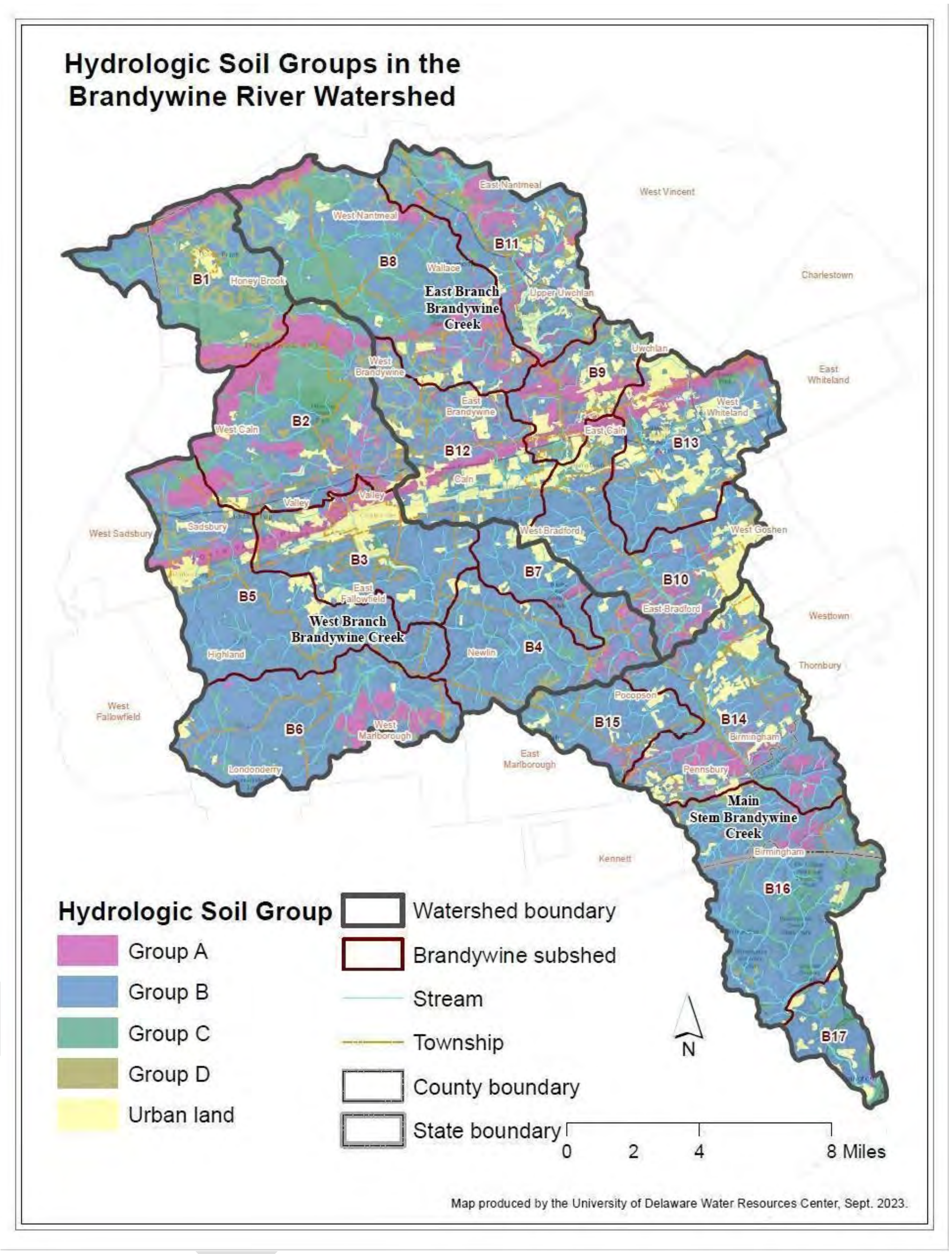
The TR-55 hydrologic model characterizes the overland flow from the drainage areas in each subwatershed, as well as storage in and flow through the five reservoirs in the watershed (Figure 3.2).



Map produced by the University of Delaware Water Resources Center, Sept. 2023.

Figure 3.2 Flood control facilities in the Brandywine watershed

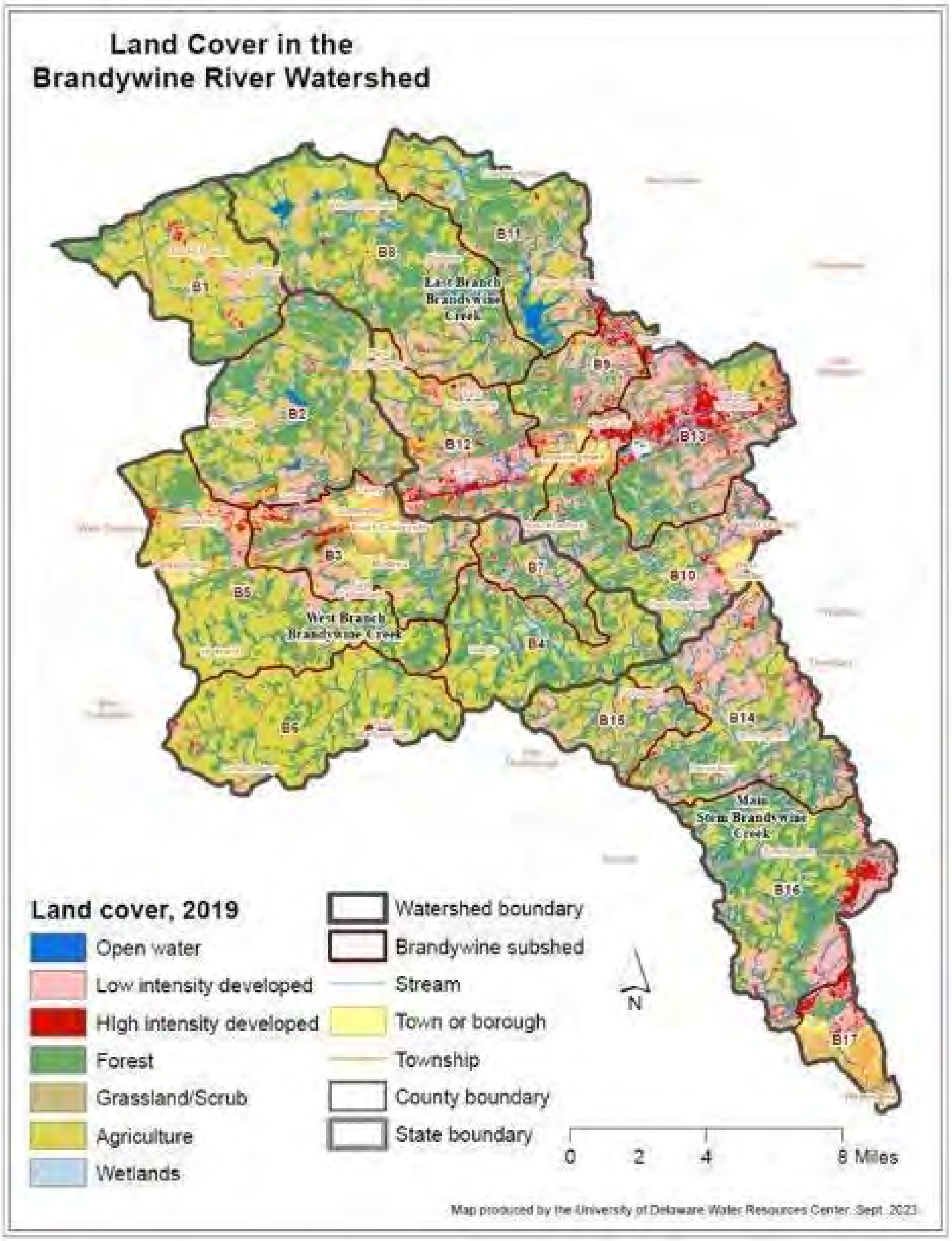
The TR-55 model employs data from the 18 subwatersheds, ranging in area from 6 to 27 square miles. The TR-55 model utilizes 4 USDA hydrologic soil groups (HSG), A, B, C, and D, and most of the Brandywine Watershed is comprised of relatively well draining Group B hydrologic soils which include sand and gravel and some silt (Figure 3.3).



Map produced by the University of Delaware Water Resources Center, Sept. 2023.

Figure 3.3 Brandywine Creek Hydrologic Soil Groups

Land use data for each subbasin is derived from NOAA Cooperative Science Centers in 2019 (see Figures 3.4 and 3.5). Table 3.2 summarizes existing land use data for the Brandywine Watershed (2020) for 11 land use categories ranging from single family residential, office, industrial, commercial to wooded/protected land open space to agriculture. The subwatersheds range from heavily agricultural near Honeybrook Township and along the West Branch like Buck Run and Doe Run to more urban/suburban near the City of Coatesville, Downingtown Borough, West Chester Borough, and the City of Wilmington. Table 3.2 also includes estimated land use with potential future development for each subwatershed based on zoning and estimated change in land use based on the transition from existing to full build out projections, as described in Chapter 4.



Map produced by the University of Delaware Water Resources Center, Sept. 2023

Figure 3.4 Land Cover in the Brandywine Watershed

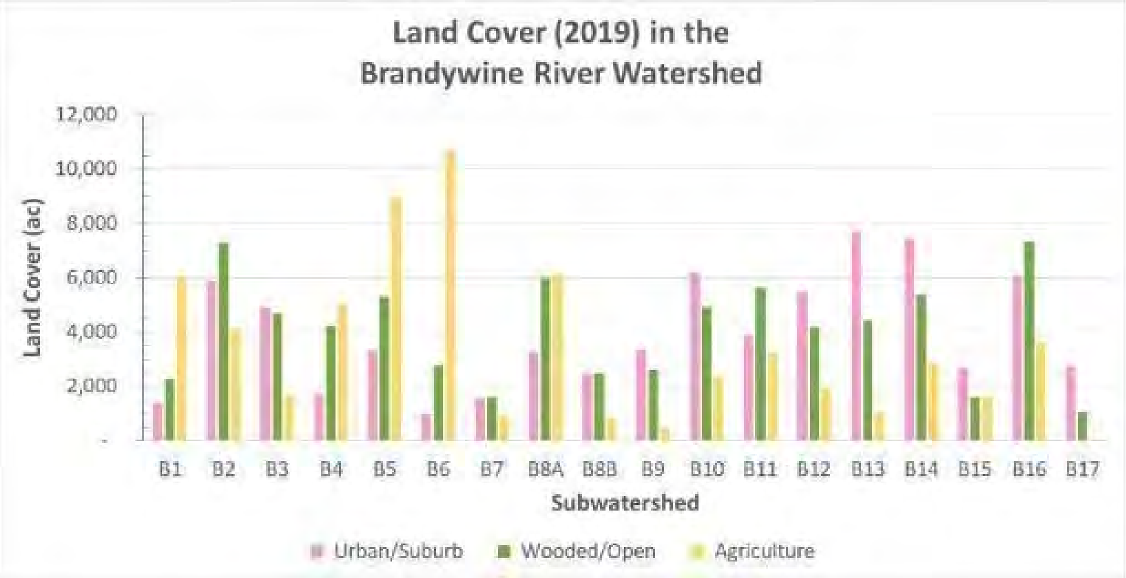


Figure 3.5 Brandywine Watershed Land Cover by Subwatershed

Table 3.2 Brandywine Watershed Existing (2020) and Full Buildout Land Cover

Order	SHDNUM	Single Family Reside	Multi-family Residentia	Office	Industrial	Transportation/Utility	Commercial	Institutional	Protected Lands	Wooded	Agriculture	Mining	Water	Vacant	Total (ac)	Total (mi^2)
1	B1	920	119	72	109	73	5	70	230	1,738	6,032	26	38	246	9,678	15.1
2	B2	5,029	194	108	99	326	10	137	310	6,302	4,121	-	252	404	17,292	27.0
3	B3	2,828	565	170	480	563	19	232	191	3,884	1,689	62	65	541	11,287	17.6
4	B4	1,327	3	13	3	259	-	115	66	3,695	5,021	-	140	295	10,937	17.1
5	B5	2,459	138	135	123	277	51	110	65	4,767	8,990	13	102	367	17,597	27.5
6	B6	745	15	56	7	123	-	24	15	2,455	10,683	-	62	254	14,439	22.6
7	B7	1,349	49	38	5	94	-	36	246	1,179	915	-	16	193	4,121	6.4
8	B8	4,975	143	116	14	281	3	182	155	7,354	6,911	21	383	582	21,119	33.0
9	B9	2,488	161	232	137	119	57	160	258	2,004	463	-	69	261	6,410	10.0
10	B10	4,195	596	385	230	308	96	334	468	3,899	2,319	13	148	392	13,383	20.9
11	B11	3,396	24	112	41	282	4	37	85	4,497	3,264	1	594	437	12,775	20.0
12	B12	3,946	406	252	117	222	103	410	536	3,069	1,941	-	61	504	11,568	18.1
13	B13	4,633	635	736	206	773	298	226	430	3,411	1,072	199	96	491	13,206	20.6
14	B14	6,166	415	230	20	237	33	348	504	3,777	2,819	-	197	880	15,627	24.4
15	B15	2,211	60	16	-	18	11	357	26	1,198	1,605	-	29	353	5,884	9.2
16	B16	3,975	243	559	49	134	851	243	1,174	5,672	3,614	-	326	158	16,998	26.6
17	B17	347	800	342	285	299	390	289	350	509	44	-	184	34	3,874	6.1

Estimated Buildout

Order	SHDNUM	Single Family Reside	Multi-family Residentia	Office	Industrial	Transportation/Utility	Commercial	Institutional	Protected Lands	Wooded	Agriculture	Mining	Water	Vacant	Total (ac)	Total (mi^2)
1	B1	4,274	149	72	207	73	50	70	230	1,515	2,813	26	38	182	9,698	15.2
2	B2	5,689	197	201	148	326	267	137	310	5,815	1,692	-	252	404	15,438	24.1
3	B3	3,109	619	193	629	563	21	238	191	3,875	1,635	62	65	541	11,742	18.3
4	B4	1,546	7	13	3	259	-	115	66	3,661	4,125	-	140	295	10,231	16.0
5	B5	3,157	155	144	202	277	111	110	65	4,595	6,290	13	102	(779)	14,442	22.6
6	B6	1,076	15	56	7	123	23	24	15	2,386	9,328	-	62	254	13,369	20.9
7	B7	1,411	58	38	5	94	-	36	246	1,122	604	-	16	193	3,822	6.0
8	B8	5,502	143	116	19	281	3	182	155	6,923	4,738	21	383	582	19,046	29.8
9	B9	2,533	161	233	260	119	64	160	258	1,965	247	-	69	261	6,330	9.9
10	B10	4,371	604	385	242	308	97	334	468	3,829	1,571	13	148	392	12,763	19.9
11	B11	3,609	24	131	154	282	4	37	85	4,419	2,414	1	594	437	12,191	19.0
12	B12	4,238	410	252	135	222	162	420	536	2,953	906	-	61	504	10,798	16.9
13	B13	4,698	635	806	268	773	301	226	430	3,366	851	199	96	491	13,140	20.5
14	B14	6,338	415	230	20	237	47	348	504	3,707	1,952	-	197	880	14,876	23.2
15	B15	2,266	60	16	-	18	11	357	26	1,194	1,170	-	29	353	5,500	8.6
16	B16	4,687	260	559	49	134	852	243	1,174	5,511	2,275	-	326	158	16,228	25.4
17	B17	347	800	342	285	299	390	289	350	509	44	-	184	34	3,874	6.1

Land Use Change

Order	SHDNUM	Single Family Reside	Multi-family Residentia	Office	Industrial	Transportation/Utility	Commercial	Institutional	Protected Lands	Wooded	Agriculture	Mining	Water	Vacant	Total (ac)	Total (mi^2)
1	B1	3,353	30	-	97	-	45	-	-	(223)	(3,219)	-	-	(64)	20	
2	B2	661	3	93	49	-	256	-	-	(487)	(2,429)	-	-	-	(1,854)	
3	B3	281	54	24	149	-	3	7	-	(8)	(53)	-	-	-	456	
4	B4	220	4	-	-	-	-	1	-	(34)	(896)	-	-	-	(706)	
5	B5	698	17	9	79	-	60	-	-	(172)	(2,700)	-	-	(1,146)	(3,155)	
6	B6	331	-	-	-	-	23	-	-	(69)	(1,355)	-	-	-	(1,070)	
7	B7	61	8	-	-	-	-	-	-	(57)	(311)	-	-	-	(298)	
8	B8	527	-	-	4	-	-	-	-	(431)	(2,173)	-	-	-	(2,073)	
9	B9	45	-	1	122	-	7	-	-	(39)	(215)	-	-	-	(80)	
10	B10	176	8	-	12	-	1	-	-	(70)	(748)	-	-	-	(620)	
11	B11	213	-	19	113	-	-	-	-	(78)	(850)	-	-	-	(583)	
12	B12	292	3	-	18	-	58	9	-	(116)	(1,035)	-	-	-	(770)	
13	B13	65	-	70	62	-	3	-	-	(45)	(221)	-	-	-	(66)	
14	B14	172	-	-	-	-	14	-	-	(70)	(867)	-	-	-	(751)	
15	B15	55	-	-	-	-	-	-	-	(4)	(435)	-	-	-	(384)	
16	B16	712	17	-	-	-	1	-	-	(161)	(1,339)	-	-	-	(771)	
17	B17	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

The TR-55 model used soils, land use, and topographic data for each of the 18 subwatersheds. Land use data is inserted into to compute curve number (CN), which is roughly the ratio of runoff to precipitation in a particular subwatershed. Time of concentration (Tc) is the length of time it takes for a particle of water to flow from the highest part of a watershed to the lowest end or the outlet point. For time of concentration, length, slope, and velocity of channel flow were estimated from USGS STREAMSTATS. For each of the 18 subwatersheds, design storm estimates were applied in the TR-55 model for the 2-, 10-, 50-, 100-, 500-, 800- (Ida), and 1,000-year storm events and the four flood scenarios.

As an example, the Buck Run (B5) TR-55 model, largely rural watershed, where 50% of the watershed is agriculture, 25% is wooded and 25% is urban suburban (Figure 3.6). Table 3.3 and Figure 3.7 show the model input parameters and design storm data for the 2-year through 1000-year storms from NOAA Atlas 14 estimates. Figure 3.8 portrays the TR-55 output of the 2-year peak flow of 1,497 cfs, 10-year peak of 4,000 cfs, and 100-year peak of 10,572 cfs. To verify and calibrate the hydrologic model, the modeled peak discharges in subwatersheds such as Buck Run were compared with USGS stream gage data (Figure 3.9) and adjusted parameters until the modeled peak discharge mirrored the recorded Ida peak at the USGS stream gages.

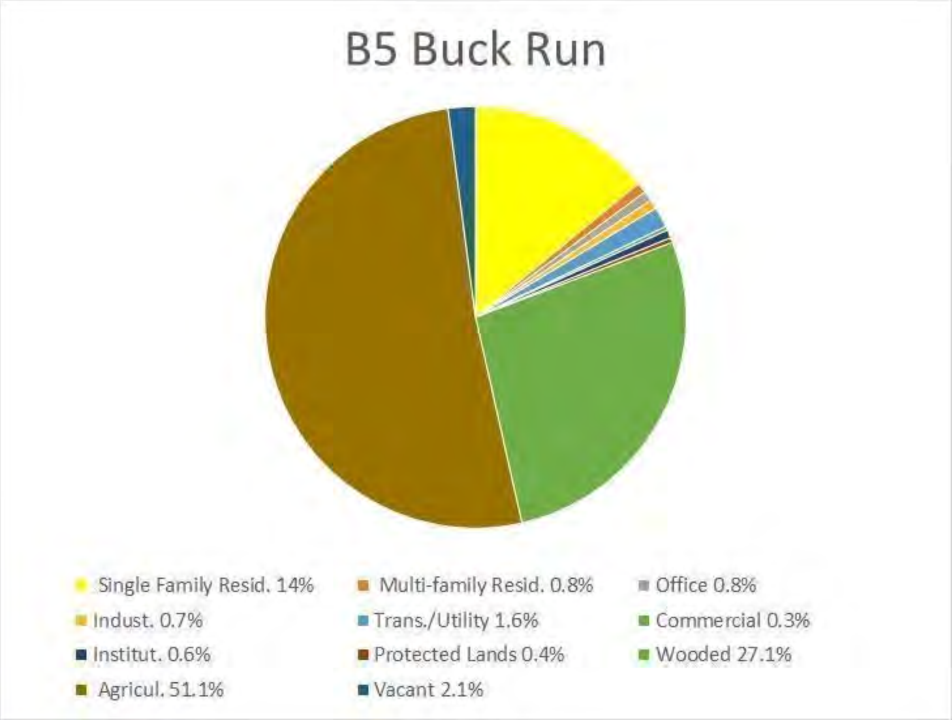
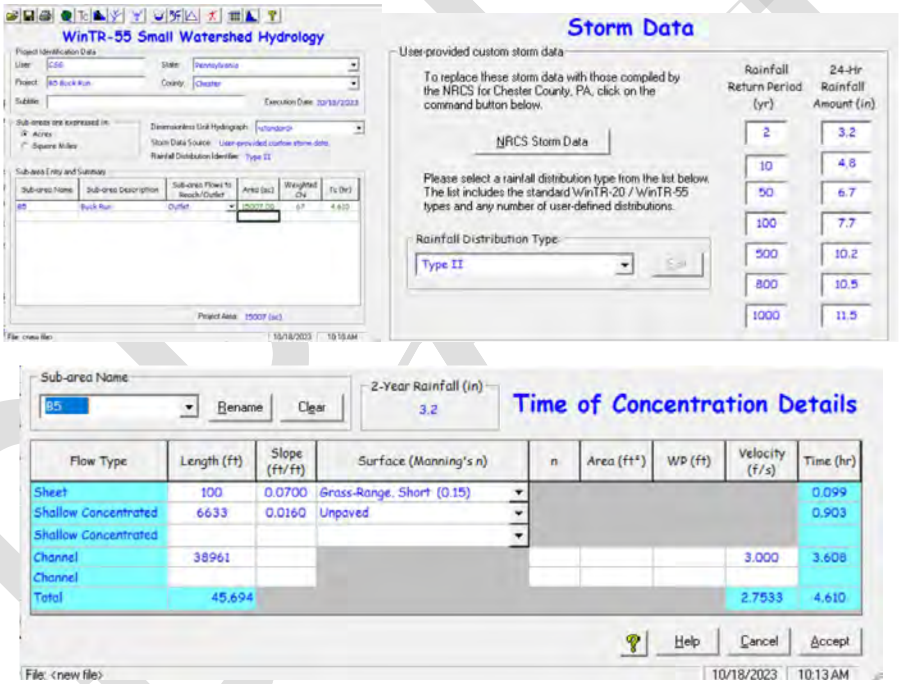


Figure 3.6 Buck Run (B5) land use in the Brandywine Creek watershed

Table 3.3 Buck Run (B5) TR-55 model input parameters

B5 Buck Run			
Land Use	**(ac)**	**(mi2)**	**%**
SF Resid	2,459	3.84	14.0%
MF Resid	138	0.22	0.8%
Office	135	0.21	0.8%
Ind.	123	0.19	0.7%
Trans	277	0.43	1.6%
Comm.	51	0.08	0.3%
Institutional	110	0.17	0.6%
Prot. Lands	65	0.10	0.4%
Wooded	4,767	7.45	27.1%
Agric.	8,990	14.05	51.1%

B5 Buck Run			
Land Use	**(ac)**	**(mi2)**	**%**
Vacant	367	0.57	2.1%
Total	17,597	27.50	100.0%
HSG Soil Type B			
Time of Concentration			
Tsf	L = 100 ft	S = (860-853 ft)/100 = 7.0%	forest
Tsc	L = 6633 ft	S = (763.62-653.72)/6655 = 1.6%	unpaved
Tch	L = 38,961 ft	S = (653.72-256.48)/38961 = 1.0%	V= 3ft/sec


WinTR-55 Small Watershed Hydrology

Project Identification Data

State: Pennsylvania

Project: B5 Buck Run

County: Chester

Execution Date: 10/18/2023

Sub-areas are expressed in:
● Acres
○ Square Miles

Dimensionless Unit Hydrograph: <standard>

Storm Data Source: User-provided custom storm data

Rainfall Distribution Identifier: Type II

Sub-area Entry and Summary

Sub-area Name	Sub-area Description	Sub-area Flows to Reach/Outlet	Area (ac)	Weighted CN	Tc (hr)
B5	Buck Run	Outlet	15007.00	67	4.610

Project Area: 15007 (ac)

10/18/2023 10:10 AM

Storm Data

User-provided custom storm data

To replace these storm data with those compiled by the NRCS for Chester County, PA, click on the command button below.

NRCS Storm Data

Please select a rainfall distribution type from the list below. The list includes the standard WinTR-20 / WinTR-55 types and any number of user-defined distributions.

Rainfall Distribution Type: Type II

Rainfall Return Period (yr)	24-Hr Rainfall Amount (in)
2	3.2
10	4.8
50	6.7
100	7.7
500	10.2
800	10.5
1000	11.5

Sub-area Name: B5

2-Year Rainfall (in): 3.2

Time of Concentration Details

Flow Type	Length (ft)	Slope (ft/ft)	Surface (Manning's n)	n	Area (ft²)	WP (ft)	Velocity (f/s)	Time (hr)
Sheet	100	0.0700	Grass-Range, Short (0.15)					0.099
Shallow Concentrated	6633	0.0160	Unpaved					0.903
Shallow Concentrated								
Channel	38961						3.000	3.608
Channel								
Total	45.694						2.7533	4.610

File: <new file> 10/18/2023 10:13 AM

Figure 3.7 Buck Run (B5) TR-55 Model Input Data in the Brandywine Watershed

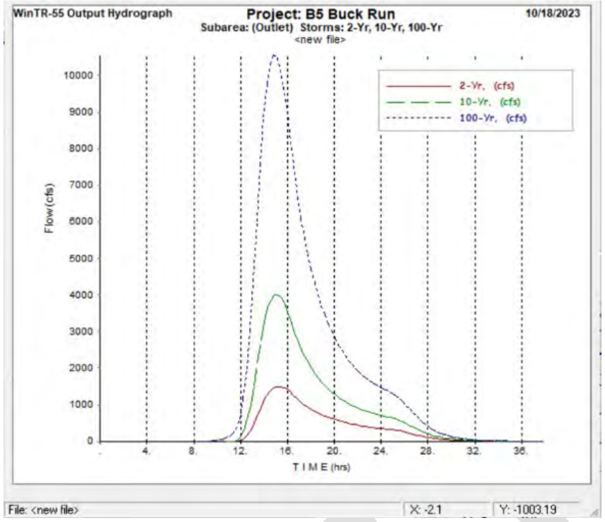


Figure 3.8 Buck Run (B5) Output Hydrograph in the Brandywine Watershed

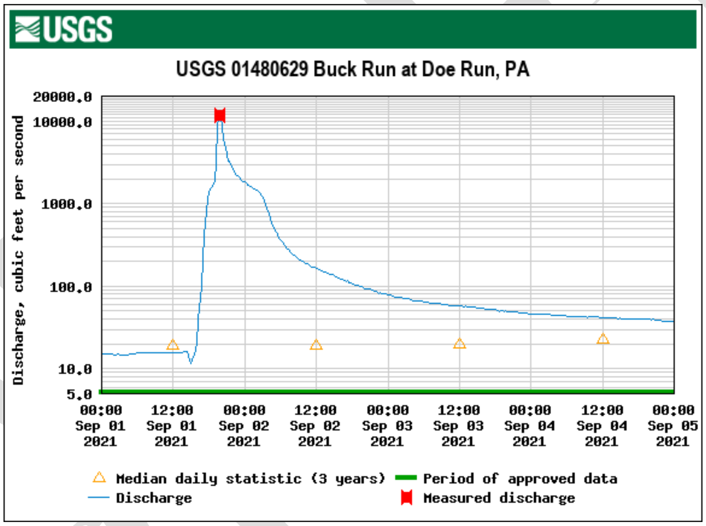


Figure 3.9 Buck Run modeled output compared with USGS stream gage data

Table 3.4 summarizes the Brandywine watershed hydrologic model output. The model confirmed the West Branch subwatersheds contributed 26,000 cfs and the East Branch 25,552 cfs, including significant flood storage due to Marsh Creek Reservoir, at the confluence during Ida. At Honeybrook, Birch Run, West Branch Modena, and Broad Run, where USGS stream gages exist, the modeled peak discharges were compared with the gaged discharge during Ida (Figure 3.10).

The TR-55 modeled peak discharges, compared to USGS stream gage peaks during Ida near and below Downingtown Borough, confirm 25,000 cfs flowed from the East Branch to the confluence with the West Branch. Adding in 2,500 cfs from Pocopson Creek, the estimated peak discharge from was estimated to be 59,000 cfs at Chadds Ford, yet 49,000 cfs was estimated during Ida at the Chadds Ford stream gage. The photos identifying high water marks during Hurricane Ida, shown in Chapter 2, proved valuable in verifying and calibrating the USDA TR-55 hydrologic and USACOE HEC-RAS hydraulic models.

The reduction in flow, to 49,000 cfs, from the modeled 59,000 cfs coming in from the East and West Branches at Lenape Park, during Ida may be explained by attenuation, or reduction due to the large area of open space providing floodplain storage between Lenape Park at the confluence of the East and West Branches of the Brandywine and Chadds Ford, which is detailed later in this chapter.

Table 3.4 Brandywine Watershed TR-55 Model Output

				Incremental				Cumulative							
ID	**Subbasin**	**Area (ac)**	**Area (mi2)**	**2-yr (cfs)**	**10-yr (cfs)**	**100-yr (cfs)**	**100-yr cfs/mi2**	**2-yr (cfs)**	**10-yr (cfs)**	**100-yr (cfs)**	**Ida Peak (cfs)**	**Area (mi2)**	**cfs/mi2**	**USGS Gage**	**Area (mi2)**
	West Br. Brandywine														
B1	WB Honeybrool	9,678	15.1	342	1,021	2,980	197	342	1,021	2,980	2,700	18.7	144	WB Honeybrook	
B2	Hibernia	17,292	27.0	927	2,382	6,062	225	1,269	3,403	9,042					
B2A	Birch Run	2,908	4.5	244	848	2,614	575	1,325	2,855	6,728	7,120	45.8	155	WB Coatesville	
B3	WB Coatesville	11,287	17.6	778	1,880	4,576	260	2,103	4,735	11,304	12,300	55.0	224	WB Modena	55
B4	WB Embreeville	10,937	17.1	4	812	1,908	112	8,015	9,809	26,209	Confluence with EB				
B5	Buck Run	17,597	27.5	869	2,235	5,687	207	5,687	4,461	11,338	6,000	22.6	265	Buck Run at Doe Run	
B6	Doe Run	14,439	22.6	889	2,226	5,651	250	889	2,226	5,651					
B7	Broad Run	4,128	6.4	225	613	1,659	259	225	613	1,659	1,400	6.4	219	Broad Run Northbrook	
		88,266	137.8												
	East Br. Brandywine														
B8A	Struble Lake	15,373	24.0	687	2,053	5,920	246	687	2,053	5,920					
B8B		5,746	9.0	259	775	2,235	249	946	2,828	8,155					
B11	Marsh Creek	12,775	20.0	492	1,445	4,130	207	492	1,445	4,130					
	Marsh Creek Reservoir			24	100	369		24	100	369	380	20.3	19	Marsh Cr. Downingtown	
B12	Beaver Creek	11,568	18.1	534	1,475	3,992	221	534	1,475	3,992					
B9	EB Downingtow	6,410	10.0	404	1,082	2,873	287	1,908	5,485	15,389	15,900	60.6	262	EB near Downingtown	
B10	EB below Dwng	13,383	20.9	702	1,833	4,837	231	2,610	7,318	20,226	21,000	89.9	234	EB below Down	89.9
B13	Valley Creek	13,206	20.6	837	2,098	5,326	258	837	2,098	5,326					
		78,461	122.6					3,447	9,416	25,552	Confluence with WB				
	Main Stem Brandywine														
B15	Pocopson Creek	5,884	9.2	476	1,080	2,560	278	476	1,080	2,560					
B14	Main Stem Chac	15627	24.4	661	1,879	5,217	214	11,762	20,086	59,084	48,400	287.0	169	Brandywine Chadds Ford	
B16	below Chadds F	16934	26.5	200	619	1,851	70	11,962	20,705	59,703					
B17	Main Stem Wilm	3878	6.1	433	1,038	2,523	416	12,395	21,743	60,136	33,400	314.0	106	Brandywine Wilmington	

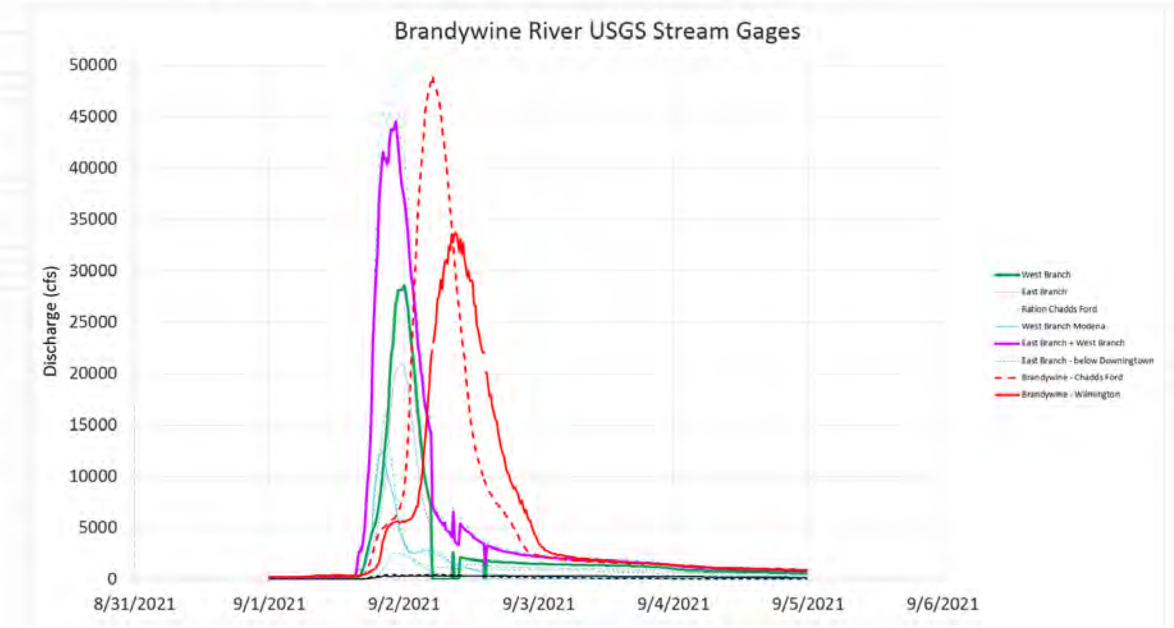


Figure 3.10 Brandywine Stream Gage and TR-55 Hydrographs for Hurricane Ida (September 1, 2021)

3.3. Climate Impact Analysis

As temperatures increase, the atmosphere can hold more water vapor leading to a greater potential for precipitation. There have already been noticeable changes in precipitation patterns over the past 20 years compared to the prior century, and even more changes are projected in this century. For example, the U.S. National Climate Assessment notes that the northeastern United States has already seen a greater increase in extreme precipitation than any other region, with a 60% increase in intense storms between 1958 and 2022. These increases in rainfall exacerbate flood risk which already has caused billions of dollars in damages across the US in recent years. Thus, it is critical for flood studies to incorporate potential changes in rainfall and streamflow into hydrologic and hydraulic modeling of streams to evaluate future risks.

Precipitation change factors estimate the increase in precipitation that may occur in the future for storms of varying frequency and duration. The study incorporated two different methods to calculate precipitation change factors for the Brandywine River watershed for two CMIP5 global climate models (GCM) scenarios (representative concentration pathways (RCP) 4.5 and RCP 8.5); the 1-, 2-, 5-, 10-, 25-, 50-, 100-, and 500-year recurrence intervals; the 1-, 2-, 3-, 6-, 12-, and 24- hour event durations; and for each decade between 2030 and 2100. These results can be found in Appendix 4.

The TR-55 models were used to estimate peak discharge for the 2-, 10-, 50-, 100-, 500-, 800- (Ida), and 1000-year flood events for four modeled scenarios:

1) existing 2020 land use conditions
2) existing land use conditions with climate change induced increase in precipitation
3) full build-out land use conditions with existing precipitation
4) full build-out conditions with climate change induced increase in precipitation.

Table 3.5 summarizes existing NOAA Atlas 14 precipitation depth and the projected increase in precipitation due to climate change and warming of the atmosphere. For example, the current 100-year storm, 7.6 inches, is projected to increase to 8.3 inches in 2050. These estimated increase in NOAA Atlas 14 precipitation volume due to climate change acceleration of the hydrologic cycle ranges from 8% to 10%. The TR-55 models were run for the 18 subwatersheds for each of the four scenarios. Figure 3.11 depicts the flood scenario analysis for Honeybrook (B1), a largely rural area, and West Valley Creek, (B11) primarily urban/suburban near the Exton Mall. In the Honeybrook subwatershed, climate change accounts for more of the increase in flood discharge than full build out conditions and in the full build out conditions plus climate change scenario, half of the increase in flood discharge is due to development and half is due to climate change. In the West Valley Creek (B11) subwatershed, almost all the increase in flood discharge is due to climate change and little or none is due to increased development because most of this watershed is already fully built out. Figure 3.12 summarizes the modeled 100-year peak discharges for the four scenarios for all 18 subwatersheds. The detailed model outputs for all storm event frequencies can be found in Appendix 3.

Table 3.5 Brandywine River NOAA Atlas 14 precipitation depth for existing/projected conditions (CDM Smith, 2024)

Event Duration	**Atlas 14 precipitation depths (in) Brandywine River watershed Recurrence Interval (yr)**							
	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr
3-hour	1.6	1.9	2.4	2.7	3.2	3.6	4.0	4.9
6-hour	1.9	2.3	2.9	3.4	4.0	4.5	5.1	6.4
12-hour	2.4	2.8	3.6	4.1	5.0	5.7	6.5	8.6
24-hour	2.7	3.3	4.1	4.8	5.8	6.7	7.6	10.0
Event Duration	**Atlas 14 future precipitation depths (in) Brandywine River Recurrence Interval (yr)**							
	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr
3-hour	1.7	2.1	2.6	3.0	3.6	4.0	4.4	5.5
6-hour	2.1	2.5	3.2	3.7	4.4	5.0	5.6	7.1
12-hour	2.5	3.1	3.9	4.5	5.5	6.3	7.2	9.5
24-hour	2.9	3.5	4.4	5.2	6.3	7.3	8.3	11.0
Event Duration	**Increase in NOAA Atlas 14 precipitation depths due to climate change**							
	1-yr	2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	500-yr
3-hour	9%	10%	10%	10%	11%	11%	12%	12%
6-hour	9%	9%	9%	10%	10%	11%	11%	11%
12-hour	8%	8%	9%	9%	10%	10%	11%	11%
24-hour	7%	8%	8%	9%	9%	10%	10%	10%

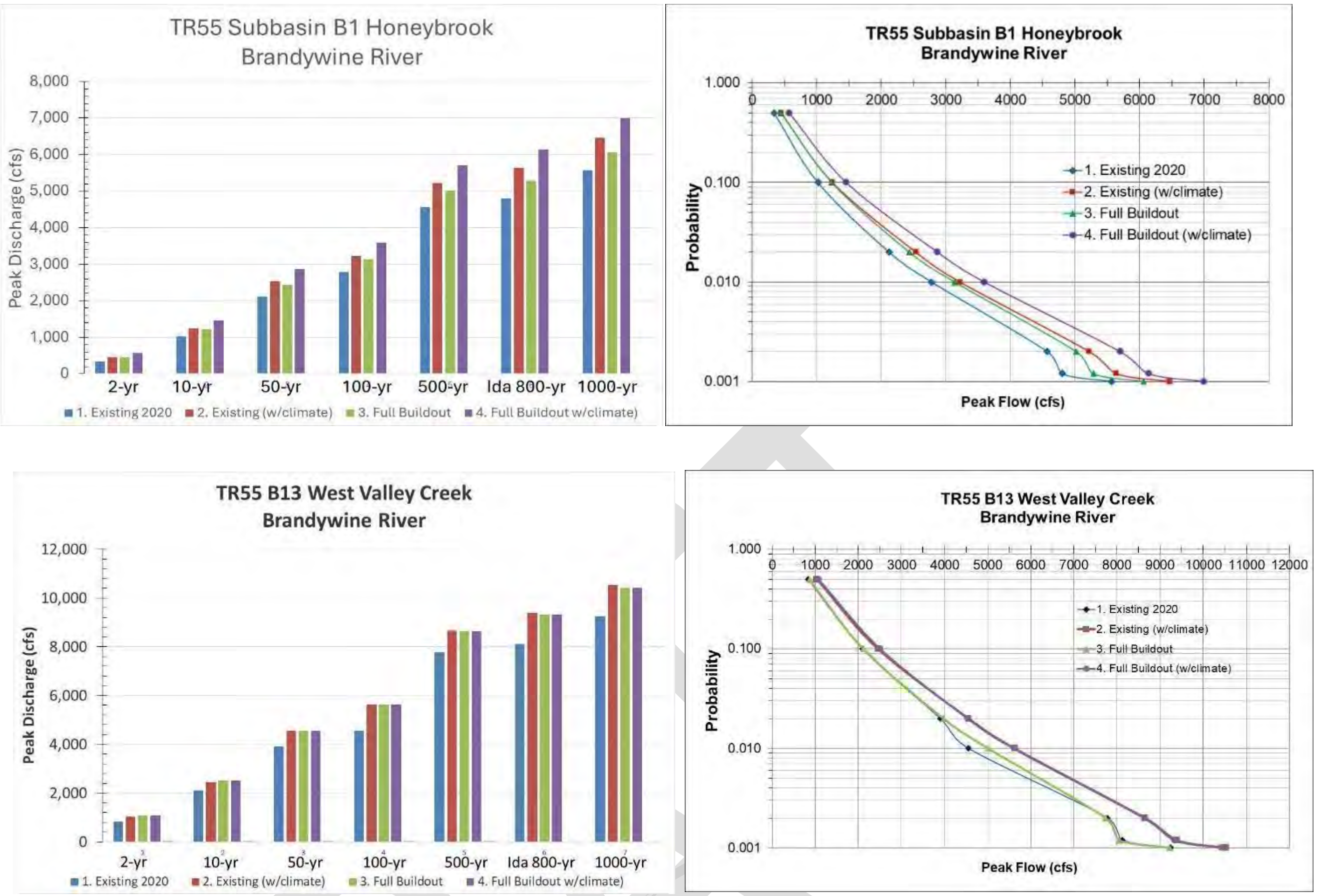


Figure 3.11 TR-55 Flood Model Scenarios in Two Brandywine Subwatersheds

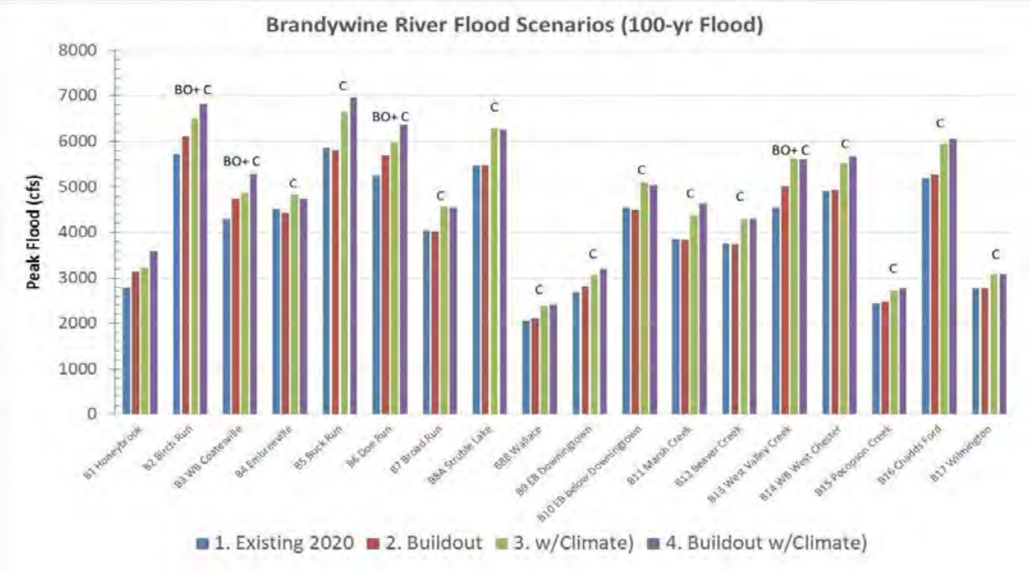


Figure 3.12 Brandywine Watershed TR-55 Model Scenarios by Subwatershed for the 100-Yr Flood Event

3.4. Marsh Creek Reservoir

A state park, Marsh Creek Reservoir, owned and operated by the Pennsylvania Department of Natural Resources (PA DCNR) has the largest reservoir storage capacity in the Brandywine watershed and surface area at normal pool of 535 acres (DRBC, Docket No. D-64-15 CP) and captures the drainage from 20 square miles behind a rolled earth and rock-fill dam on the East Branch Brandywine Creek. Marsh Creek Reservoir was built for water supply downstream for users in Pennsylvania and Delaware, low flow augmentation, flood control, and recreation. The designed elevations and storage volumes for Marsh Creek Reservoir are as follows:

Purpose	Elevation (ft)	Storage (billion gallons)
Conservation pool	315.0 ft	0.400 BG
Normal pool	359.5 ft	4.47 BG
Flood pool	365.5 ft	5.63 BG
Maximum pool	375.0 ft	7.8 BG

Using TR-55, Marsh Creek Reservoir was modeled to account for flood storage benefits using stage-volume curves provided by PA DCNR. According to the model, 4,100 cfs flowed into the reservoir during Hurricane Ida and 370 cfs flowed out downstream to Downingtown (Figure 3.13). Marsh Creek reservoir reduced the peak Ida discharge by 3,700 cfs, which is a significant reduction, and the reservoir water level peaked at elevation 365.5 feet above sea level (msl) and 2 feet below the overflow spillway elevation. Marsh Creek Reservoir provided significant flood storage during Hurricane Ida.

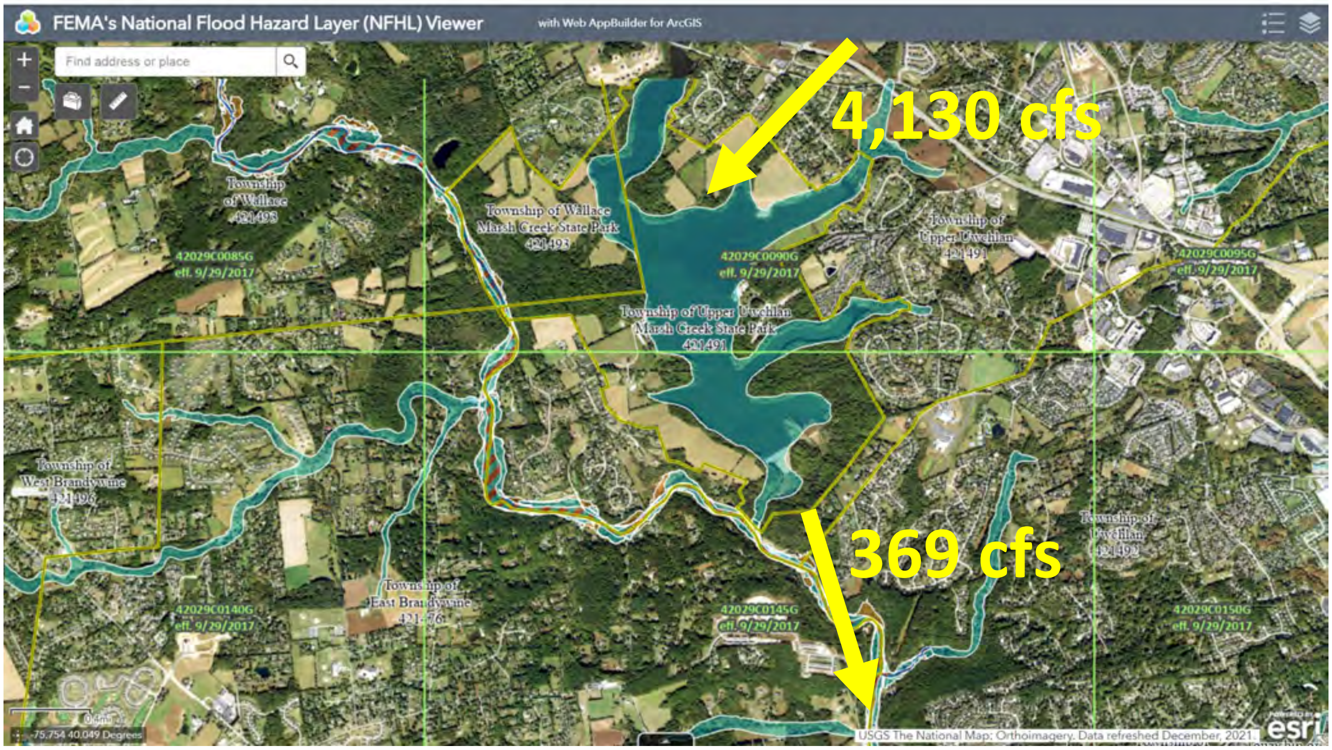


Figure 3.13 Marsh Creek Reservoir Inflow vs. Outflow during Hurricane Ida

3.5. Floodplain Storage

The hydrologic model was used to investigate the level of floodplain storage along the Brandywine. As shown in Table 3.6, the floodplain along the mainstem and East and West Branches of the Brandywine have 16.5 billion gallons of potential storage capacity including: 3.6 billion gallons along the mainstem Brandywine in Delaware; 4.3 billion gallons along the mainstem Brandywine in Pennsylvania; 3.0 billion gallons along the East Branch; and 5.7 billion gallons along the West Branch. In addition, as discussed in Section 2.2 of the report, during Hurricane Ida the floodplain areas attenuated the peak flood flows from the East and West Branches of 54,000 cfs down to 49,000 cfs, at the Chadds Ford and further reduced the peak flow down to 33,000 cfs at the Wilmington gage (Figure 3.14).

Table 3.6 Floodplain Storage along the Brandywine from Lenape Picnic Park (Pocopson Township, PA) to Wilmington, DE

Stream Section	Distance (mi)	Storage Depth (feet)	Floodplain Vol. (MG)
East Branch Brandywine (PA)	14.5	20	2,972
West Branch Brandywine (PA)	18.8	20	5,684
East + West Branch (PA)	33.3	20	8,656
Mainstem Brandywine (PA)	9.7	20	4,270
Mainstem, EB, WB (PA)	43.0	20	1,293
Mainstem (DE)	9.5	20	3,553
Total	**53.1**	**20**	**16,480**

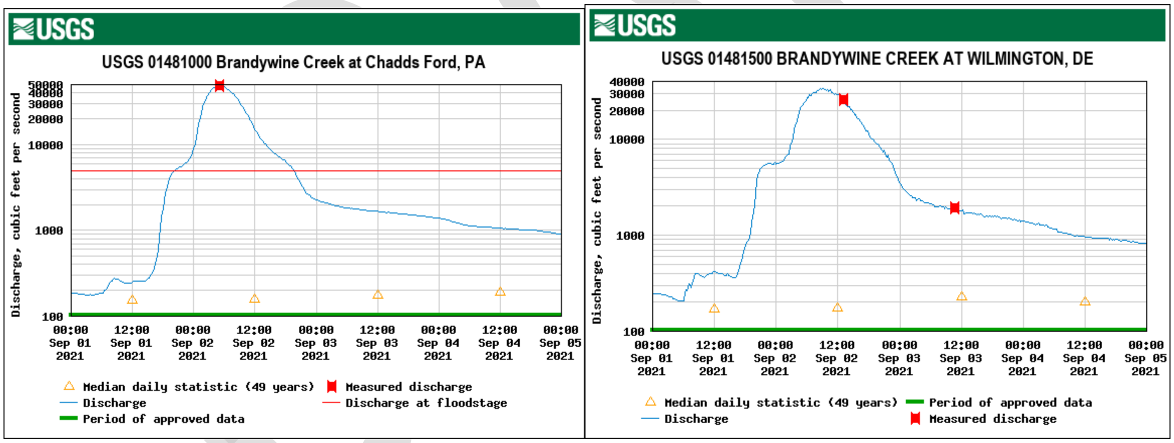


Figure 3.14 USGS stream gage hydrographs at Wilmington and Chadds Ford, PA during Hurricane Ida

3.6. Hydraulics

HEC-RAS, a hydraulic model developed by FEMA, and LIDAR mapping was used to examine riverine flooding in the Brandywine watershed. Existing USACOE HEC-RAS hydraulic models were available for: (1) Brandywine mainstem in Delaware; (2) Brandywine mainstem in Pennsylvania; (3) East Branch Brandywine near Downingtown Borough; (4) West Branch Brandywine near Embreeville and the City of Coatesville; and (5) Beaver Creek tributary that flows to Downingtown. These models were used to evaluate existing conditions and proposed flood mitigation strategies by the following approach:

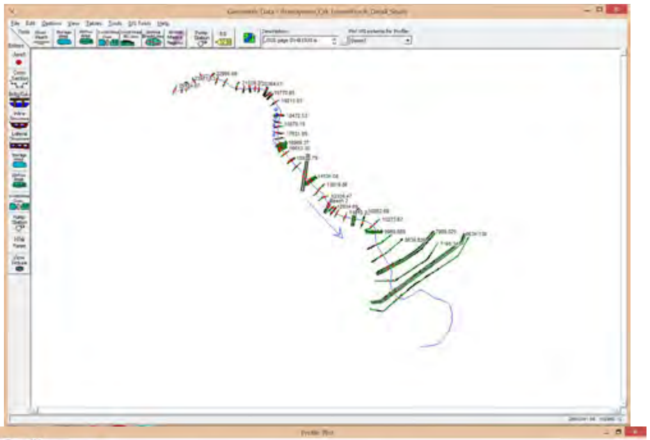
- Update existing HEC-RAS hydraulic models to reflect current conditions.
- Incorporate USGS field surveys of Hurricane Ida high-water marks along Brandywine River.
- Include stream cross section geometry and bridge/culvert data.
- Input stream discharge data from USGS stream gages and TR-55 hydrologic models.
- Run HEC-RAS model flood profiles for 10-, 25-, 50-, 100-, and 500-year flood events (Table 5.24).
- Run HEC-RAS model for Hurricane Ida.
- Evaluate model output and map velocity, flood depth, elevation.
- Evaluate flood mitigation solutions with HEC-RAS model.

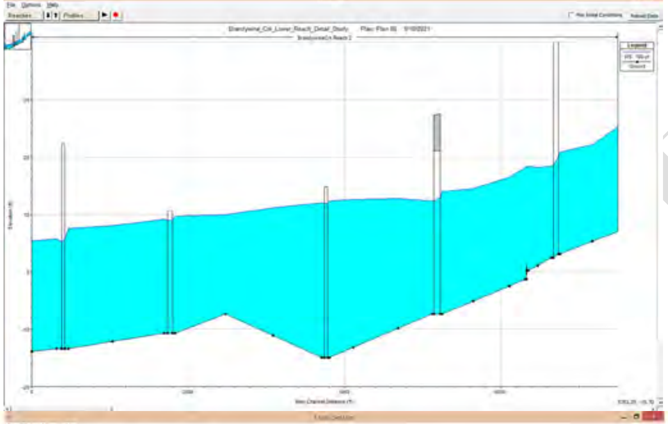
The following summarizes the findings from the HEC-RAS model for stretches of the Brandywine Creek:

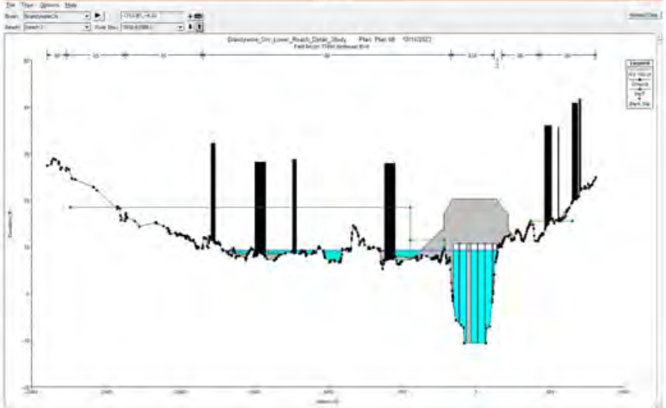
Brandywine Mainstem DE HEC-RAS: The HEC-RAS model for mainstem Brandywine in Delaware begins at river station 6,480 ft above the mouth near the Amtrak viaduct at 13.4 ft below sea level and runs 50,000 ft to Station 24,528 at 72 ft msl just above DuPont Dam No. 6 near Hagley Mills (Table 3.7) Figure 3.15 depicts the plan and profile view of the Brandywine HEC-RAS model in Delaware, where the river is wide at tidewater near the confluence of the Christina River and then narrows up in the gorge of the Brandywine up to Hagley Mills. Key HEC-RAS cross sections at the known flood sites are included at Northeast Wilmington at the 11th St. bridge, Brandywine Bancroft Dam No. 4, DuPont Dam No. 6 near Hagley Mills, and Rockland Road and Rockland Mills (Figure 3.15).

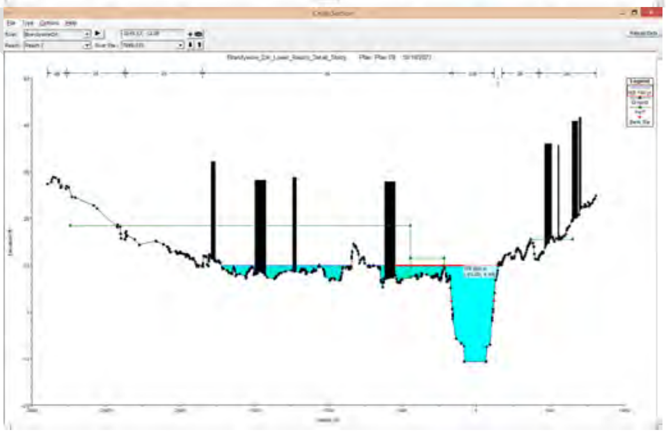
Table 3.7 HEC-RAS Model Output for the Mainstem Brandywine in DE for the 100-year Storm Event

River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Hydr Depth	Vel Chnl	Flow Area	Top Width
		(cfs)	(ft)	(ft)	(ft)	(ft/s)	(sq ft)	(ft)
6,480	100-yr	34070	-13.4	5.7	14.5	9.1	3771	265
6,548		AMTRAK						
6,634	100-yr	34070	-13.4	7.5	13.2	8.2	4383	526
7,855	100-yr	34070	-10.7	9.1	15	6.4	5465	1520
7,921		11th St. Br.						
7,999	100-yr	34070	-10.7	9.9	14.7	6.6	5347	1640
9,874	100-yr	34070	-14.9	11.9	19.9	6.7	5218	308
9,929		16th St. Br.						
9,969	100-yr	34070	-14.9	12.3	21.2	6.5	5434	275
11,286	100-yr	34070	-7.3	12.3	16.8	12.7	2802	185
11,352		Market St. Br.						
11,411	100-yr	34070	-7.3	14	18.2	10	3519	250
12,807	100-yr	34070	2.5	18.4	10.6	16.3	2546	239
12,862		Washington St.						
12,919	100-yr	34070	3.1	20.9	10.9	13.5	3286	302
14,391	100-yr	34070	10.9	27.8	10	11.4	4053	425
14,449		Van Buren St.						
14,507	100-yr	34070	11.5	28.9	11.5	10.4	4318	374
14,777	100-yr	34070	11.3	30	10.1	8.5	5659	560
14,858		I-95 Br.						
14,959	100-yr	34070	11.2	30.7	11.3	7.7	5979	529
15,877	100-yr	34070	12.1	31.9	12.5	11.4	3664	294
15,913		City Dam No. 2						
15,933	100-yr	34070	17.2	34.8	10.7	10.8	3790	355
16,676	100-yr	34070	16.7	36.1	11.1	12.4	3374	352
16,692		Footbridge						
16,708	100-yr	34070	16.7	36.4	10.8	12.5	3274	359
16,793		Conrail Br.						
16,829	100-yr	34070	17.6	37.1	13.2	12.8	2896	350
16,876	100-yr	34070	18	37.1	12.5	13.3	2745	353
16,925		Augustine Br.						
16,969	100-yr	34070	18.7	37.4	12.5	13.6	2728	354
18,420	100-yr	34070	24.1	47	15.5	8.7	4957	372
18,459		Dam No. 3						
18,473	100-yr	34070	25	47.2	14.4	9	4868	382
19,960	100-yr	34070	29.1	51	16.4	10.3	3579	218
19,996		Bancroft Dam No. 4						
20,006	100-yr	34070	40	57.5	13.8	12	3005	218
20,824	100-yr	34070	42.8	65.5	17.8	12.8	2990	168
20,843		Footbridge						
20,858	100-yr	34070	39.4	66.6	23.1	10.6	3654	158
22,953	100-yr	34070	58.8	73.6	11.2	11.5	3208	287
22,976		Falls Dam No. 5						
22,996	100-yr	34070	63.9	80.1	13.2	9.3	4313	377
24,341	100-yr	34070	65.8	84.1	12.4	15.5	2629	214
24,356		Sewer Cossing						
24,371	100-yr	34070	69	85.5	12.6	16.2	2639	235
24,489	100-yr	34070	77	91.1	9.9	13.4	3063	309
24,490		DuPont Dam No. 6						
24,525	100-yr	34070	72	93	16.1	7.6	4972	393




Profile Plot
File Options Help
Brandywine_Crk_Lower_Reach_Detail_Study Plan: Plan 06
Legend
Ground
Main Channel Distance (ft)


Cross Section
File Type Options Help
Brandywine_Crk_Lower_Reach_Detail_Study Plan: Plan 06
Legend
Ground
Bank Sta


Cross Section
File Type Options Help
Brandywine_Crk_Lower_Reach_Detail_Study Plan: Plan 09
Legend
Ground
Bank Sta

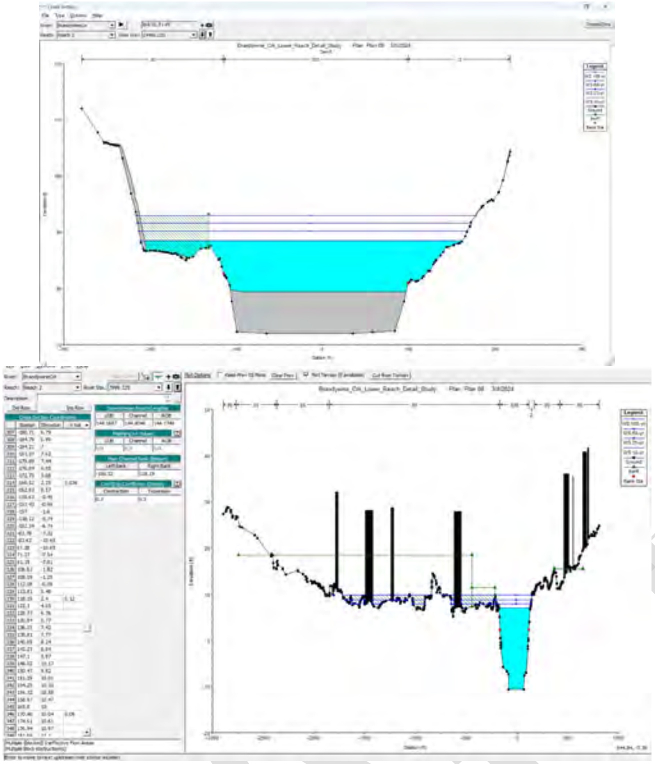
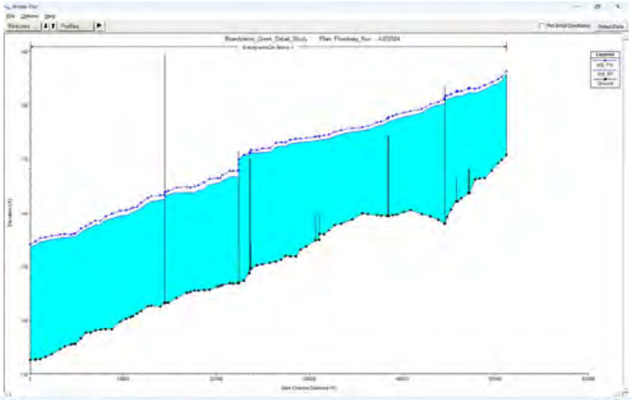


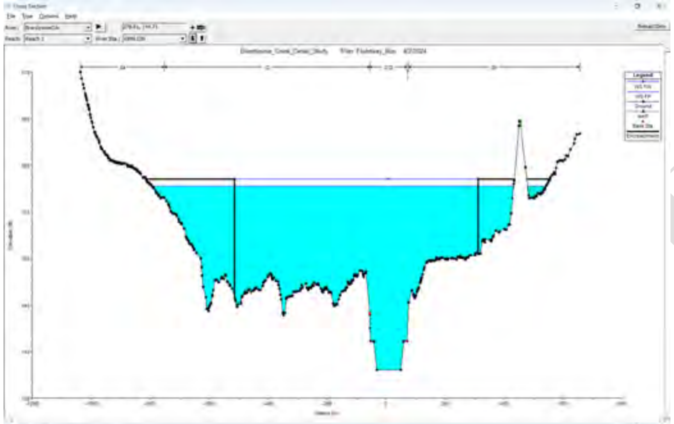
Figure 3.15 HEC-RAS model plan, profile, and cross-sections along the Brandywine in Delaware

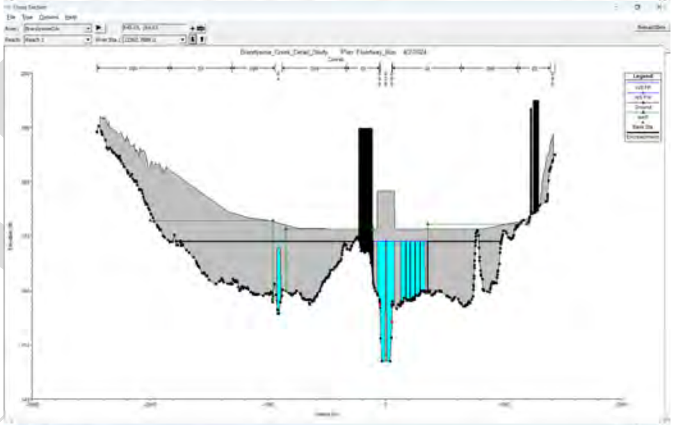
Brandywine Mainstem PA HEC-RAS Model: The mainstem Brandywine in Pennsylvania HEC-RAS model originates at the DE/PA state line at station 2,294 ft at elevation 133 ft msl and extends 45,000 ft to and rises 30 ft to station 47,088 ft at elevation 163 ft near Lenape Park (Table 3.8). Key cross sections include flood hazard sites at the Route 100 bridge downstream from Chadds Ford, the railroad viaduct at the Brandywine Museum and Route 1 bridge, and the Lenape bridge and dam at Route 52 (Figure 3.16).

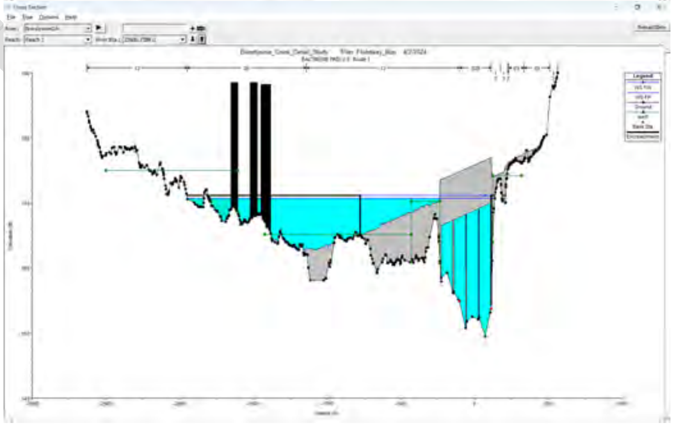
Table 3.8 HEC-RAS Model Output for the Mainstem Brandywine in PA for the 100-year Storm Event

River Sta	Q Total (cfs)	Min Ch El (ft)	W.S. Elev (ft)	Hydr Depth (ft)	Vel Chnl (ft/s)	Flow Area (sq ft)	Top Width (ft)
2,294	32,711	133.6	155.7	15.5	5.7	7546	487
14,382	32,205	143.2	163.2	13.0	7.0	6974	535
14,471	Rte 100 Br.						
14,548	32,205	143.3	163.8	13.8	6.9	6603	479
22,312	31,417	146.9	167.8	12.2	10.3	5242	431
22,363	RR Trestle						
22,414	31,417	147.0	169.8	13.6	10.0	6248	461
22,950	31,380	147.4	170.6	12.4	8.1	9185	739
23,531	31,380	148.7	171.0	10.5	6.6	8653	826
23,607	Rte 1 Br.						
23,661	31,380	149.5	171.2	12.1	6.2	10721	887
23,716	31,380	149.6	171.5	14.2	4.3	13820	970
23,724	PA Dam No. 1						
23,743	31,380	149.7	171.6	14.2	4.4	13799	969
30,661	30,949	154.9	174.1	12.3	4.1	16601	1352
30,671	PA Dam No. 2						
30,682	30,949	154.9	174.1	12.0	4.6	16173	1352
31,041	30,949	155.0	174.1	11.6	5.2	13278	1147
31,064	Inl Struct						
31,076	30,949	156.0	174.2	11.8	5.1	13683	1161
38,426	28,857	159.4	177.4	9.4	6.4	7341	779
38,474	Rte 926 Br.						
38,540	28,857	159.4	177.7	10.0	6.2	7590	757
44,506	28,375	158.0	181.1	11.3	7.0	6460	574
44,562	Rte 52 Bridge						
44,627	28,375	158.0	181.7	12.1	6.1	7154	590
45,757	28,303	162.0	182.5	10.6	5.3	11691	1100
45,808	Lenape Dam 3						
45,859	28,303	162.0	182.5	9.6	5.9	11510	1193
47,088	28,303	163.5	183.1	11.6	3.6	14946	1292


Legend
WS FW
WS FP
Ground


File
Type
Options
Help
Legend
WS FW
WS FP
Ground
Ineff
Bank Sta
Encroachment


File
Type
Options
Help
Legend
WS FP
WS FW
Ground
Ineff
Bank Sta
Encroachment


File
Type
Options
Help
Legend
WS FW
WS FP
Ground
Ineff
Bank Sta
Encroachment

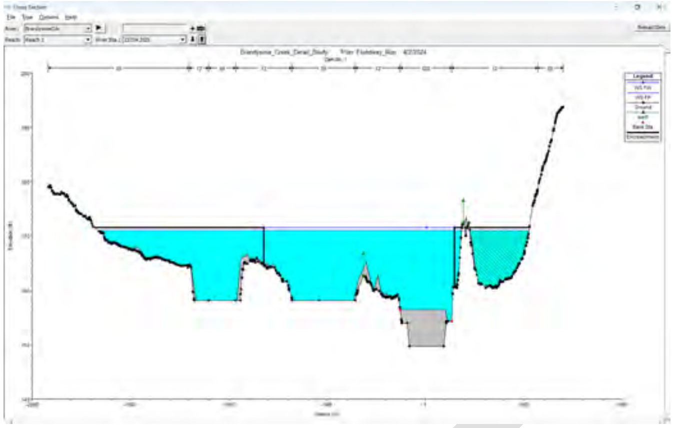


Figure 3.16 HEC-RAS model cross-sections along Mainstem Brandywine in Pennsylvania

East Branch Brandywine HEC-RAS Model: The East Branch Brandywine River HEC-RAS model begins at river station 1000 near the confluence in Lenape and extends 50,000 ft up to Station 50,000 ft above Downingtown and rises from an elevation of 100 ft above sea level to 500 ft above sea level and HEC-RAS cross sections includes flood hazard sites at roadways like Route 30 and railroad viaduct in and around Downingtown (Table 3.9 and Figures 3.17 and 3.18).

Table 3.9 HEC-RAS Model Output for the East Branch Brandywine for the 100-year Storm Event

River Sta	Q100 (cfs)l	Min Ch El (ft)	W.S. Elev (ft)	Hydr Depth (ft)	Vel Chnl (ft/sec)	Flow Area (ft2)	Top Width (ft)
44,387	8,684	223.0	231.4	4.1	3.9	3,018	1,095
44,414	Inl Struct						
44,439	8,684	223.0	231.5	4.1	3.7	3,255	1,062
45,206	8,684	222.8	231.9	5.9	7.2	1,559	736
45,309	Bridge						
45,412	8,684	223.0	232.8	4.7	6.7	1,848	810
46,530	8,404	225.0	234.7	2.7	6.8	1,956	1,074
46,545	Bridge						
46,560	8,404	225.3	235.0	2.9	6.0	2,242	1,060
46,661	8,404	225.3	235.2	3.5	6.5	1,736	669
46,795	8,399	225.2	235.4	5.4	6.4	1,419	264
46,852	Bridge						
46,902	8,399	225.3	236.2	5.8	4.2	2,310	665

47,358	8,399	229.0	236.5	3.4	6.7	1,882	695
47,407	Bridge						
47,448	8,399	229.3	237.5	4.1	5.6	2,391	731
50,449	6,868	238.4	243.5	3.5	9.5	923	1,756
50,513	Bridge						
50,557	6,868	238.8	246.3	5.6	7.1	1,220	2,107
52,015	6,868	244.6	250.3	4.6	8.8	906	2,439
52,108	Bridge						
52,186	6,868	245.0	251.7	4.8	7.8	1,020	2,342
53,447	6,868	247.1	254.4	4.8	4.7	1,819	382
53,464	Inl Struct						
53,484	6,868	247.5	255.4	5.4	4.2	2,109	390
58,358	6,549	255.5	264.6	5.3	7.7	1,366	259
58,673	6,549	256.0	265.3	8.2	7.1	953	252
58,710	Bridge						
58,755	6,549	256.3	266.2	8.2	5.5	1,185	274
65,481	5,520	273.4	280.9	3.9	7.7	835	217
65,503	Bridge						
65,519	5,520	273.8	282.3	5.1	5.6	1,220	237
65,835	5,520	274.5	282.6	4.8	7.8	794	166
66,184	5,520	275.8	283.6	6.1	7.3	778	128
66,463	5,520	276.6	284.2	3.8	8.2	913	237
66,845	5,677	277.7	285.4	3.6	8.6	980	275
67,068	5,677	278.4	286.2	3.3	8.7	923	282
67,284	5,677	279.0	287.3	5.4	6.5	1,256	268
67,458	5,677	279.5	287.3	3.6	9.3	920	253
67,703	5,677	280.2	288.4	3.4	8.6	968	286
68,067	5,677	281.3	289.6	3.8	9.3	819	215
68,083	Bridge						
68,101	5,677	281.6	292.5	5.4	5.6	1,549	287

72,166	5,677	296.4	303.9	3.3	8.5	1,037	450
72,205	Bridge						
72,238	5,677	296.9	306.1	4.4	6.0	1,646	621
77,738	4,155	320.1	326.1	4.9	10.7	420	208
77,777	Bridge						
77,822	4,155	320.5	328.9	6.2	7.3	662	302
86,425	4,155	351.5	357.4	4.5	8.3	511	114
86,511	Bridge						
86,567	4,155	351.9	358.7	5.2	5.6	983	463
88,856	3,700	354.0	362.9	6.7	5.9	632	147
88,888	Bridge						
88,919	3,700	354.3	363.2	7.1	5.5	714	202

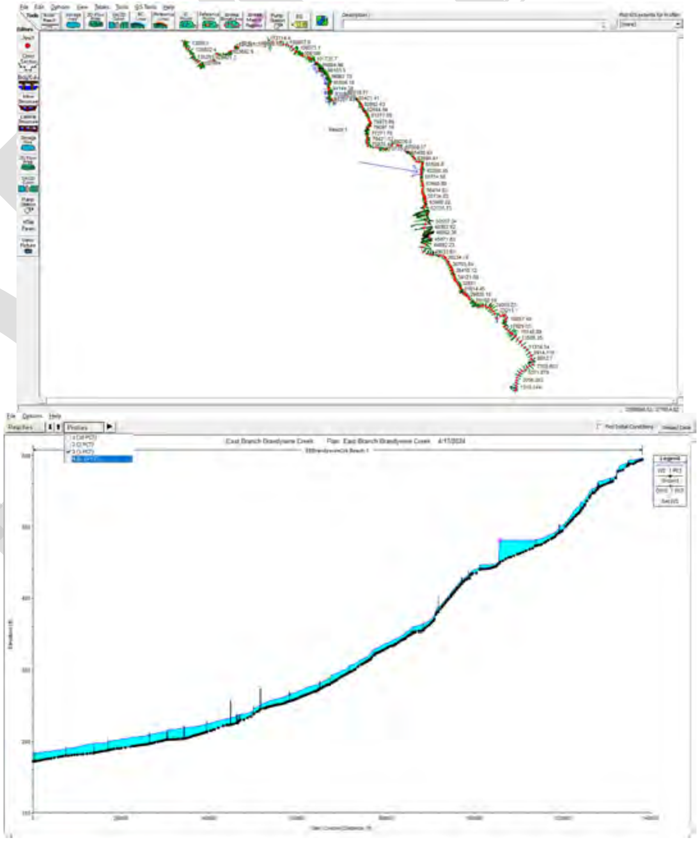


Figure 3.17 HEC-RAS model plan and profile along East Branch Brandywine

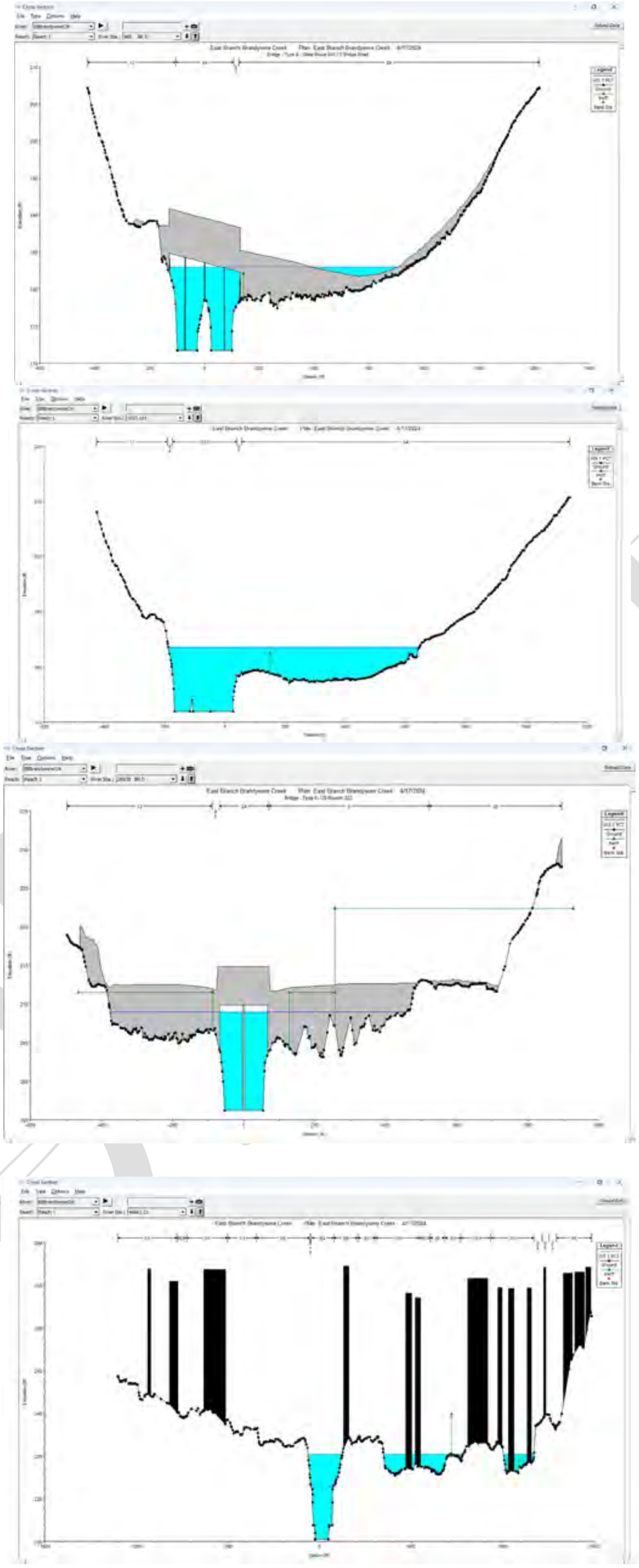


Figure 3.18 HEC-RAS model cross-sections along East Branch Brandywine

West Branch Brandywine HEC-RAS Model: The West Branch Brandywine River HEC-RAS model begins at station 1000 ft near Embreeville and then flows upstream to 83,796 feet from an elevation of 173 feet msl to 286 ft msl or a distance of 80,000 feet or 20 miles and a rise of 110 feet (Table 3.10). HEC-RAS cross sections along the West Branch at Embreeville, Modena, South Coatesville, and Coatesville illustrates the channelization of the Brandywine and obstructions that may backup floodwaters from highway and railroad bridges (Figures 3.19 and 3.20).

Table 3.10 West Branch HEC-RAS Model Output

River Sta	Q Total	Min Ch El	W.S. Elev	Hydr Depth	Vel Chnl	Flow Area	Top Width
	(cfs)	(ft)	(ft)	(ft)	(ft/s)	(sq ft)	(ft)
1,960	21,941	173.3	188.7	8.5	11.5	4,663	550
4,127	21,941	175.2	192.8	10.0	10.1	4,160	418
4,177	Bridge						
4,227	21,941	175.3	194.7	10.5	6.4	5,410	513
17,100	20,833	185.5	201.5	5.6	7.0	6,321	1,128
17,130	Bridge						
17,160	20,833	185.5	201.7	6.0	7.2	6,514	1,084
34,531	20,361	204.8	219.4	8.0	2.4	14,884	2,159
34,561	Bridge						
34,589	20,361	204.8	219.4	8.6	2.3	15,867	2,198
38,509	20,361	204.4	220.0	9.4	14.7	1,837	1,198
38,568	Bridge						
38,634	20,361	204.4	225.9	14.2	8.9	3,381	1,055
40,318	20,112	208.4	227.9	12.2	7.4	3,766	344
40,379	Bridge						
40,452	20,112	208.8	230.0	13.5	6.0	4,826	375
42,293	20,112	212.6	230.8	10.9	3.4	11,743	1,194
42,351	Inl Struct						
42,383	20,112	214.0	230.9	10.2	3.5	10,134	1,108
48,108	20,112	215.0	235.0	10.3	6.9	5,318	517
48,155	Bridge						

48,208	20,112	215.0	235.5	10.5	5.5	6,028	574
58,437	12,851	231.9	247.3	8.9	4.2	5,910	1,012
58,505	Bridge						
58,554	12,851	232.0	249.5	10.7	4.0	5,802	858
61,809	12,622	239.2	253.5	10.5	5.4	3,288	555
61,858	Bridge						
61,889	12,622	239.2	254.3	11.7	5.0	3,627	453
62,010	12,622	239.9	254.5	8.6	4.8	3,849	445
62,051	Inl Struct						
62,086	12,622	243.5	254.4	5.3	8.2	2,593	485
71,485	11,732	259.7	271.4	6.0	10.1	2,764	557
71,552	Bridge						
71,644	11,732	260.2	273.8	6.7	9.9	3,105	876
73,100	11,150	263.1	276.2	5.3	7.0	2,807	598
73,143	Bridge						
73,196	11,150	264.3	276.7	5.5	7.6	2,344	450
76,795	11,105	269.4	284.6	12.3	7.8	1,461	119
76,818	Inl Struct						
76,836	11,105	277.3	288.8	8.9	9.7	1,157	130
78,045	11,105	275.7	292.9	11.8	10.5	1,227	154
78,072	Bridge						
78,095	11,105	275.6	293.5	12.5	9.3	1,378	136
79,842	11,018	278.1	295.7	5.2	13.1	1,248	242
79,890	Bridge						
79,898	11,018	278.2	296.3	5.6	12.3	1,317	236
79,915	11,018	278.2	296.8	5.6	11.5	1,505	267
79,956	Bridge						
80,023	11,018	278.2	299.2	6.4	6.5	2,763	710
81,719	11,018	284.9	302.1	11.1	9.7	1,591	218
81,833	Bridge						

83,225	11,018	285.7	304.4	8.1	7.0	1,959	497
83,315	11,018	286.2	307.3	7.4	4.2	4,090	905
83,755	Bridge						
83,796	11,018	286.2	307.4	6.5	4.0	4,944	875
83,837	10,389	287.6	307.3	8.9	6.6	1,804	320
83,958	Bridge						

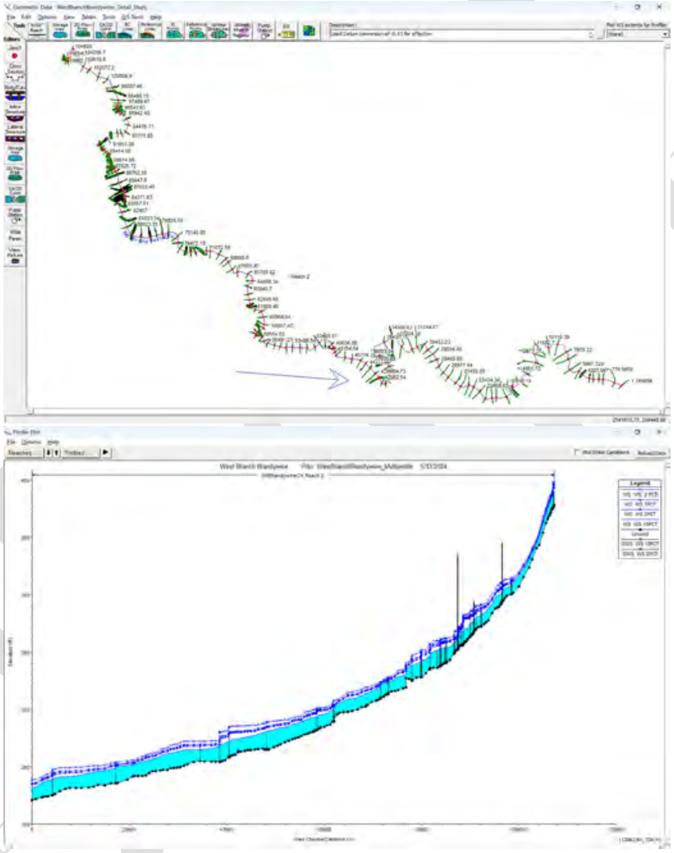
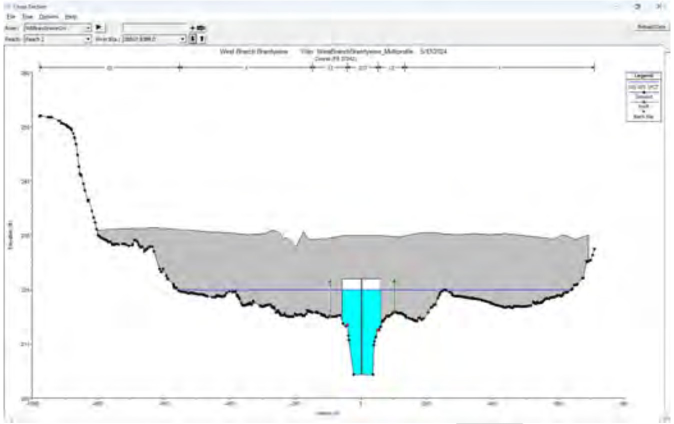
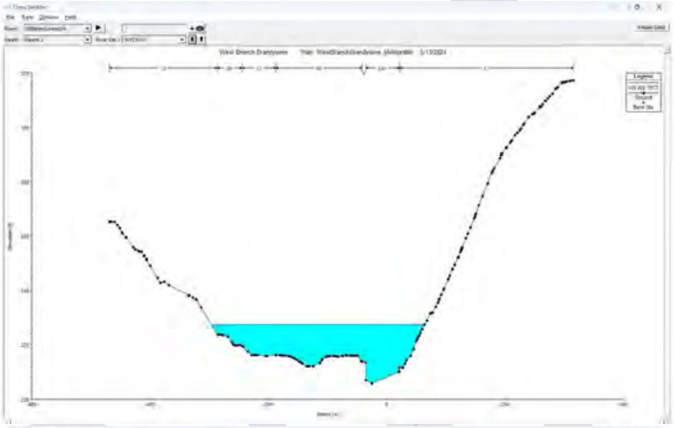
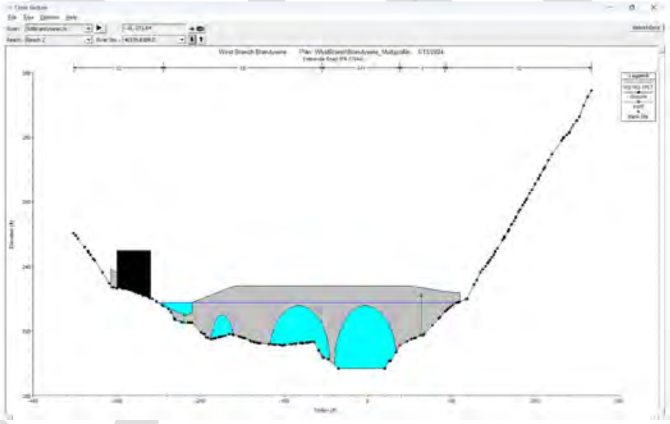
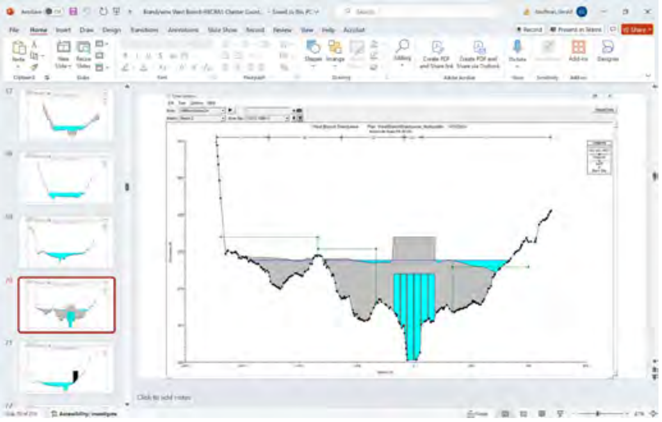


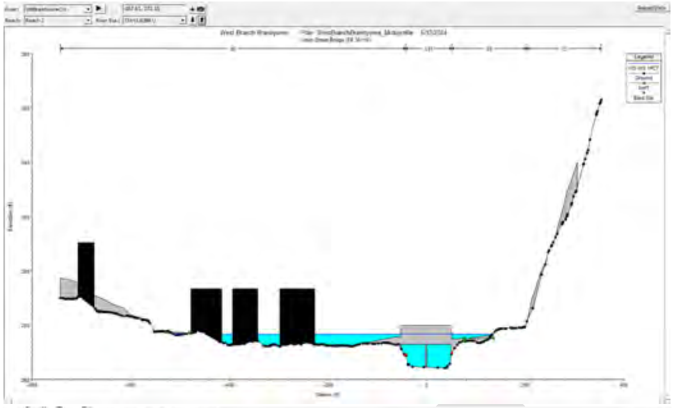
Figure 3.19 HEC-RAS model plan and profile along West Branch Brandywine

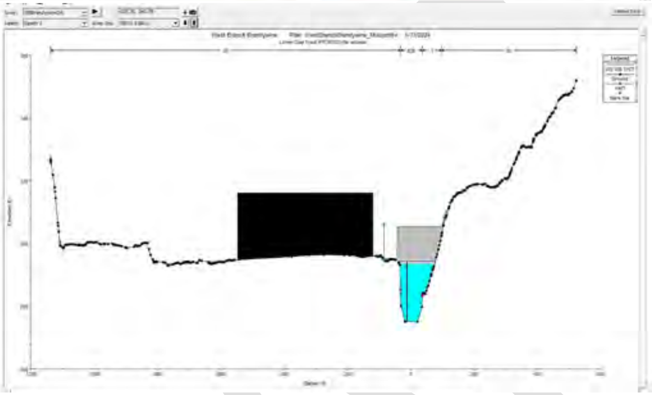


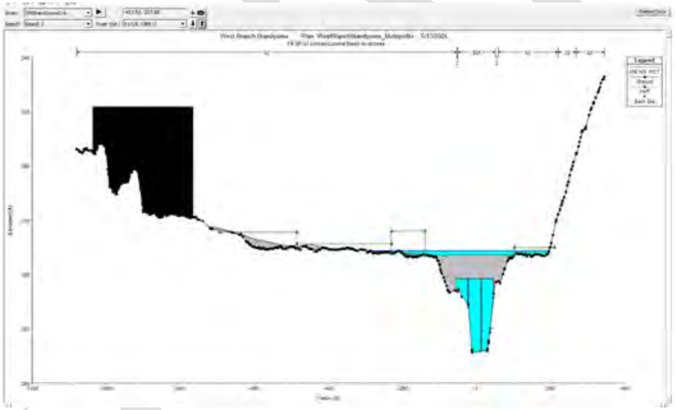


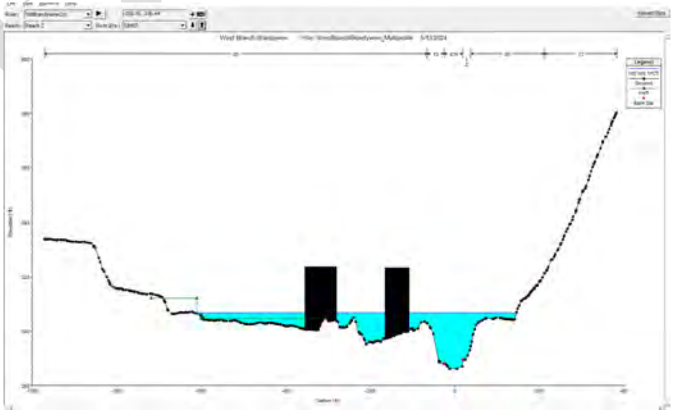


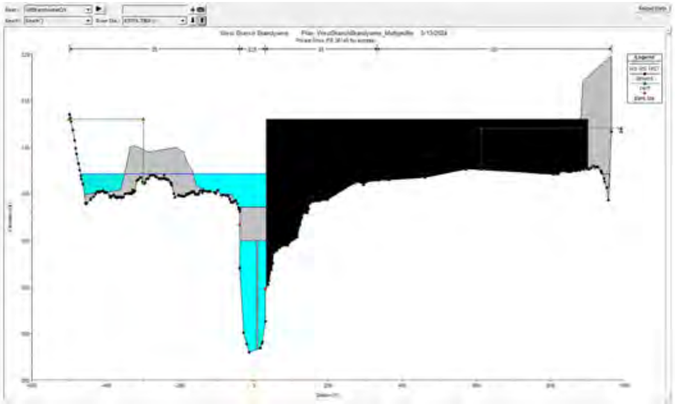


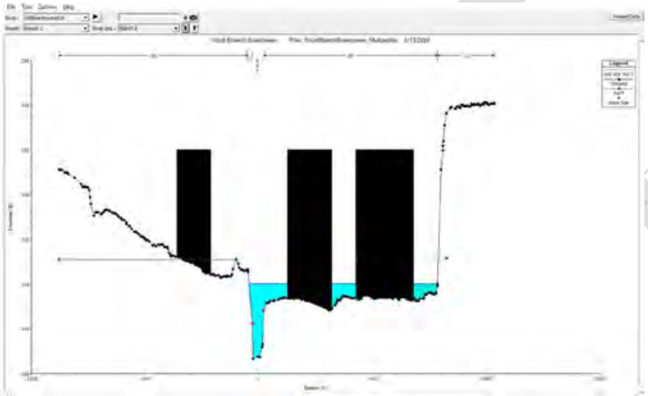

West Branch Brandywine
Legend
Ground
Bank Sta

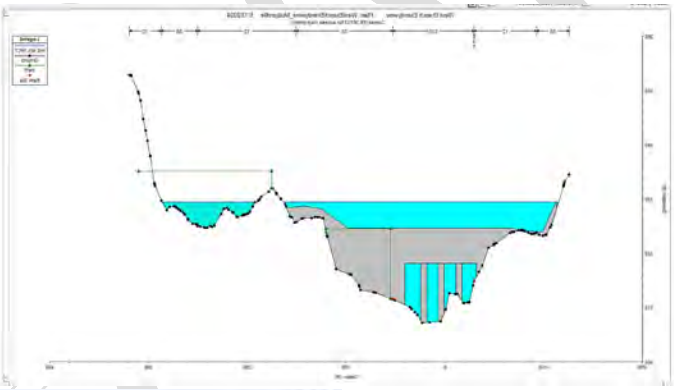

West Branch Brandywine
Legend

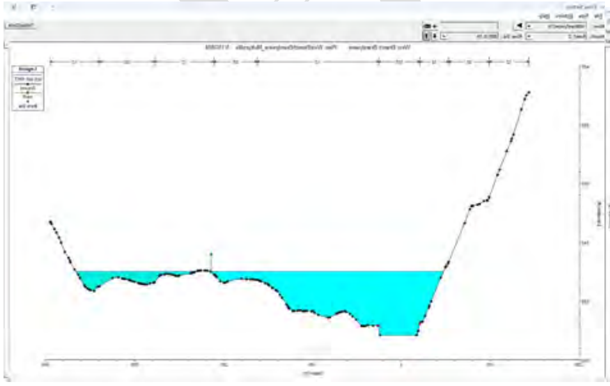

West Branch Brandywine
Legend

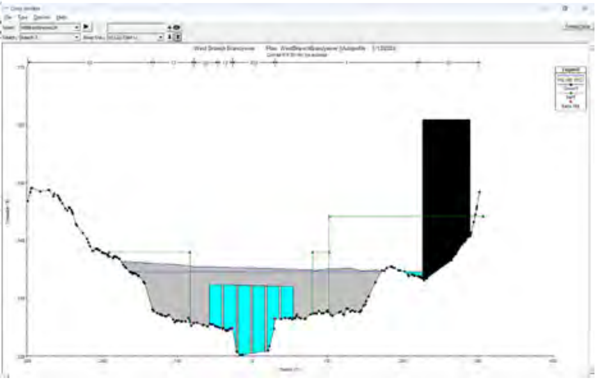

West Branch Brandywine
Legend











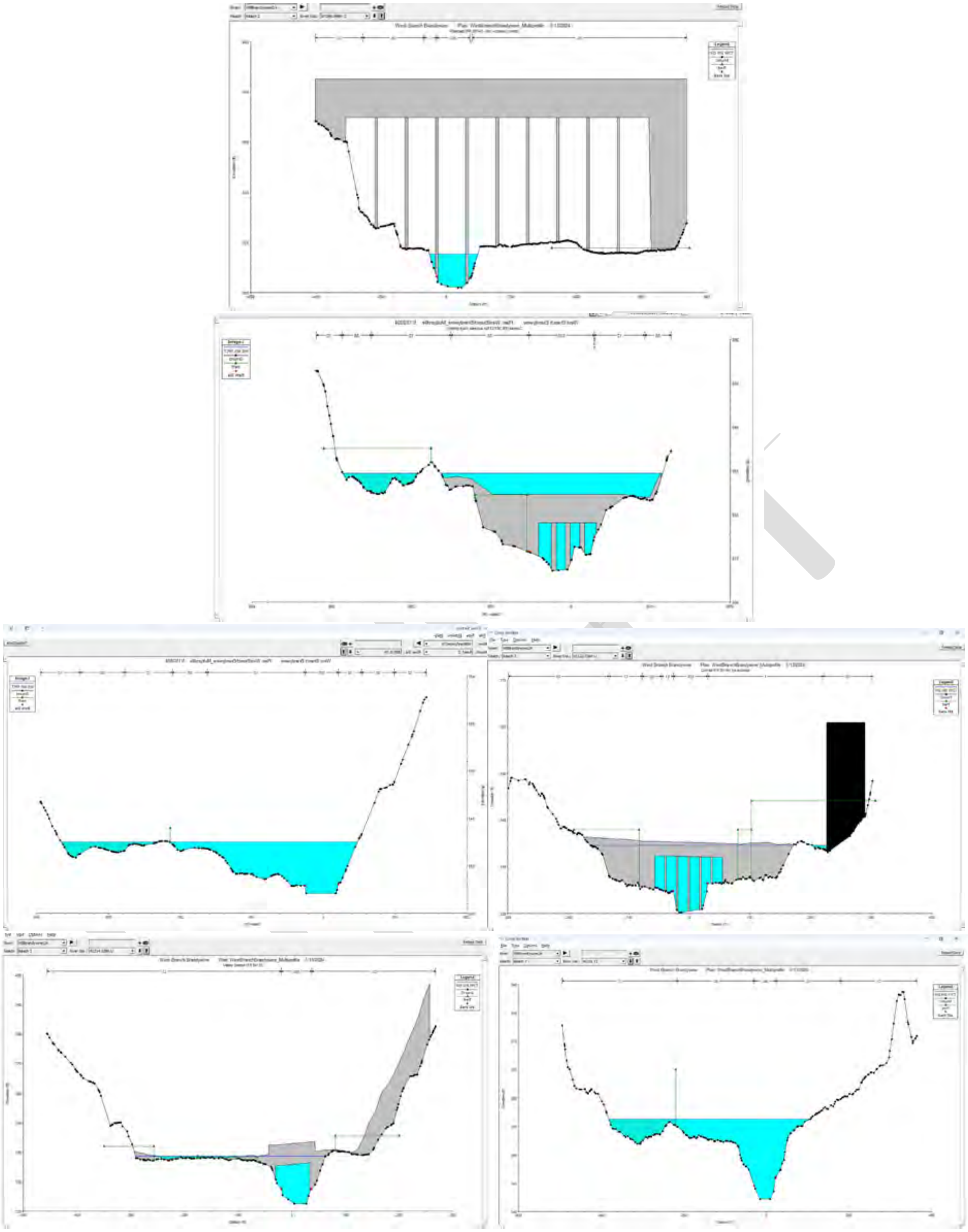


Figure 3.20 HEC-RAS model cross-sections along West Branch Brandywine

Table 3.11 summarizes significant 100-year flood elevation increases at bridges and structures along the Brandywine Creek and tributaries that may be considered for reconstruction to prevent flood damage. Additional discussion of bridge and structural recommendations can be found in Chapter 6.

Table 3.11 Significant 100-year flood elevation increase at structures along the Brandywine

Structure Location	RM (mi or ft)	Thalweg (ft)	Deck (ft)	DS WSEL. (ft)	US WSEL (ft)	Diff (ft)
Main Stem - Delaware						
AMTRAK RR	1.2	-14.0	31.0	11.0	12.0	1.0
US Rte. 13/NE Blvd	1.5	-10.0	24.0	13.0	14.0	1.0
Jessup St./16th St.	1.9	-15.0	20.0	14.0	14.0	0.0
Bancroft Dam No. 4	3.7	40.0	45.0	48.0	58.0	10.0
Rockford Falls Dam No. 5	4.3	60.0	68.0	68.0	81.0	13.0
DuPont Exp. Sta. Dam No. 6	4.6	66.0	79.0	84.0	89.0	5.0
Rockland Rd	7.3	118.0	148.0	135.0	141.0	6.0
Main Stem - Pennsylvania						
Rte. 100	14,500	142.0	188.0	161.0	162.0	1.0
Railroad	22,500	147.0	178.0	165.0	170.0	5.0
US Rte. 1	23,600	149.0	176.0	168.0	171.0	3.0
PA Dam No. 1	23,700	150.0	156.0	168.0	171.0	3.0
Rte. 925	38,500	159.0	181.0	176.0	177.0	1.0
Rte. 52	44,500	158.0	188.0	179.0	181.0	2.0
East Branch Brandywine						
Rte. 162	17,600	188.0	213.0	198.0	200.0	2.0
Rte. 282	50,400	239.0	254.0	244.0	247.0	3.0
Dorlan Mill Rd	65,500	274.0	289.0	280.0	282.0	2.0
Private Drive	68,000	281.0	290.0	288.0	292.0	4.0
Reeds Rd	72,000	297.0	307.0	304.0	307.0	3.0
Lyndell Rd.	77,700	320.0	332.0	326.0	329.0	3.0
Rte. 282	101,800	440.0	451.0	443.0	446.0	3.0
Barneston Dam No. 5	106,300	448.0	485.0	475.0	481.0	6.0

Structure Location	RM (mi or ft)	Thalweg (ft)	Deck (ft)	DS WSEL. (ft)	US WSEL (ft)	Diff (ft)
North Manor Rd.	114,400	473.0	486.0	478.0	480.0	2.0
Wyebrook Creek Rd	119,800	492.0	510.0	496.0	500.0	4.0
West Branch Brandywine						
Rte. 842	4,200	175.0	196.0	193.0	195.0	2.0
Railroad	38,500	205.0	230.0	220.0	225.0	5.0
Embreeville Rd	40,400	209.0	234.0	228.0	230.0	2.0
Railroad	58,600	232.0	247.0	247.0	249.0	2.0
Strasburg Rd	61,900	240.0	263.0	253.0	255.0	2.0
Mortonville Rd	71,600	260.0	277.0	271.0	274.0	3.0
Lower Gap Rd	78,000	275.0	305.0	296.0	298.0	2.0
First St	79,900	278.0	301.0	296.0	299.0	3.0
RR Cleveland Cliffs	81,700	286.0	304.0	302.0	305.0	3.0
Private Dr.	83,800	288.0	304.0	307.0	309.0	2.0
RR Pedestrian Path	87,600	304.0	322.0	315.0	320.0	5.0
Dam	87,800	305.0	310.0	318.0	320.0	2.0
Eigencrest Rd	88,200	306.0	324.0	321.0	323.0	2.0
Railroad	88,500	308.0	324.0	323.0	330.0	7.0
Vallet Station	92,300	322.0	343.0	337.0	339.0	2.0
Rte. 30	96,600	345.0	400.0	357.0	359.0	2.0
Beaver Creek						
Private Driveway	23,150	382.0	397.0	389.0	395.0	6.0
Private Driveway	23,950	399.0	407.0	407.0	411.0	4.0
Private Driveway	24,500	407.0	415.0	414.0	418.0	4.0
Bondsville Rd	25,250	417.0	423.0	423.0	425.0	2.0
Hadfield Rd	29,500	442.0	447.0	447.0	449.0	2.0
Private Driveway	32,950	457.0	467.0	466.0	468.0	2.0
Beaver Run						
Fairview Rd	10,450	376.0	383.0	382.0	384.0	**2.0**

Structure Location	RM (mi or ft)	Thalweg (ft)	Deck (ft)	DS WSEL. (ft)	US WSEL (ft)	Diff (ft)
Bennetts Run						
Railroad	880	165.0	174.0	175.0	177.0	2.0
Brinton Bridge Rd	1,520	169.0	176.0	177.0	179.0	2.0
Private Rd	8,040	215.0	222.0	220.0	223.0	3.0
Pocopson Rd	10,920	233.0	238.0	239.0	241.0	2.0
Parkersville Rd	11,880	239.0	244.0	245.0	247.0	2.0
Birch Run						
Martins Corner Rd	9,400	602.0	607.0	607.0	611.0	4.0
Dam	10,200	304.0	304.0	306.5	308.5	2.0
Buck Run						
Springdell Rd	16,600	328.0	336.0	337.0	347.0	10.0
Railroad	21,200	342.0	367.0	350.0	354.0	4.0
Buck Run Rd	23,100	345.0	361.0	356.0	359.0	3.0
Railroad	28,100	364.0	376.0	373.0	377.0	4.0
Copeland Run						
West Lancaster Ave	1,950	268.0	272.0	271.0	274.0	3.0
Private Dr	2,250	272.0	275.0	275.0	279.0	4.0
West Prospect Ave	2,700	282.0	285.0	284.0	286.0	2.0
Little Buck Run						
Rte. 10	3,300	479.0	484.0	482.0	485.0	3.0
Rte. 372	5,000	500.0	514.0	504.0	510.0	6.0
Main St.	6,250	515.0	518.0	519.0	525.0	6.0
Rte 10	7,250	548.0	563.0	551.0	557.0	6.0
Pocopson Creek						
Railroad	200	164.0	178.0	176.0	178.0	2.0
Rte. 926	3,800	175.0	191.0	184.0	189.0	5.0
Ring Run						
Chadds Ford School Rd	850	160.0	175.0	171.0	173.0	2.0

Structure Location	RM (mi or ft)	Thalweg (ft)	Deck (ft)	DS WSEL. (ft)	US WSEL (ft)	Diff (ft)
Rte. 1	4,100	1809.0	193.0	187.0	191.0	4.0
Legend Lane	4,600	186.0	197.0	193.0	197.0	4.0
Constitution Dr	4,900	192.0	203.0	196.0	201.0	5.0
Sucker Run						
Access Rd	3,400	313.0	324.0	322.0	326.0	4.0
Access Rd	4,200	322.0	339.0	330.0	336.0	6.0
Railroad	7,300	341.0	382.0	352.0	357.0	5.0
Grove Ave	9,400	357.0	367.0	363.0	365.0	2.0
Footbridge	9,600	358.0	366.0	363.0	365.0	2.0
Rte. 372	10,500	366.0	375.0	372.0	374.0	2.0
Mt. Carmel St.	11,800	378.0	386.0	382.0	386.0	4.0
Railroad	13,500	394.0	402.0	398.0	402.0	4.0
Bondsville Rd	4,000	271.0	279.0	275.0	279.0	4.0
Thornridge Dr	5,100	278.0	281.0	282.0	284.0	2.0
Municipal Dr	6,600	291.0	291.0	288.0	300.5	12.5
Bailey Rd	8,700	294.0	299.0	297.5	303.0	5.5
Goo Csrlson Blvd	9,200	294.0	307.0	300.0	312.0	12.0
Goo Csrlson Blvd	10,400	300.0	312.0	306.0	312.0	6.0
Barleysheaf Rd	12,400	310.0	319.0	316.0	318.5	2.5
Loomis Ave	13,300	315.0	322.5	319.5	325.0	5.5
Setzer Ave	14,500	322.0	327.0	327.0	329.0	2.0
Valley Creek (East Branch Brandywine)						
Rte. 100	13,300	292.0	307.0	300.0	302.0	2.0
Rte 30	14,100	294.0	306.0	303.0	305.0	2.0
Exton Mall Access	14,600	298.0	314.0	305.0	307.0	2.0
Exton Mall Access	15,300	299.0	316.0	308.0	310.0	2.0
Valley Rd	17,500	306.0	316.0	311.0	313.0	2.0
Ship Rd	18,900	311.0	322.0	316.0	320.0	4.0

Structure Location	RM (mi or ft)	Thalweg (ft)	Deck (ft)	DS WSEL. (ft)	US WSEL (ft)	Diff (ft)
Chester Valley Trail	21,000	325.0	334.0	325.0	335.0	10.0
Railroad	21,500	327.0	345.0	334.0	340.0	6.0
Church Farm Lane	23,500	338.0	341.0	340.0	344.0	4.0
Valley Creek Blvd	24,600	344.0	358.0	346.0	351.0	5.0

Chapter 4 Watershed Buildout Assessment

4.1 Overview

To better understand how future development scenarios might impact flooding events, a watershed-wide buildout assessment was completed. A build-out analysis predicts the development potential allowed by existing zoning regulations and can demonstrate the strengths and weaknesses of existing municipal regulations. Build-out analyses can be an effective tool for demonstrating the importance of strong natural resource ordinances, appropriate zoning and proactive land preservation efforts at the municipal, landscape or watershed level. Not only can this tool reveal the effectiveness of existing zoning in guiding future development, but it also highlights land that may be more appropriate for land preservation. For the Brandywine Flood Study, a build-out analysis was utilized to assess where in the watershed development may occur and how the land use changes during development may impact stormwater runoff volumes, leading to potential increases in flooding conditions.

4.2. Methodology

The first step of this analysis removes all lands currently developed or permanently protected, leaving parcels that have development potential.

- Permanently protected lands include land preserved through conservation easement, agricultural easement, deed restriction, publicly owned land and Homeowners Association (HOA) open space.
- Developed land was defined as parcels greater than four acres, parcels that have more than 30 percent of the land in intensive land uses, such as impervious surfaces, and utility right-of-ways, and irregular parcels with existing development and/or limited access or opportunity for additional subdivision.

Once parcels with development potential were identified, natural resources and other constrained land were removed. Since this analysis was conducted for the entire watershed, natural resource restriction baselines were determined based on best practices and recommendations from the Chester County Planning Commission. The following baselines were assumed for this analysis:

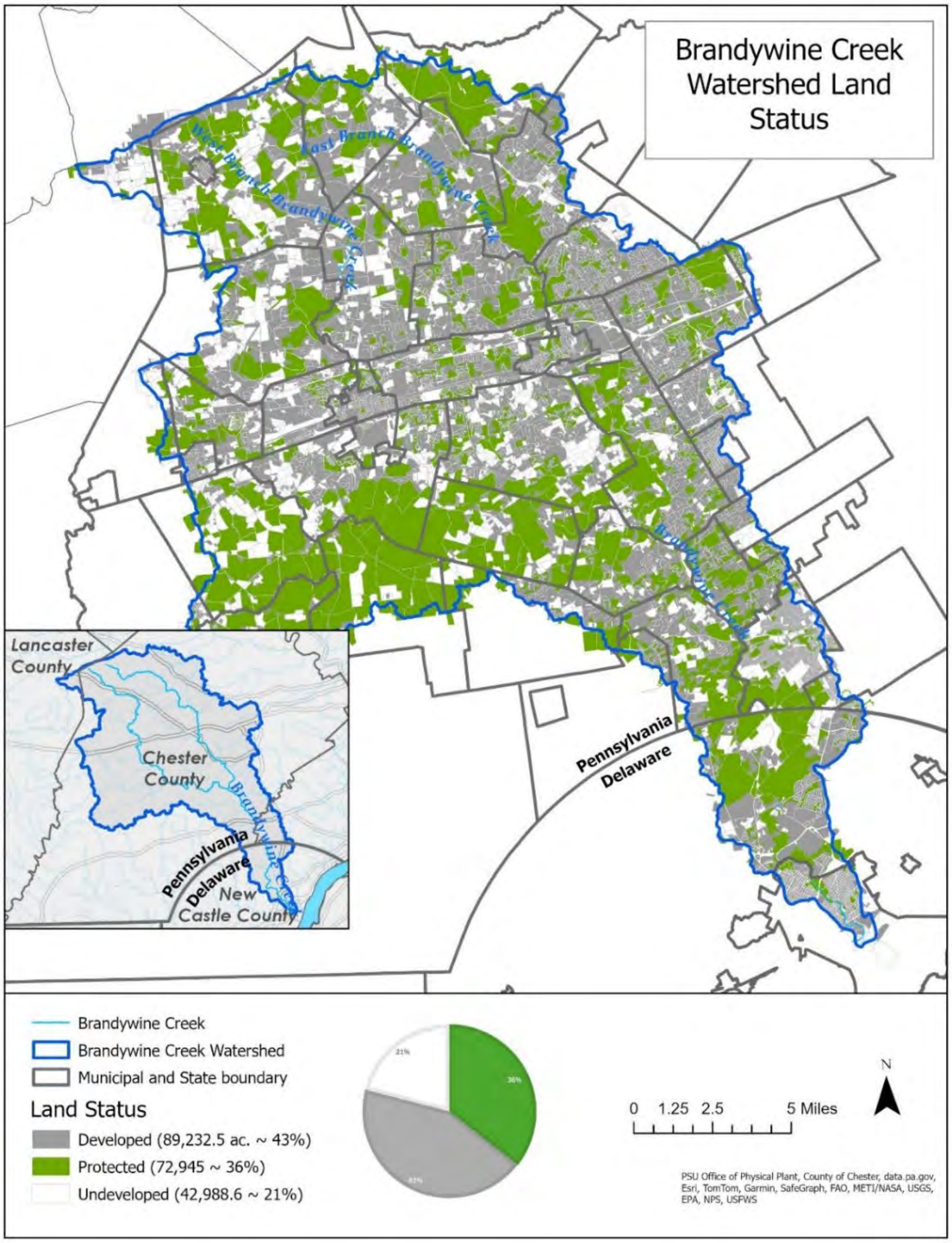
Natural Resource Regulation – Baselines

- 100-year floodplain – 0% disturbance
- Riparian Buffer (75 feet) – 0% disturbance
- Wetlands – 0% disturbance
- Wetland buffer (50 feet) – 20% disturbance
- Slopes
    - Steep (25%+)- 15% disturbance
    - Moderate Slopes (15-25%) – 30% disturbance
- Woodlands – 50% disturbance

These baselines were removed from the developable acres at the parcel level.

The third step in this analysis reviewed the local municipal zoning for all parcels included in this analysis, to determine the maximum impervious surface allowed by-right based on the local zoning district.

Finally, based on the local zoning, impervious surface estimates were calculated for each developable parcel to determine the maximum by-right development potential. Figure 4.1 provides the Brandywine watershed land status.



PSU Office of Physical Plant, County of Chester, data.pa.gov, Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, EPA, NPS, USFWS

Figure 4.1 Brandywine Watershed Conservation Land Status

4.3 Results

The final build-out calculation provides a clear picture of the development potential over the entire municipality. The resulting map (Figure 4.2) shows potential additional acres of impervious coverage if all undeveloped parcels were developed by right. While this map shows the worst-case scenario in terms of development, it also reveals opportunities for land preservation.

If all parcels are developed according to the existing zoning, an estimated 25,760 acres of impervious surface could be added to the watershed and approximately 23,747 new parcels could be added through subdivisions (Table 4.1). This development activity could also cause the loss of about 2,066 acres of woodland and an estimated 16,319 acres of agricultural land (Table 4.2).

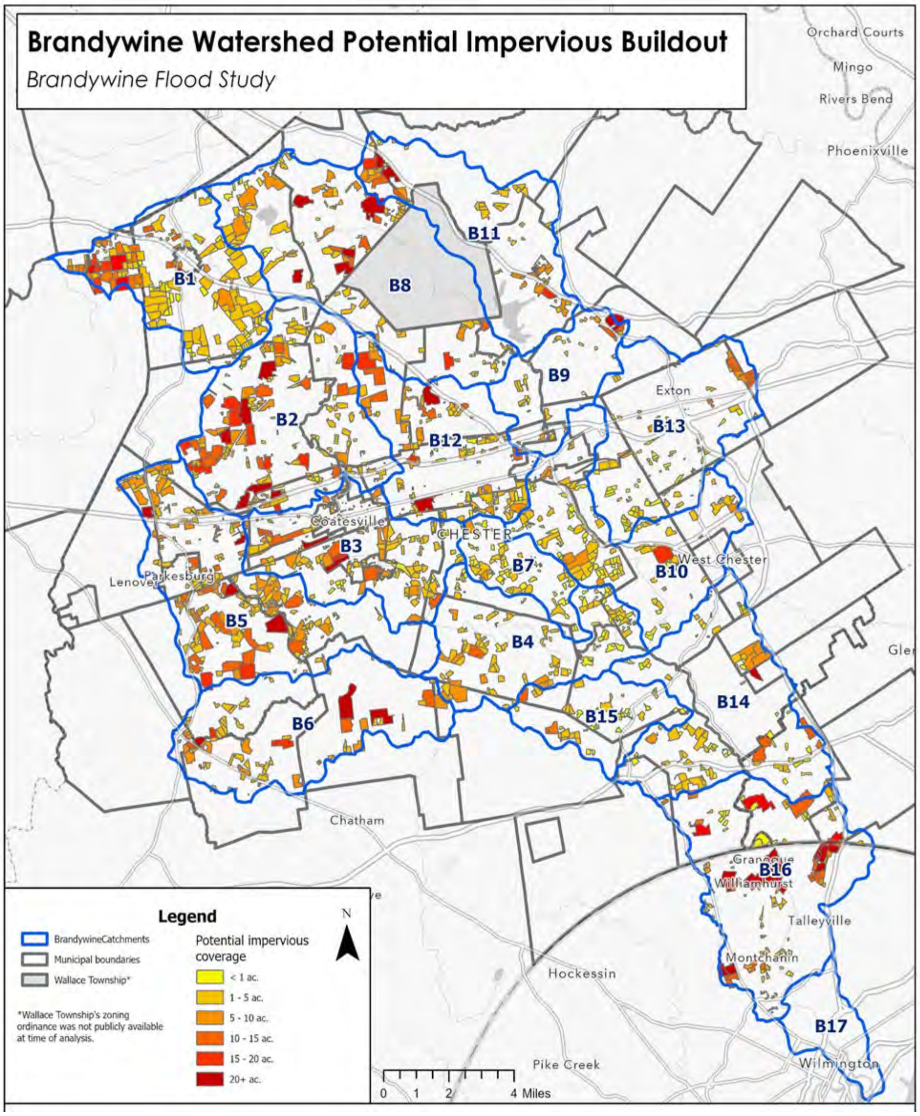


Figure 4.2 Brandywine watershed potential impervious buildout

Table 4.1 Impervious surface estimates by subbasin

Impervious Surface Estimates by Subbasin	
Subbasin	**Estimated additional impervious surface (acres)**
B1	505
B2	828
B3	20,093
B4	224
B5	863
B6	354
B7	70
B8	531
B9	176
B10	198
B11	345
B12	381
B13	200
B14	186
B15	55
B16	729
B17	23
Total	**25,760**

Table 4.2 Maximum Development Impact

Maximum Development Impact	
Potential Impervious Coverage	25,760 acres
Number of additional parcels	23,747 parcels
Potential woodland loss	- 2,066 acres
Potential loss of agricultural lands	-16,319 acres

In contrast, this hypothetical buildout also reveals the preservation potential of all the undeveloped parcels within the Brandywine watershed. If all parcels included in this analysis were protected, approximately 13,775 acres of woodland, 1,701 acres of floodplains and 595 acres of riparian areas could be preserved (Table 4.3).

Table 4.3 Preservation potential by existing land use category

Preservation Potential	
Potential Land Use	**Acres**
Woodland preservation	13,775
Floodplain preservation	1,701
Riparian buffer preservation	595

The buildout analysis also reveals potential changes in land use if all undeveloped parcels are developed. Based on existing zoning, over 7,600 buildable acres are in single family residential zoning, while over 640 buildable acres are in industrial zoning and 450 buildable acres are zoned commercially. Additionally, agricultural lands are likely to see the most impact from development (Figure 4.3). The results of the watershed buildout assessment were incorporated in the H&H models to characterize flooding impacts to current flood-prone areas and identify communities, which may be subject to increases in flood risk, in the future.

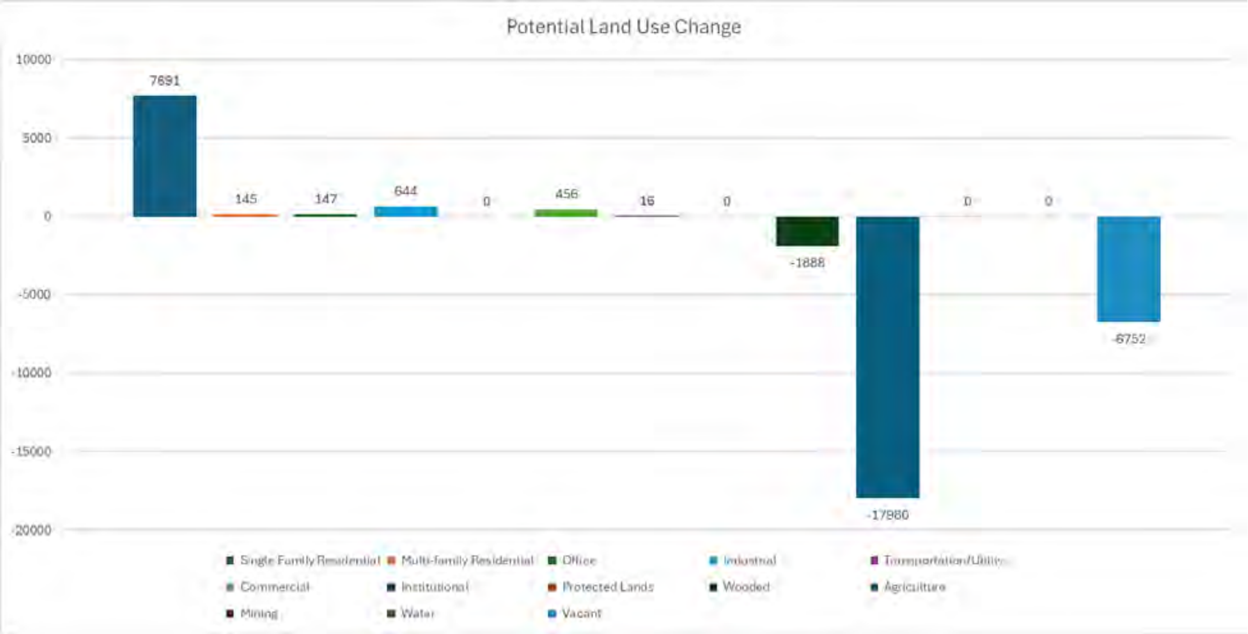


Figure 4.3 Potential land use change

Chapter 5 Public Engagement and Outreach

5.1. Overview

From the commencement of the study, robust public engagement was a priority to ensure that the public's experience was received and documented. Foci of public input included how flooding affected families, individuals and businesses, and where flooding is occurring and impacting all aspects of daily life, including work, lifestyles, and travel.

The study aimed to offer a diversity of public engagement options to receive feedback directly from within the communities that experience flooding impacts. Multiple locations around the watershed were identified so that public meetings were easily accessible by community members. Each location was intentionally aligned with the existing local efforts for flooding within the community. Public meeting locations were selected with emphasis to be within walking distance for residents most drastically impacted by flooding in developed areas. The following public meetings were held at various locations throughout the watershed:

- The greater Coatesville area was identified as the primary developed area on the West Branch of the Brandywine Creek, with the highest concentrated population in this subwatershed. This study also sought alignment with the City of Coatesville's own underground stormwater infrastructure study, focused on the Gibbons Run culvert, which was funded by FEMA and Chester County.
- The Borough of Downingtown also has a dense population located along Beaver Creek and the East Branch Brandywine Creek. As such, the Borough is frequently impacted by flooding. The study team coordinated with the Borough of Downingtown's Flood Advisory Committee to host a public meeting at the Borough Hall and for resident participation in the study.
- In recognizing the barrier of the state line for attendees' travel abilities, two public meeting location options were offered in the lower Pennsylvania stretches of the mainstem Brandywine Creek at the Chadds Ford Township building and the Brandywine Museum of Art campus, also in Chadds Ford.
- To coincide with other flood study and mitigation efforts, two meeting locations were held in the City of Wilmington, Delaware to further prioritize the engagement of those residents that were most impacted by recent flood events.

Overall, multiple methods were implemented to ensure public engagement, feedback and knowledge of the project. To ensure reaching all stakeholders in the watershed, public engagement beyond the public meetings was critical to the project's outreach and engagement. In addition to public meetings, engagement and outreach activities and materials included:

- participation in public outreach events
- flood study website
- media and press coverage
- surveys for public engagement and feedback
- interactive flood map for public input
- an advisory committee
- outreach to municipalities and development of individual municipal reports

These efforts were supported by significant coverage from 20 local and regional media outlets. They highlighted the study's crucial role in addressing flooding issues in the region and emphasizing the collaborative nature of the study between local governments, conservation organizations, and academic institutions.

5.2. Public Meetings

Public input is a vital component of the Brandywine Flood Study, fostering a collaborative dialogue between community members and the project partners. From December 2023 to May 2024, a series of five public meetings were held across the reaches of the watershed. The intent of these meetings was to directly connect the residents most impacted by flooding to the study process.

Meeting attendance ranged from 29-111 attendees (Table 5.1).

Table 5.1 Brandywine Flood Study Public Meetings

Location	Date	Speakers	Attendees
Downingtown Borough Hall *10 W Lancaster Avenue* *Downingtown, PA 19335*	December 14, 2023 6:00 pm	Brandywine Conservancy	43
Brandywine Museum of Art *1 Hoffmans Mill Road* *Chadds Ford, PA 19317*	February 8, 2024 6:00 pm	Brandywine Conservancy, City of Wilmington	111
Coatesville City Hall *1 City Hall Place* *Coatesville, PA 19320*	March 5, 2024 6:00 pm	Brandywine Conservancy, Cedarville Engineering Group	32
Chadds Ford Township *10 Ring Road* *Chadds Ford PA 19317*	March 18, 2024 6:00 pm	Brandywine Conservancy	24
UrbanPromise Rick's Rock Servant Leadership Center *1000 E. 28th Street* *Wilmington, DE 19802*	May 9, 2024 6:30 pm	Brandywine Conservancy, University of Delaware, City of Wilmington, Eleventh Street Bridge Community Long Term Recovery Group, Green Building United/Northeast Rising, Delaware Department of Natural Resources and Environmental Control (DNREC)	29

At these meetings, attendees were encouraged to share their personal experiences with flooding, which provided valuable context and insights into the challenges faced by the community. At each public meeting, the following questions were presented to the participants to gather feedback:

- Q1: In what ways are you impacted by flooding?
- Q2: How do you currently inform yourself about flood and other weather-related incidents?
- Q3: What types of flood mitigation projects should be implemented?
- Q4: How can your local government most support you prior, during, and after hazardous events?

In addition, the meetings featured an interactive session, where participants could express their concerns, ask questions with the study partners, and discuss potential solutions, ensuring that local knowledge and perspectives were integrated into the study. Public meeting attendees recorded their feedback (Appendix 6) on maps and posters with guided questions, as well as engaged in discussions, highlighting the importance of community involvement in shaping effective flood management strategies. Public input from these meetings was recorded and uploaded into the Interactive Flood Map, an important tool in providing cumulative reporting and public transparency. This open exchange not only empowered residents but also strengthened the overall effectiveness of the flood study initiative.

Attendees at all public meetings expressed a heightened sense of concern and urgency regarding flooding in their region. The overarching themes which have emerged from public feedback include:

Community Impacts of Flooding

- Home and Property Damage: Significant losses in residential and business properties, with reports of damage to homes, infrastructure, and farmland.
- Transportation and Access Issues: Flooding restricted access to workplaces, schools, and essential services.
- Environmental and Wildlife Concerns: Damage to natural habitats and challenges related to debris accumulation and management.

Flood Preparedness and Awareness

- Residents rely on various sources for flood alerts, including smartphones, apps, and automated texts. However, there were calls for improved communication and broader public education about emergency preparedness and flood recovery programs.

Proposed Mitigation Strategies

- Infrastructure Improvements: Suggestions included resizing bridges and culverts, removing or maintaining dams, and implementing natural flood retention systems.
- Environmental Solutions: Emphasis on riparian plantings, rain gardens, bioswales, and soil improvements to enhance water absorption and reduce runoff.
- Policy Changes: Advocating for limits on development in flood-prone areas and revising regulations to enhance flood resilience.

Local Government Support

- Requests for financial assistance, education on flood insurance, and better emergency management systems.
- Desire for transparent and frequent communication regarding flood risks and preparedness.

Environmental Justice and Equity

- Communities with historically underserved populations, like Coatesville and Modena, emphasized the need for prioritized attention and funding to address systemic neglect and compounding impacts of flooding.

Broader Concerns

- Calls to leverage learnings from other regions affected by floods.
- Persistent concerns over debris management and restoration of damaged infrastructure and ecosystems.

The feedback underlines the interconnectedness of individual, community, and systemic responses in addressing flooding challenges, with strong advocacy for collaborative, equitable, and environmentally sustainable solutions.

5.3. Public Outreach Events

In addition to individual municipal meetings and a series of public meetings across the watershed, passive communication of this study was being conducted concurrently at 35 partner events in order to engage with over 1,000 individuals throughout the bi-state region (Table 5.2). Methods of communication included general attendance and promotion, presentations, flyers, QR codes, active tabling, focused meetings and targeted discussion regarding the Brandywine Flood Study and access to the Public Survey and Interactive Flood Map.

Table 5.2 Partner events for the Brandywine Flood Study outreach

Partner Events	Location	Date
PSATS Stormwater Conference	King of Prussia, PA	11/13-14/2024
FEMA Delaware River Climate Practitioners Workshop	Philadelphia, PA	10/28/2024
Chester County Water Resources Authority Stormwater Summit	South Coatesville, PA	10/11/2024
Chester County Planning Commission Planners' Forum	West Chester, PA	10/2/2024
Delaware River Watershed Forum	Bethlehem, PA	09/27/2024
PWEA Pennsylvania Stormwater Summit	King of Prussia, PA	09/26/2024
University of Pennsylvania, Sustainability & Environmental Planning	Philadelphia, PA	02/27/2024
Christina Watershed Municipal Partnership Member Meeting	Downingtown, PA	11/15/2024
Pop-up Trailside Tabling	First State National Historic Park, Wilmington, DE	08/3/2024
Pop-up Trailside Tabling	Brandywine Museum of Art, Chadds Ford, PA	07/19/2024
Upper Uwchlan Township	Chester Springs, PA	06/29/2024
Trail Blazer 5k Run	Children's Country Week Association - Paradise Farm Camps, East Bradford, PA	06/6/2024
Chester County Walking Dam Tours	Struble Dam (Honey Brook, PA), Hibernia Dam (West Caln), Barneston Dam, (Wallace, PA)	May and June 2024
Delaware County Sustainability Conference	Widener University, Chester, PA	05/30/2024
Brandywine Creek Greenway Regional Roundtable	Valley Township, PA	05/29/2024
Community Fishing Day at Anson B Nixon Park	Kennett Square, PA	05/19/2024
Brandywine Creek Greenway Regional Roundtable	Hagley Museum and Library, Wilmington, DE	05/15/2024

Partner Events	Location	Date
Brandywine Creek Greenway Regional Roundtable	West Bradford, PA	05/10/2024
Chester County Watershed Roundtable	Chester County Government Services Center, West Chester, PA	05/3/2024
Chadds Ford Township Meeting	Chadds Ford, PA	04/29/2024
City of Wilmington Earth Day Celebration 2024	Wilmington, DE	04/19/2024
Downingtown Resilience Fund Meeting	Belfor Property Restoration, Exton, PA	04/18/2024
West Chester University, PLN Studio Guest Lecture	Business of Public Management Center, West Chester, PA	04/8/2024
WeConservePA 2024 Pennsylvania Land Conservation Conference	Bethlehem, PA	04/3/2024-04/5/2024
Uwchlan Township	Exton, PA	03/8/2024
Christina Watershed Municipal Partnership Member Meeting	Northbrook Marketplace, Pocopson, PA	01/19/2024
Unionville Community Fair 2023	East Marlborough, PA	10/14-15/2023
Downingtown Flood Study Committee Meeting	Downingtown, PA	10/12/2023, 11/9/2023, 12/14/2023
Delaware River Watershed Forum	Wilmington, PA	09/28-29/2023
Delaware Nature Society's Monarch Migration Celebration 2023	DuPont Environmental Education Center, Wilmington, DE	09/16/2023
Chester County Water Resources Authority Stormwater Summit	Virtual Meeting (Zoom)	09/15/2023

5.4. Flood Study Website

The project team launched a website in coordination with the study kick-off on August 22, 2023. It has been an essential tool for keeping partners and the public informed and updated throughout the study. The Brandywine Flood Study website (www.brandywine.org/conservancy/brandywine-flood-study) (Appendix 7) includes:

- the study's geography
- project goals and timeline
- key partners
- links to the Public Input Survey and the Interactive Flood Map
- frequently asked questions (FAQs)
- link to the Flood Study Communications Toolkit
- previous and upcoming public meetings
- list of funders

The Flood Study Communications Toolkit includes everything that partners and the public may need to promote and increase engagement with the study from residents and on social media. This Toolkit includes a general information flyer, a flood study survey flyer with a QR code that links directly to the survey, a sample flood study article, and flood study graphics including partner logos and a geographic coverage map. Sample promotional language is included for sharing the public input survey, the Interactive Flood Map and the Brandywine Flood Study on social media, websites, email communications, and in virtual presentations.

5.5. Public Survey

A 22-question survey was distributed by partners in public platforms such as Facebook, the Brandywine Flood Study website, five public meetings, and 35 public outreach events. The survey garnered 175 responses, and select questions were extracted and developed into posters for interaction with attendees at the public meetings. The survey results are included in the report's appendices (Appendix 6).

Results from both Pennsylvania and Delaware were collected, with participants offering additional comments on site-specific flooding and general flood impacts.

Survey Analysis:

Based on the 175 individual survey responses, an overwhelming majority (95%) voiced their concern about increased frequency and/or intensity of future flooding. The majority of survey participants (86%) responded that they consider flooding an issue and experience it personally multiple times a year (70%). This greatly affects their ability to travel for work, recreation, entertainment and essential services (79%), with work, travel and home being most impacted by the effects of flooding.

Participants reported that they are more likely to experience detrimental flooding impacts to their residence, business and ability to travel in the summer (29%) and fall (32%), than in the spring (23%) or winter (15%). Flooding to road infrastructure, temporary and short-term travel delays were the most commonly experienced flood impacts. However, 26% of participants experienced damage to their residences and 37% experienced damage to other private property such as vehicles, landscaping, boats and other personal property. More than half (51%) of the survey participants experienced property damage due to flooding, but only 28% reported having flood insurance. More than 66% of participants experienced some degree of financial losses due to flooding. While 25% responded that they only experienced losses valued under $500, 31% were affected by financial losses from $25,000 to more than $100,000 in valued assets and repair costs for flood damages.

Survey respondents felt the areas of greatest vulnerability to flooding were public infrastructure (roads, bridges, culverts, stormwater retention and public water systems) (86%), private and public property (81%), and the risk of injury and loss of life being a concern (62%) by participants.

Participants mostly reported living in single family homeowners with small to medium household sizes (1-5 residents per location). While most use their smartphone weather app and online weather services for information on flood and other weather-related incidents, the majority (88%) of respondents were willing to sign up for flood alert systems in their state, county or municipality.

The flood mitigation projects that were most supported by survey participants for implementation were as follows:

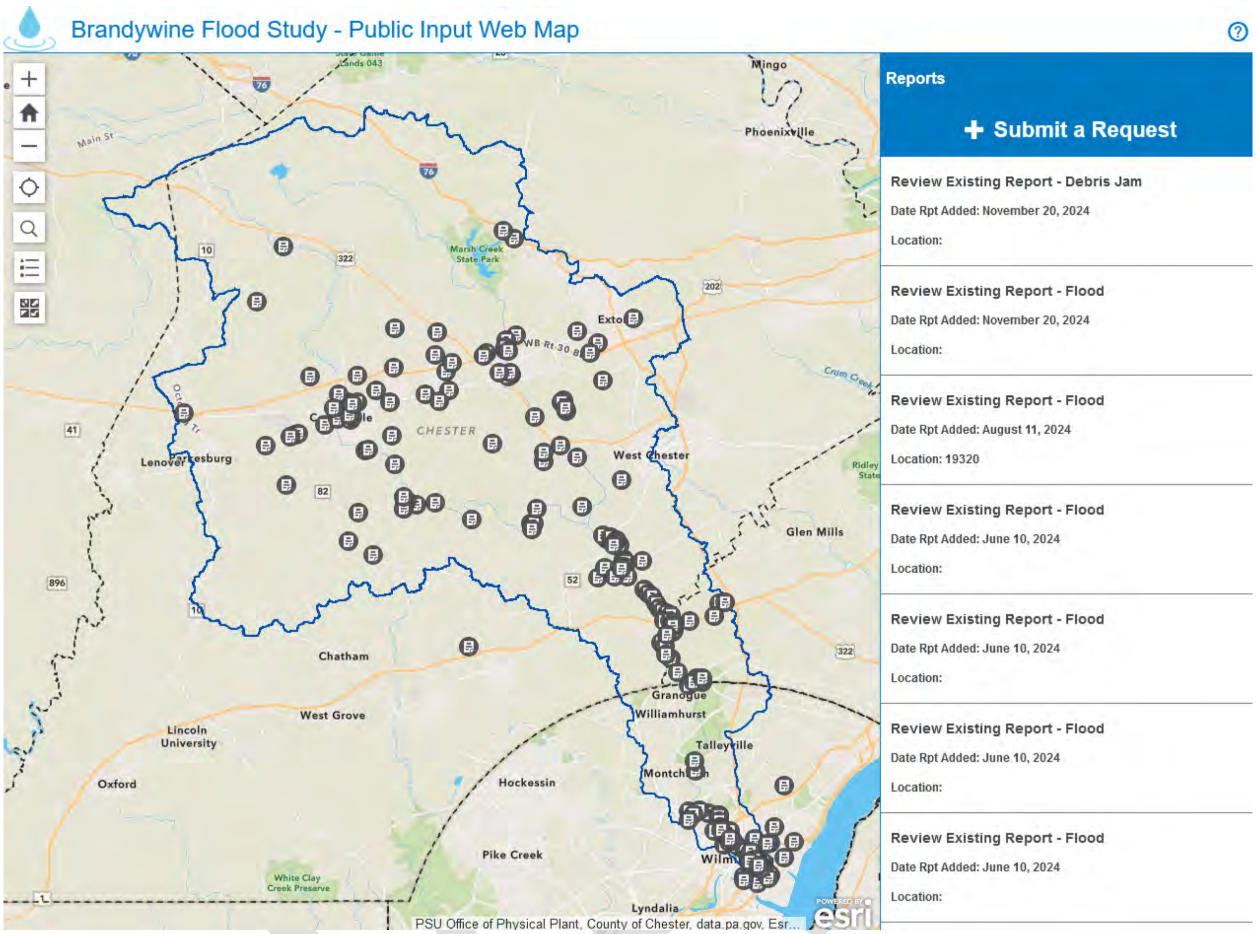
- 81% - Limiting development in flood prone areas
- 67% - Rain gardens/basin, bioswales, permeable pavements, native plantings and shade trees, green roofing, etc.
- 60% - Correct sizing of bridges and culverts
- 56% - Planting trees along streams

Eighty-two percent of the respondents supported the States of Pennsylvania and Delaware allocating more funds through state budgets for flood control projects to be developed and constructed by local water management authorities. Those that did not support this allocation of funds offered comments regarding the rate of development, referencing flood control as a federal duty to fund, and concern about lack of information or mismanagement of funds. Forty-one percent of the participants were willing to pay more in property tax or assessments for additional flood control measures in their area, but 20% were not willing to pay more, with 38% responding, “Not Sure.” When presented with additional options for funding flood control, 34% supported a stormwater fee, while 26% supported utilizing existing funds. Many participants responded that they needed additional information about the existing budget allocations to make an informed decision about possible flood control spending. Additional methods of financial support for flood controls were offered such as increased taxes and fees on development, grants, fundraising, as well as allocating federal, state and county funds.

5.6. Interactive Flood Map

The Interactive Public Input Web Map , available on the Brandywine Flood Study website, provides an interactive platform for community members to report and view flood-related issues in the Brandywine watershed. Users can mark locations of concern, such as flood damage, infrastructure problems, or environmental impacts, on a shared map (Figure 5.1). Users can also directly add photos, videos and comments to the locations marked. This tool encourages collaboration and transparency by integrating public observations into the flood study, helping prioritize mitigation efforts (Appendix 6).

All results from the Interactive Flood Map were compiled into an Excel spreadsheet and categorized by municipality (or by county in Delaware). Over 190 data points were recorded through the mapping tool, reflecting input from 22 municipalities across the Brandywine Creek Watershed. Most concerns were concentrated in Wilmington, Delaware, where Hurricane Ida caused significant damage, with Chadds Ford Township ranking second due to similarly severe impacts.



Brandywine Flood Study - Public Input Web Map

Reports

+ Submit a Request

Review Existing Report - Debris Jam
Date Rpt Added: November 20, 2024
Location:

Review Existing Report - Flood
Date Rpt Added: November 20, 2024
Location:

Review Existing Report - Flood
Date Rpt Added: August 11, 2024
Location: 19320

Review Existing Report - Flood
Date Rpt Added: June 10, 2024
Location:

Review Existing Report - Flood
Date Rpt Added: June 10, 2024
Location:

Review Existing Report - Flood
Date Rpt Added: June 10, 2024
Location:

Review Existing Report - Flood
Date Rpt Added: June 10, 2024
Location:

Figure 5.1 View of Public Interactive Web Mapping Tool

5.7. Public Engagement Efforts and Feedback

Through vigorous and sustained efforts to engage the public and gain insight into localized flooding impacts, this study engaged with over 1,500 individuals to gather public input across all mediums. All findings from the public engagement efforts are included in the study's appendices (Appendix 6). A summary of selected public comments by prominent themes is included below.

Communication and Safety

- Increased local notification systems and frequency of notifications before and during severe precipitation events.
- Uniform, simplified messaging about flood forecasts, risks, etc.
- More tools to make historical and projected flood information available, meaningful, and actionable for the general public.
- Additional support to emergency services to assist vehicles in unsafe flood situations.
- Additional and more rapid installation of barricades, signage, and communication prior to and during flood events of blocked or closed roadways.

"I found ReadyChesCo to be a valuable resource for getting updates and communications particularly in regards to flood prediction and extreme weather. I would like to encourage DelCo to deploy a similar system."

Structural Solutions

- Green stormwater infrastructure installed where impervious surfaces cannot be removed (roadways and existing development), coupled with education, signage and green stormwater infrastructure and landscaping installation guides for home and business owners.
- Ensuring disadvantaged communities are not left behind in future flood mitigation efforts.
- Evaluation and repair of municipal stormwater and sewer infrastructure systems.
- Evaluation, repair, and retrofits made to roadways, bridges and culverts that experience frequent flooding.

"Storm water management must include adequate, functioning stormwater retention basins."

Non-Structural Solutions

- Additional municipal comprehensive planning and required review of stormwater management plans with each development application.
- Prioritization of open space preservation in headwater regions as well as flood prone areas.
- Addition of flood-specific zoning ordinances and ensure compliance from proposed and existing development.

"Can we require developer regulations to be more stringent than the current 100-year flood maps?"

5.8. Advisory Committee

An Advisory Committee was assembled at the start of the project, open to anyone interested, and regularly attended by representatives and specialists from the following organizations, in addition to study partners:

- 2nd Century Alliance
- Arcadis
- Brandywine Red Clay Creek Alliance
- Brandywine River Restoration Trust
- Center for Watershed Protection
- Chadds Ford Township
- Chester County Conservation District
- Chester County Department of Emergency Services
- Chester County Planning Commission
- Christina Watershed Municipal Partnership
- Christina-Brandywine River Remediation Restoration Resilience
- City of Coatesville
- City of Wilmington
- Coalition of Delaware River Watershed
- Collaborate Northeast
- Delaware County Department of Emergency Services
- Delaware County Heritage Commission
- Delaware County Planning Commission
- Delaware Department of Natural Resources and Environmental Control
- Delaware Geologic Survey
- Delaware Nature Society
- Delaware Sea Grant
- Delaware State Parks
- Downingtown Borough
- Downingtown Flood Advisory Committee
- Eleventh Street Bridge Community Long-Term Recovery Group
- Gaadt Perspectives
- Gannett Fleming
- Greater Wilmington Housing Providers
- Green Building United
- Hagley Museum and Library
- Kirkwood Community Center
- Municipal Emergency Management Coordinators
- Municipal Public Works Directors
- National Oceanic and Atmospheric Administration
- National Park Service
- Natural Resources Conservation Service of Pennsylvania and Delaware
- Partnership for the Delaware Estuary
- Pennsbury Township
- Pennsylvania Department of Conservation and Natural Resources
- Pennsylvania State Parks
- Perkiomen Mapping & Flood Mitigation Study for Pennsylvania Representative Joe Webster
- Private and Public Water Providers
- The Nature Conservancy of Pennsylvania and Delaware
- United States Geological Survey (USGS)
- University of Delaware Institute for Public Administration
- USDA Pennsylvania Natural Resources Conservation Service
- West Chester University- Hydrogeology Department
- Wilmington Area Planning Council

The Advisory Committee participants were engaged in their capacity as technical experts and stakeholders. At each of the six meetings, technical and outreach updates were presented regarding the study process. Advisory Committee meetings were held October 4, 2023; December 4, 2023; February 13, 2024; April 3, 2024; May 14, 2024; and September 23, 2024, with more to be held for the report draft review.

An in-person Advisory Committee workshop was held on May 14, 2024, at Stroud Water Research Center. The workshop was opened with brief technical and outreach updates. Following the updates the attendees were divided into five groups, each group focused on the following themes: Communications, Non-Structural Solutions, Structural Solutions, Build-Out Scenarios, Related Studies and Solutions. Based on the key themes, the following key comments provided by the participants include:

Communication

- Communication challenges and demographic-specific solutions.
- Importance of unified messaging at all scales.
- Provide the public with specific, relatable scenarios on what they can expect from different types of storms and flood events in the future.
- Increased awareness and engagement in state, county and local emergency alert systems.
- Public concerns about reducing local flooding but increasing downstream flooding through dam removal.
- Increased education and efforts regarding dam removal, bridge replacement, floodplain, levee setbacks, stormwater infrastructure.
- Dam safety and maintenance are important to limit the potential for catastrophic failure during flood events, with less current regulation in Delaware than Pennsylvania.

Non-Structural Solutions

- Understanding the pace of preservation and effects of current preservation efforts.
- Preservation funding, costs and prioritization processes.
- Regulatory recommendations towards timber harvesting and slope ordinances.
- Can we use Municipal Separate Storm Sewer System (MS4) and Pollution Reduction Plan (PRP) to identify opportunities for potential projects?
- Identify non-floodplain tributary storage and how to attenuate smaller tributaries?
- Identifying opportunities within floodplains for increased storage capacity through naturalized solutions, increased habitat and carbon storage

Structural Solutions

- Prioritization of flood mitigation in disadvantaged communities.
- Cost/benefit analysis for stormwater best management practices.
- Cost of relocation of populations out of floodplains.
- Site-specific recommendations in Downingtown, Coatesville, Chadds Ford and Wilmington.

Build-Out Scenarios

- Review and improvements of Build-Out Scenario Tool to best identify areas of the greatest amount of development potential.
- Encourage town centers and urban areas for redevelopment to utilize existing impervious coverage.
- The important role that mature forests play in flood mitigation, and the importance of preservation in the headwater areas.
- De-paving incentivization program and education regarding maintenance of impervious surfaces.

Related Studies and Solutions

- *Plan for Restoring Wilmington's Rivers* (2023) – Christina-Brandywine River Remediation Restoration Resilience (CBR4) is an initiative to address legacy toxic contamination, restore the native ecology and prepare for the changing climate as well as other threats to river health in the lower Christina River and tidal Brandywine River.
- *Gibbons Run Culvert Study* – Comprehensive evaluation of the Gibbons Run Culvert system, including evaluation of existing system's flow capacity, development of conceptual plans to redirect flow away from the Gibbons Run system, and video survey, conducted by Cedarville Engineering Group for the City of Coatesville, Pennsylvania.
- *Lower Brandywine Flood Study* – This study focuses on the flooding in communities on the Brandywine in Wilmington, Delaware. This study will identify flood risks and vulnerable areas with community participation. The outcome of this study will be to draft flood relief strategies for implementation and publish a cost-benefit analysis for these strategies. This study is being conducted by the City of Wilmington and the University of Delaware Water Resources Center.
- *Community Rewilding on the Brandywine* – This study, led by the University of Delaware, Green Building United, and Northeast Rising, focused on flooding in communities directly northeast of Brandywine Creek in Wilmington, Delaware. As part of this effort, a Community Coalition was formed to give residents a direct voice to impact flood relief strategies in the neighborhoods adjacent to 11th Street and Northeast Boulevard. The study was made possible by National Fish and Wildlife Foundation funding awarded to Green Building United and included the University of Delaware's living shoreline study at the 11th Street Bridge, green asset mapping in the area by graduate students, and support to Northeast Rising. As a result, a climate education and outreach program was developed, and flood relief strategies were selected by residents for implementation, including a bioswale and rain garden at Johnston Playground. The community leadership team and coalition provided programming around nature-based experiences, community meetings and workshops, and engagement with decision makers including the City of Wilmington. A Northeast Community Emergency Response Training team has emerged out of this programming, spearheaded by a longstanding community leader and Northeast Rising ambassador. This study was conducted by the University of Delaware in partnership with Green Building United and Northeast Rising.
- *Delaware Department of Natural Resource and Environmental Control (DNREC) Composite Flood Risk Analysis* – This technical pilot study is focused on the flooding in communities of Northeast

and South Wilmington, Delaware to identify the combined flood risk from coastal, riverine, and urban stormwater runoff, identify flood sites within Environmental Justice Areas and update non-regulatory flood prediction maps. A technical report and mapping layers will be published in Winter 2025, to be included in the Flood Planning Tool on DNREC's website. Funded by FEMA, this study is being conducted by the Delaware Department of Natural Resources and Environmental Control in partnership with WSP USA Environment & Infrastructure Solutions, Inc. This study is in coordination with the Lower Brandywine Study with participation from the City of Wilmington.

5.9. Municipal Reports

A thorough outreach effort was conducted to all municipalities within the Brandywine Watershed. Dozens of municipalities were engaged, which included flood study partners meeting with municipal staff from multiple departments, including executive and legislative officials, directors of public works, directors of emergency services and engineers. Outreach meetings were conducted from September 2023 through December 2024. Meetings included a set of guiding questions regarding specific impacts and locations of flooding in order to identify potential solutions. This included road closures and evacuation routes, existing stormwater basins and infrastructure issues such as planned or expected retrofitting of culverts, bridges and roadways. Emergency notification systems were identified, as well as popular methods of municipal communication such as email, text or social media alerts and newsletters for residents. In addition to reviewing current MS4 projects within the municipality, many municipalities had items listed within the Chester County's Hazard Mitigation Plan, which was reviewed, and the statuses of all flood-related projects were updated. Active or recently completed flood and restoration projects were identified and long-term flood resiliency, potential climate mitigation plans, and conservation easements were discussed.

Municipalities engaged in the planning process which resulted in the municipal inventory and assessment detained in the Appendix 1 from the following municipalities:

Birmingham Township
Caln Township
Chadds Ford Township
City of Coatesville
Borough of Downingtown
East Bradford Township
East Brandywine Township
East Caln Township
East Marlborough Township
East Nantmeal Township
Highland Township
Honey Brook Borough
Honey Brook Township
Modena Borough
Parkesburg Borough
Pennsbury Township
Pocopson Township
Sadsbury Township
Thornbury Township
Upper Uwchlan Township
Uwchlan Township
Valley Township
West Bradford Township
West Brandywine Township
West Marlborough Township
West Whiteland Township
Wallace Township

The feedback collected throughout the planning process underlines the interconnectedness of individual, community, and systemic responses in addressing flooding challenges. It also highlights the public's desire for collaborative, cost-effective, and environmentally sustainable solutions.

Chapter 6 Structural Recommendations

6.1 Overview

To address the scope and breadth of flooding challenges in the Brandywine Watershed, a variety of structural solutions are necessary. Potential solutions vary in terms of scale, complexity, capacity, and expense, but each can play a role in mitigating the impacts of flooding in local communities.

This section outlines the importance of structural approaches to community flood mitigation efforts. Once in place, structural solutions typically provide relatively immediate relief from flood risk to both people and property by physically manipulating the way water moves through the landscape. However, it is important to note that many of the structural solutions described here must be considered in terms of their potential impacts both up and downstream to consider whether alleviation of flooding in one community will not exacerbate flooding in another.

The types of structural flood mitigation projects considered in this study include:

- Floodplain restoration
- Flood mitigation dry ponds
- Replacement, rehabilitation, or removal of bridges, culverts, or dams
- Modifications to existing flood control facilities and reservoirs
- Stormwater basin retrofits

Potential flood mitigation strategies were identified in each of the categories listed above. Generally, flood storage capacity and peak flow rate reduction were the primary factors that determined the study's recommendation for each project. Each category of structural solutions incorporated additional evaluation criteria. The details for the project sites investigated are further discussed in the sections below. Additional local stormwater mitigation measures are recommended, however initial analyses were not included in this study.

6.2 Floodplain Restoration

Floodplains are nature's buffer zones between waterways and adjacent lands. They provide space for streams to rise and spread out of their channels, naturally slowing and storing flood waters. They also offer numerous other ecological benefits, including wildlife habitat, pollution filtering, and carbon sequestration. However, development in and around floodplains over the past hundred years has greatly compromised their functionality.

Plum Run in the lower Brandywine Creek watershed prior to restoration (photo courtesy of the Brandywine Red Clay Alliance)

Plum Run after restoration by the Brandywine Red Clay Alliance in 2021 (photo courtesy of the Brandywine Red Clay Alliance)

The HEC-RAS models, discussed in Chapter 3, were utilized to identify relatively flat and wide floodplain areas that attenuate the flood waters along stream reaches, providing substantial flood storage. Along the 52.5 miles of the Brandywine and its tributaries, the floodplain area has 16.5 billion gallons of storage capacity (See Table 6.1).

From the mouth of the Brandywine for 6 miles up to Hagley where the Brandywine rises steeply above the fall line in the river canyon, the floodplain provides less storage with an estimated storage of 244 million gallons per stream mile (mg/mi). As the river flattens out upstream in the Piedmiont, the mainstem of the Brandywine in Delaware upstream from Hagley and in Pennsylvania from the arc boundary up to Lenape Park provides significant floodplain storage of 440 to 450 MG/mi with lesser storage provided in the East Branch (205 MG/mi) and West Branch (302 MG/mi).

Table 6.1 Floodplain Storage in the Brandywine Watershed

Reach	Min Ch El	W.S. Elev	Depth	Velocity	Width	Volume	Vol/mi	Reach
	(ft)	(ft)	(ft)	(fps)	(ft)	(million gal)	(mg/mi)	(mi)
Mainstem Brandywine Del.						2,700	450	6.0
Mouth to Rising Sun Lane Br.	72.0	95.2	14.7	9.2	349	854	244	3.5
Mainstem Brandywine Pa.	171.0	188.6	17.6	4.4	784	4,270	440	9.7
East Branch Brandywine Pa.	593.6	596.9	3.3	5.3	30	2,972	205	14.5
West Branch Brandywine Pa.	428.0					5,684	302	18.8
						16,480	**314**	**52.5**

Floodplain restoration may be implemented for ecological benefits, such as increased nutrient exchange, erosion decreases, and water quality improvement, and provide retention of water during flood events, reducing localized flooding impacts. The project team identified potential floodplain restoration sites and developed hydraulic models to assess these locations in the Brandywine Creek watershed. Hydraulic analyses were performed using the two-dimensional (2D) capabilities USACE's HEC-RAS model. Where available, the models used bathymetry data, bridge and dam geometry from FEMA effective HEC-RAS models. At these sites, the terrain of the floodplain areas were lowered to increase overbank flooding.

Table 6.2 shows findings from initial analyses at these project sites. Factors used to determine potentially viable projects included existing upstream structures, estimated cost of grading and hauling floodplain material, and downstream peak flow and volume reduction estimates. Detailed results for each site can be found in Appendix 8.

Table 6.2 Initial Analysis of Potential Floodplain Restoration Sites

Site	Municipality	Watershed	Concept	Determination
Brandywine Conservancy properties	Chadds Ford Township, PA	Brandywine Creek	Floodplain restoration/ Legacy dam removal	Recommended

Mary Street Riparian Corridor	Downingtown Borough, PA	Beaver Creek	Floodplain/ Streambank restoration	Further analysis recommended
Valley Run/Beaver Creek Confluence	Caln Township, PA	Beaver Creek	Floodplain/ Stream restoration	Further analysis recommended
Brandywine Picnic Park	East Bradford and Birmingham Townships, PA	Brandywine Creek (mainstem)	Floodplain restoration/ Storage capacity improvements	Not recommended - minimal impact
Johnsontown Park	Downingtown Borough, PA	East Branch Brandywine	Floodplain/ Streambank restoration	Not recommended - minimal impact
Parkside Soccer Fields	Downingtown Borough, PA	East Branch Brandywine	Floodplain/ Streambank restoration	Not recommended - minimal impact
Manor Road/Kings Highway	City of Coatesville, PA	West Branch Brandywine	Floodplain restoration/Storage capacity improvements	Not recommended - minimal impact

6.3 Flood Mitigation Dry Ponds

Dry ponds, or detention basins, can detain flood waters to reduce peak flow rates. Typically for stormwater management, these basins capture water from storm events and then release water slowly to a stream or other waterbody or into the stormwater drainage system.

A dry basin can capture and detain stormwater runoff to delay much of the runoff from reaching the stream during the rain event.

Several potential dry pond sites were identified and analyzed to determine their effectiveness for flood benefits. Table 6.3 summarizes the results from initial analyses at these sites. Details for each site can be found in Appendix 8.

Table 6.3 Initial Analysis of Potential Flood Mitigation Dry Ponds

Site	Municipality	Watershed	Concept	Determination
Chester County Public Safety Training Campus	South Coatesville	West Branch Brandywine	Flood storage capacity improvements	Not recommended - minimal impact
Ingleside Golf Course	Caln	Beaver Creek	Flood storage capacity improvements	Not recommended - minimal impact
Route 113 clover leaf	Downingtown/ East Caln	Beaver Creek	Flood storage capacity improvements	Not recommended - minimal impact
Paradise Valley Nature Area	East Bradford	Valley Creek	Flood storage capacity improvements/ diversion	Not recommended - minimal impact
East Fallowfield Park	East Fallowfield	Dennis Run	Flood storage capacity improvements	Not recommended - minimal impact
West Branch near Valley Station Road	Coatesville	West Branch Brandywine	Dry dam/flood storage capacity improvements	Not recommended - minimal impact
Buck Run near Laurel Forge Road	Newlin	Buck Run	Dry dam/flood storage capacity improvements	Not recommended - infeasible

6.4 Evaluation of Existing Flood Control Facilities

Historic floods along the Brandywine in the first half of the 20th century drove initial flood control strategies identified in the Brandywine Watershed Work Plan. Beginning in the 1950's, the Brandywine Creek Watershed Work Plan included 12 flood control projects and other conservation measures:

- Seven multi-purpose reservoirs (five for both flood control and water supply)
- Five flood control only projects
- Forested and agricultural actions to increase infiltration and reduce sedimentation

Chambers Lake/Hibernia Dam at Hibernia County Park in West Caln Township is a multi-purpose dam that provides flood control, water supplies and recreation.

After several amendments to the Plan, only five projects were constructed in the Upper Brandywine Watershed between 1970-1994:

1. Struble Dam - Flood Control, Fishing
2. Barneston Dam - Flood Control
3. Marsh Creek Dam - Water Supply, Flood Control, Recreation, Flow Augmentation
4. Beaver Creek Dam - Flood Control
5. Chambers Lake/Hibernia Dam on Birch Run - Water Supply, Flood Control, Recreation

This study conducted an initial assessment of additional flood storage potential at these five existing dams. Beaver Creek Dam and Chambers Lake/Hibernia Dam completed rehabilitation projects to meet current Pennsylvania Dam Safety standards in 2020 and 2022, respectively, and as the dams currently restrict discharge up to the 100-year storm, additional modifications to the structures were not identified during this study.

Beaver Creek Dam – Change of Operation to Provide Additional Flood Storage

Beaver Creek Dam was operated from 1992 to 2020 with an impoundment of approximately 7.2 million gallons within an 11-acre sediment pool. During rehabilitation work on the dam from 2021 to 2022, the reservoir was drained. As of 2024, CCWRA has submitted an application to PADEP to change the official operation of Beaver Creek Dam to a dry dam. This change in operation to a dry dam will provide additional flood storage upstream of the dam embankment where the normal impoundment has been dewatered. The change in operation also provides environmental benefits for wetlands and native wildlife habitat.

Beaver Creek Dam in East Brandywine Township previously had a normal impoundment with approximately 7.2 million gallons. August 24, 2020.

Beaver Creek Dam is proposed to operate as a dry dam following a completed rehabilitation project in 2022 which will provide additional flood storage, October 3, 2024.

Barneston Dam Rehabilitation

Barneston Dam, one of the five flood control dams in the Upper Brandywine Creek watershed, is located in Wallace Township across the East Branch Brandywine Creek. The dam was built in 1983 by CCWRA and USDA Soil Conservation Service, now the Natural Resources Conservation Service (NRCS). Barneston Dam is owned and operated by CCWRA and provides flood protection for residents in Chester County.

- **Current Conditions and Capacity** - Barneston Dam is 43 feet high and is maintained as a “dry” dam, which means there is no lake or impoundment behind the dam during normal, sunny days. However, the dam detains flood waters flowing to the upper portion of East Branch Brandywine Creek during storm events that drain are constricted by the small size of the culvert spillway at Barneston Dam. This principal spillway is a four foot by four foot box culvert at the same elevation as the stream.

  The dam has two additional spillways, a 240-feet wide concrete drop spillway approximately 33.5 feet above the stream, and a vegetated auxiliary spillway that is 39.5 feet above the stream. The flood storage pool to the crest of the concrete drop spillway is approximately 1,520 acre-feet (or 495 million gallons). From 1983 through 2024, there has never been any flow through these overflow spillways – all flood waters have been detained and routed through the four feet by four feet box spillway.

  Barneston Dam in Wallace Township on the East Branch Brandywine Creek is a dry dam with a standard weir control on the auxiliary spillway, August 10, 2018.

- **Potential Rehabilitation to Increase Flood Storage** - An initial engineering review and modeling evaluation identified an opportunity to reconstruct the 240-feet wide concrete drop spillway with a labyrinth weir with can provide additional flood storage between the 50-year and 100-

year storm. By modifying the concrete drop spillway, the elevation of the weir may be elevated by a few feet to provide additional storage for large storms while still meeting state and federal regulations for dam safety. While Barneston Dam will remain a dry dam, this type of spillway modification may provide additional flood storage at Barneston Dam for storms between the 50-year and 500-year events.

A labyrinth weir constructed at Lake Williams Dam in York, PA. Photo courtesy of Gannett Fleming.

Initial modeling for a spillway modification estimates that the peak flow for a 100-year event would be reduced by 66% from 1,297 cfs with the existing drop structure to 435 cfs with the assumed labyrinth weir spillway structure (Table 6.4). This reduction of 860 cfs accounts for approximately 12.4% of the peak flow estimated at the USGS stream gage on Dowlin Forge Road north of Downingtown Borough. An 860 cfs reduction in discharge would reduce the magnitude of the 100-year event down to that of approximately a 60-year event. The peak flow for a 500-year event would be reduced by 1,100 cfs from 2,229 cfs with the existing drop structure to 1,080 cfs with the assumed labyrinth weir spillway structure. This reduction accounts for approximately 11.3% of the peak flow estimated near Downingtown. An 1,100 cfs reduction in discharge would reduce the magnitude of the 500-year event down to that of approximately a 310-year event.

Table 6.4 Summary Analysis of Proposed Labyrinth Weir Spillway and Drop Spillway Structure

Parameter	50-year Event	100-year Event	200-year Event	500-year Event	6-hour PMP Event	12-hour PMP Event
Peak Outflow - Existing Drop Spillway (cfs)	598	1,297	2,229	3,871	28,667	29,457
Peak Outflow - Labyrinth Weir Spillway (cfs)	419	435	1,086	2,790	29,569	30,188
Relative Difference in Outflow	-30.1%	-66.5%	-51.3%	-27.9%	3.2%	2.6%

- **Potential Benefit** - The benefit of making this modification is to reduce the flood waters passing through Barneston Dam during very large storm events in the upper East Branch Brandywine Creek watershed. This modification will not reduce flood waters downstream of the dam for smaller storms, such as the 5-year, 10-year or 25-year events. However, for very large storms, between the 50-year, 100-year and 500-year storm events, this modification could either fully control or at least delay any additional flood waters continuing in the East Branch Brandywine Creek.
- **Rehabilitation Process** - Federal legislation, known as the Watershed Protection and Flood Prevention Act (PL-566, authorizes NRCS, who is the federal sponsor for Barneston Dam, to work with local communities and watershed project sponsors to address public health and safety concerns and potential environmental impacts of aging dams. NRCS provides technical and financial assistance in planning, designing, and implementing watershed rehabilitation projects. The first step in a Rehabilitation Project is to conduct a Planning Study to evaluate needs, objectives, and alternatives for potential rehabilitation of the dam.

Review of Other Dams and Reservoirs

Additional review is proposed for dam modification potential and/or operations at Struble Lake, Marsh Creek Reservoir, and Rock Run Reservoir. Struble Dam is owned and operated by CCWRA, while the lake is managed by Pennsylvania Fish and Boat Commission. Marsh Creek Reservoir and Dam are owned and operated by the Pennsylvania Department of Conservation and Natural Resources. Rock Run Reservoir, owned and operated by Pennsylvania American Water Company, is a water supply reservoir. The project team will coordinate with the responsible agencies for review of dam operations.

Under the Brandywine Watershed Work Plan, several flood control projects were not built for various reasons including modifications or combinations of proposed projects, funding, and balancing flood control and water supply uses. Three tributaries in the Brandywine Watershed have been identified as flood prone during this study.

While the Work Plan's proposed Icedale Dam on the upper West Branch was not built and replaced with Chambers Lake/Hibernia Dam. A smaller dam, currently owned by the Pennsylvania Fish and Boat Commission, was constructed on the site. The existing dam has been breached for several years and West Brandywine Township is in the process of replacing the bridge just downstream from the dam. This study has conducted initial assessments of the flood control at the dam, and while no currently viable opportunities were identified, future analysis may be warranted.

Preliminary data collection identifies Sucker Run and Buck Run as flood prone tributaries. Not included as part of this study, further analyses for both tributaries are recommended.

6.5 Bridges, Culverts, and Dams – Stream Crossings

With the abundance of streams in Brandywine Watershed are the numerous bridges, culverts, and dams along the Brandywine and tributaries that may increase water surface elevations during storm events. As the water infrastructure may require replacement or repair due to aging past their useful lives, natural hazard damage, or other factors, it provides opportunities for flood mitigation by evaluating potential to reconstruct inadequately-sized bridges and culverts or detain flood waters.

Utilizing the USDA TR-55 hydrologic model for a range of storm recurrence intervals and the USACOE HEC-RAS hydraulic model to estimate floodplain depth (ft), water surface elevation (ft), velocity (ft/s), width (ft), and volume (ac-ft and mg), this study assessed nearly 300 bridges, culverts, and dams East and West Branches of the Brandywine, and tributaries in Pennsylvania for the 10-, 50-, 100-, and 500-year storm events. These structures may be undersized and unable to convey flows from these storm events. In reality, flood waters may overtop the stream crossings and result in road closures, further impacting emergency services or other obstacles. Remedies to inadequately-sized infrastructure include removing the hydraulic structures or reconstructing them with larger waterway openings, e.g., widening a 20 ft high by 60 ft wide bridge with a wider 100 ft bridge. The HEC-RAS analysis estimated flood elevations for the current elevation of the thalweg, bridge deck, and roadway approach and then assuming the hydraulic structures were either removed or increased in hydraulic opening. The artificial increase in flood elevation is determined by subtracting the existing flood elevation from the proposed, identifying whether these structures attenuate or hold back flood flows. If the flood elevations exceed the bridge deck wind or roadway approaches, it is likely that significant flow passes over the bridge as weir flow and is not attenuating flood flows behind the bridges. Furthermore, flood velocities were estimated from the HEC-RAS model and if flood velocities are high (> 1-2 ft/s), hence, floodwaters are more moving too fast to provide attenuation. Figures 6.1 through 6.7 shows the locations of these structures and indicates whether they are restricting or detaining flood waters.

Figure 6.1 Inadequate Bridges, Culverts, and Dams along the Mainstem Brandywine in Delaware

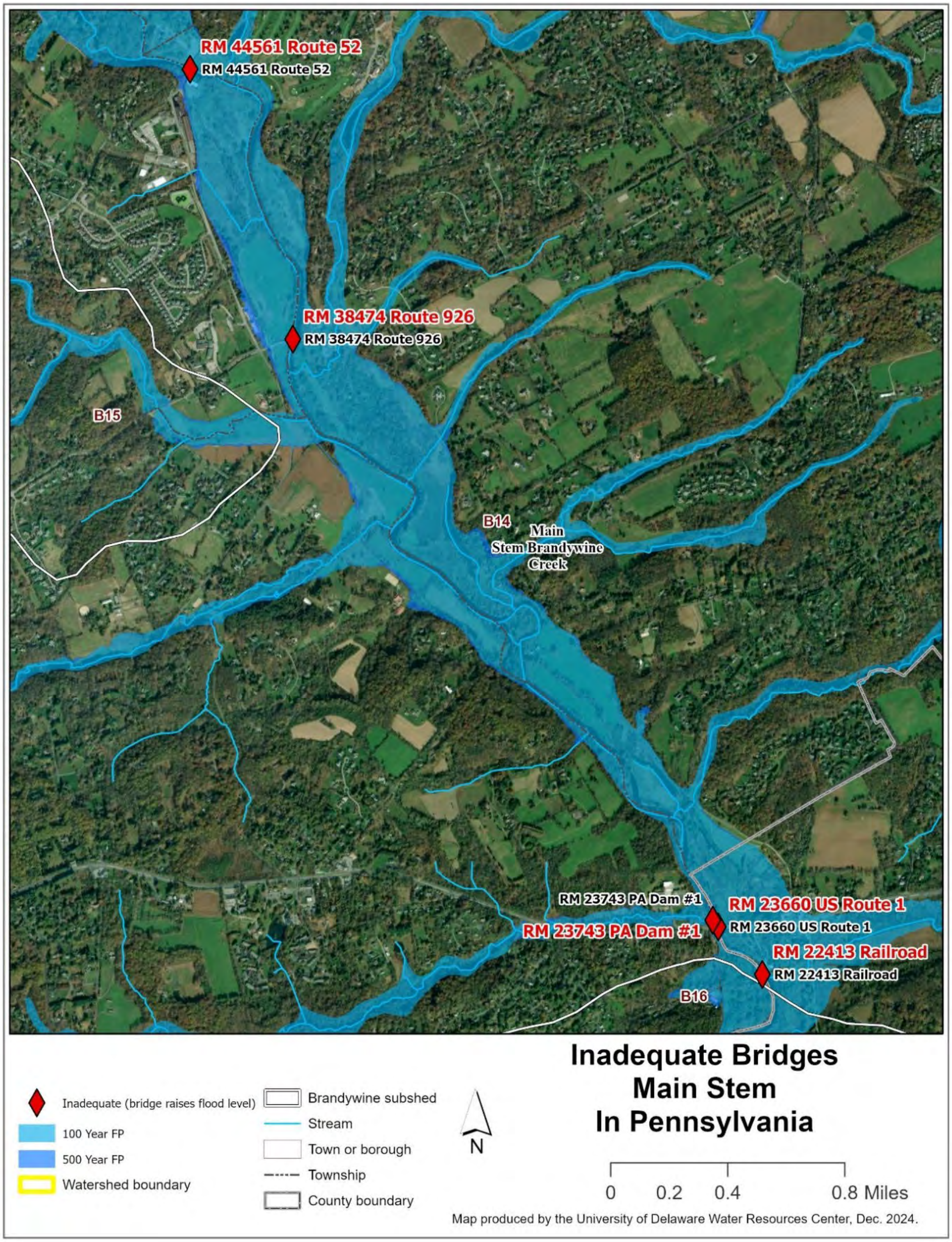


Figure 6.2 Inadequate Bridges, Culverts, and Dams along the Mainstem Brandywine in Pennsylvania

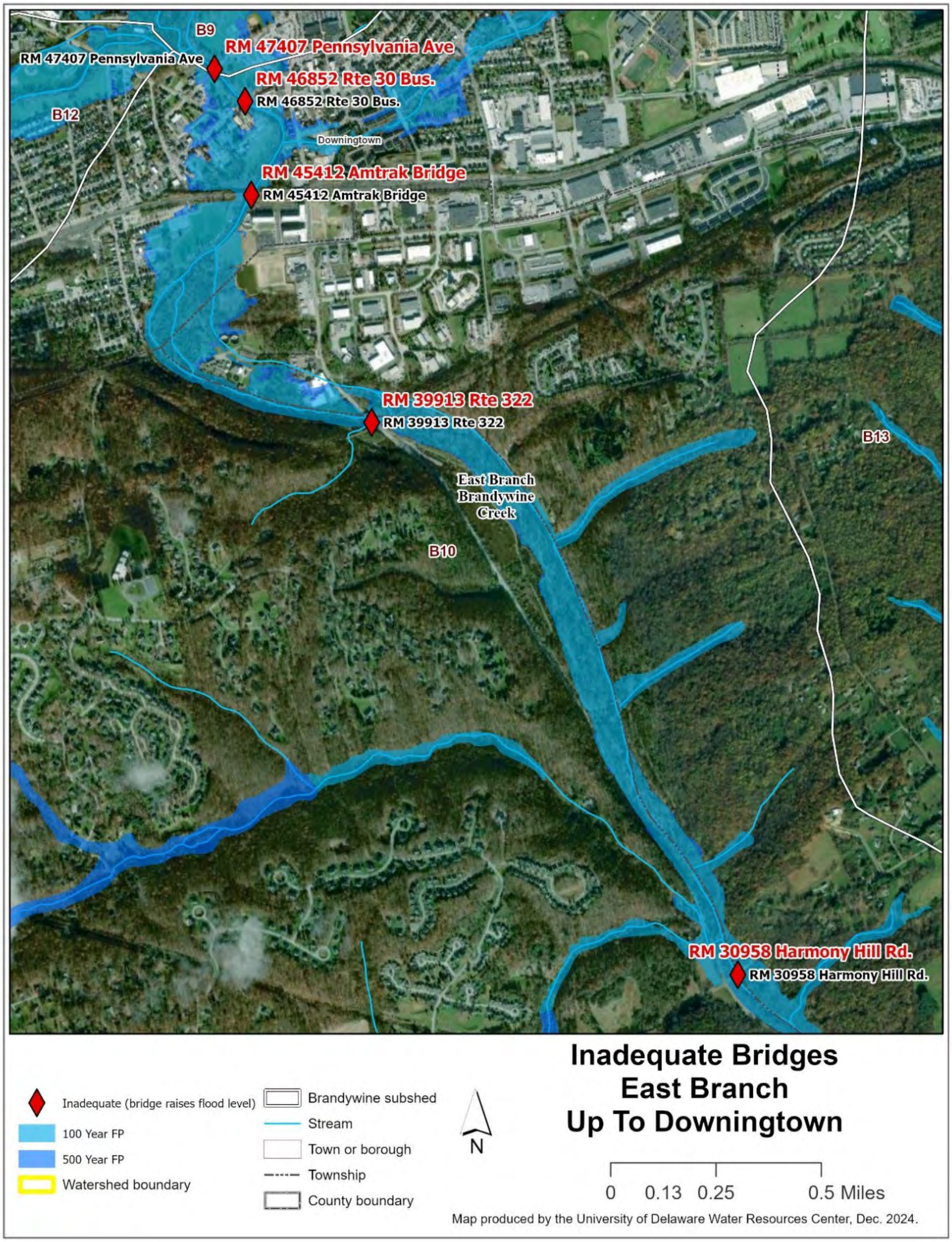


Figure 6.3 Inadequate Bridges, Culverts, and Dams along the East Branch Brandywine Downstream of Downingtown

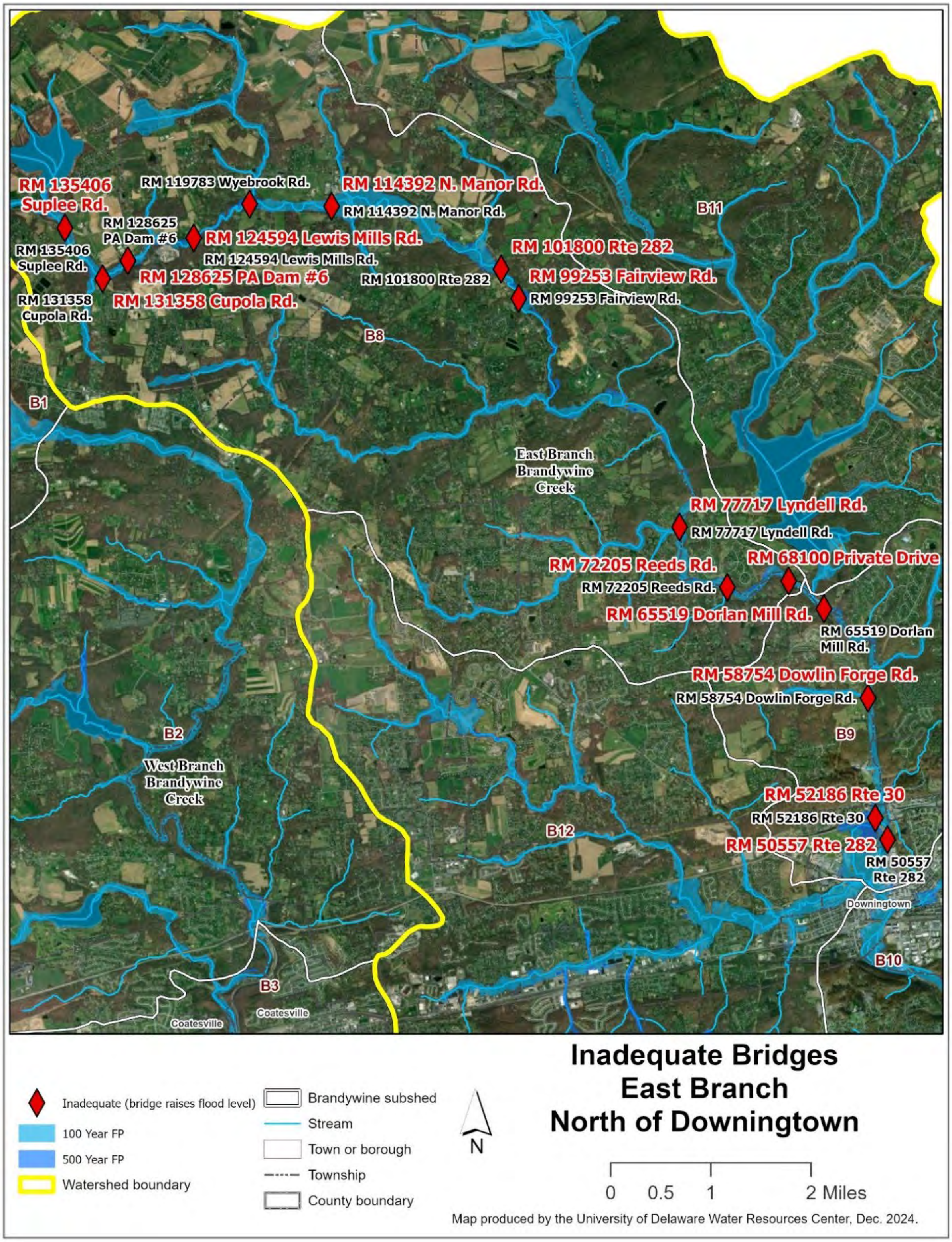


Figure 6.4 Inadequate Bridges, Culverts, and Dams along the East Branch Brandywine North of Downingtown

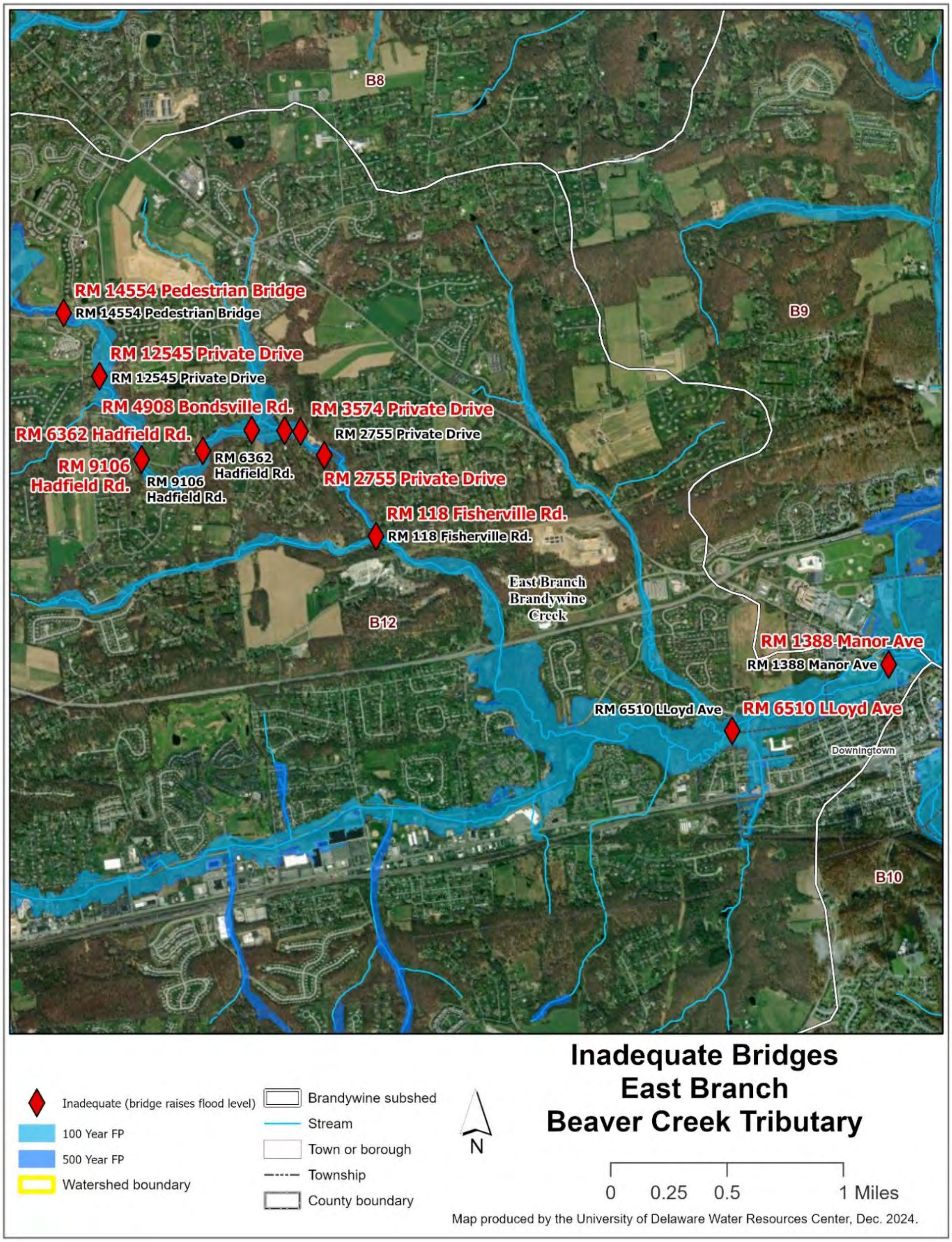


Figure 6.5 Inadequate Bridges, Culverts, and Dams along Beaver Creek

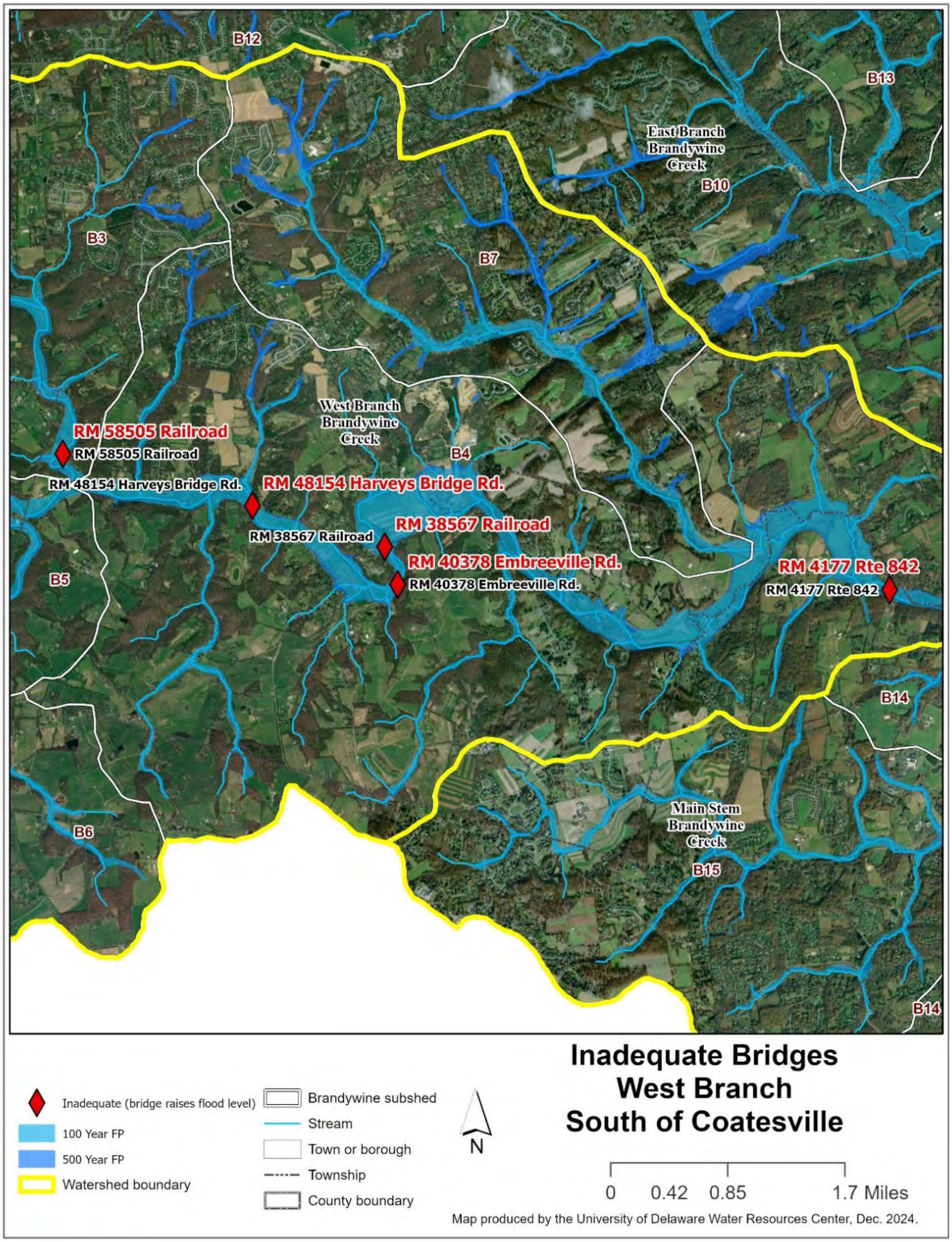


Figure 6.6 Inadequate Bridges, Culverts, and Dams along the West Branch Brandywine South of Coatesville

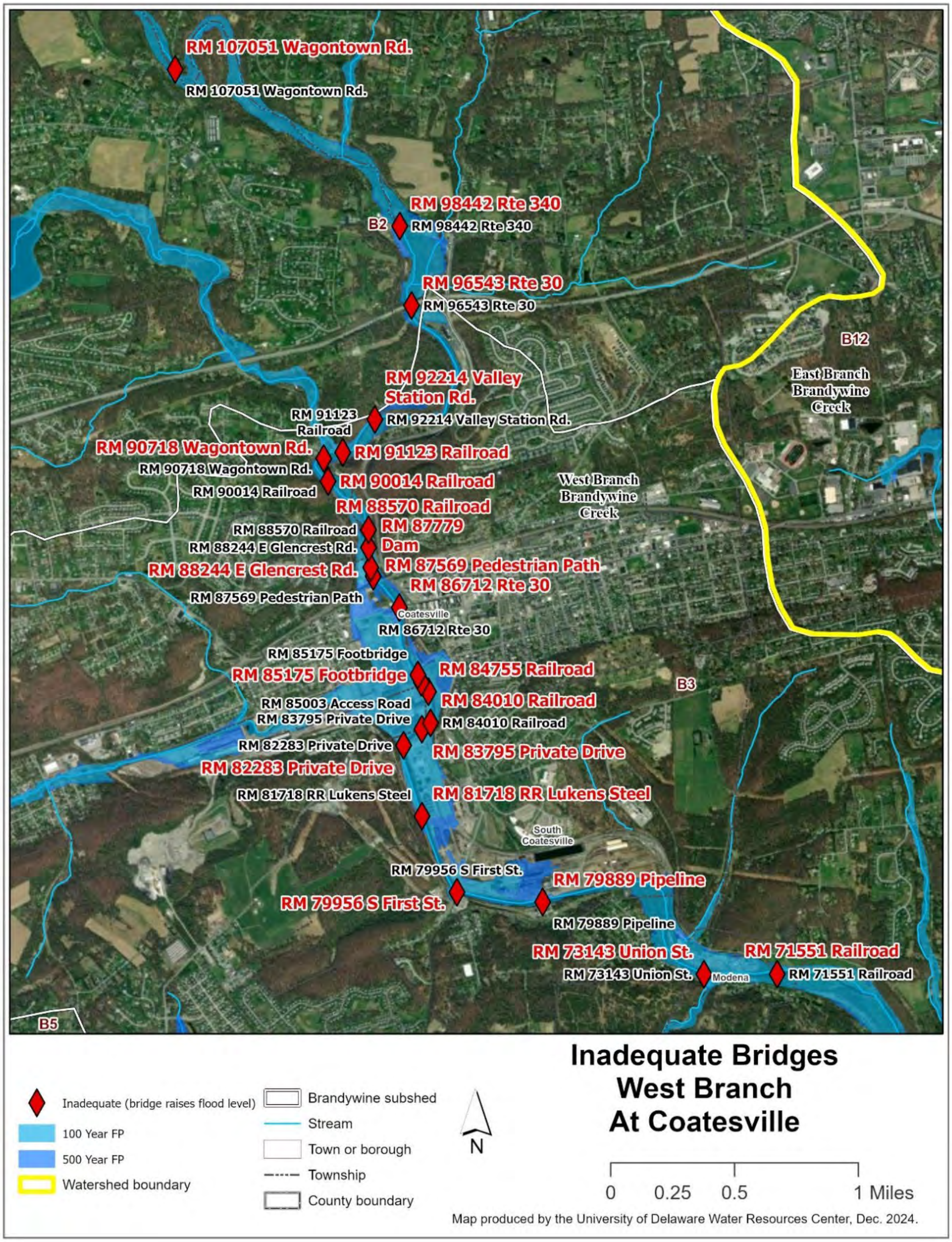


Figure 6.7 Inadequate Bridges, Culverts, and Dams along the West Branch Brandywine at Coatesville

As shown in Table 6.5, of the 291 structures reviewed, 172, or 60%, were found to be undersized and/or insufficient, resulting in increased flood levels. Thes bridges, culverts, and dams along the Brandywine, its branches, tributaries have been identified as candidates for mitigation and/or reconstruction to potentially reduce flooding in the watershed. As these structures are repaired or replaced, responsible entities and their partners should consider further evaluation of these structures which have been identified to elevate floodwaters, inundating surrounding communities, and design them to convey floodwaters beyond the current 100-year storm and assess their performance under future scenarios.

Table 6.5 Inadequately sized bridges, culverts, and dams in the Brandywine watershed

Reach	Total # of Bridges/ Culverts	# of Undersized (raising flood levels)	% Undersized
Mainstem Brandywine Del.	25	8	32%
Mainstem Brandywine Pa.	8	5	62%
East Branch Brandywine	37	20	54%
West Branch Brandywine	37	24	65%
Beaver Creek	16	9	56%
Brandywine Tributaries	168	106	63%
Total	**291**	**172**	**60%**

Construction of bridge on US Route 322 over the East Branch Brandywine Creek in East Bradford Township, August 6, 2014. Photo Courtesy of Chester County Planning Commission.

More details for bridges, culverts, and dams, which have been identified as high potential to obstruct conveyance of flows or exacerbate flooding in the Brandywine Watershed are summarized below. Detailed analysis of the stream crossing structures can be found in Appendix 8.

Mainstem Brandywine River in Delaware

RM 7970. US Rte 13 Northeast Blvd is a 300 ft span by 24 ft rise with 5 concrete piers that raises the 100 yr and 500 yr flood elevation by 1.9 ftand 2.9 ft, respectively and overtops the roadway approach by 6.4 ft. The remedy is to construct a 11th St. Flood Resistance Park to 16 ft msl on the left bank of the Brandywine upstream from the bridge to prevent the overflow of floodwaters (such as Hurricane Ida) into the surrounding Northeast neighborhood. Also we recommend raising the existing flood wall along the right bank of the Brandywine at Howard High School to 16 ft msl to provide adequate free board above the high watermark of Hurricane Ida which was 9.7 ft measured by the USGS on September 2, 2021.

RM 9929. Jessup St./16th St. Bridge is a 220 ft span by 30 ft rise with 3 concrete piers that raises the 100 yr and 500 yr floodplain elevation by 1 ft and 2.6 ft respectively and flood levels do not overtop the bridge deck or the roadway approach.

RM 19996. Bancroft Mills Dam No. 4 is a 200 ft wide by 10 ft rise concrete and masonry dam that raises the 100 yr and 500 yr flood elevation by 4.8 ft and 4.9 ft, respectively for a reach that extends 1/4 mile upstream and floods the condominiums on the right bank of the river. The recommendation is to remove Bancroft Mill Dam No. 4 and reduce the flood elevation by up to five ft for 1/4 mile upstream.

RM 24490. DuPont Experimental Station Dam No. 6 is a 200 ft wide by 10 ft high rock fill dam that raises the 100 yr and 500 yr flood elevation by 5.2 ft and 2.3 ft respectively. The recommendation is to remove Dam No. 6 to reduce flood elevation by 5 ft during the 100 yr flood and 7.5 ft during the 10 yr flood and remove the DuPont Experimental Station on the left overbank from the floodplain.

RM 7.3. Rockland Road is a 100 ft wide span by 30 ft high arch with a single pier that in combination with Rockland Dam No. 11 which is 125 ft wide by 12 ft high rock fill dam just upstream raises the 100 yr and 500 yr flood elevation by 4.5 ft and 5 ft respectively and floods the roadway approach by up to 7 ft of water during the 100 yr flood. We recommend raising the elevation of the westbound approach of the Rockland Rd. bridge by 7 feet and/or constructing a 500 ft long berm to the north of Rockland Roadd. that extends from the Brandywine Creek State Park parking lot to the bridge itself and this would prevent the overflow of water during floods over Rockland Road into the Rockland Mills condominium campus.

Mainstem Brandywine River in Pennsylvania

RM 22413. Railroad viaduct is 400 ft span by 22 ft rise with 7 iron piers and earth causeway on both sides of the river at the Brandywine Museum raises the 100 yr and 500 yr flood elevation by 3.3 ft and 0.7 ft respectively and causes flooding of the Brandywine Museum campus. We recommend removing the railroad embankment on the right side of the existing viaduct and perhaps removing the railroad embankment on the left side of the viaduct that extends to the east toward Route 100.

RM 23660. US Rte 1 Bridge is 400 ft span by 20 ft rise with 3 concrete piers raises the 100 yr and 500 yr flood elevation by 2.4 ft and 0.7 ft respectively and the flood elevation exceeds the bridge deck by 1.6 feet and the westbound approach in the Village of Chadds Ford by 8.4 ft.

RM 23743. PA Dam No. 1 at Hoffman's Mills is a 300 ft wide by 8 ft rise rockfill masonry dam just upstream from the Rte 1 bridge that raises the 100 yr and 500 yr flood elevation by 2.2 ft and 0.6 ft respectively. We recommend removing this dam to reduce flood elevations at the Rte 1 bridge by 1.4 ft and at the westbound approach by 2.2 ft.

RM 30000. Rte 926 bridge is 200 ft span by 25 ft rise with 3 concrete piers where the flood elevation overtops the bridge deck by 2 ft and the roadway approaches by 10 ft. This bridge was reconstruction recently, so we do not recommended any modications at this time.

RM 44561. Rte 52 bridge at Lenape is 180 ft wide by 20 ft rise with 2 concrete piers in the main channel and seven 7 ft high by 50 ft wide arch culverts on the right bank that raises the 500 yr flood elevation by 1.4 ft. The flood elevation exceeds the westbound approach by 2.2 ft and we recommend installing an additional bridge waterway opening alongside the culverts that have been installed to supplement the original arch bridge.

East Branch Brandywine Creek

RM 30958. Harmony Hill Road bridge is 80 ft wide by 14 ft that raises the 50 year and 100 year flood elevations by 1.7 feet and 1.3 feet respectively and the flood elevation over tops the roadway approach by 2.6 feet.

RM 39913. Route 322 bridge is 100 ft wide by 14 ft rise with 3 concrete piers that raises the 100 year and 500 year flood elevation by 0.7 feet and 1.0 feet respectively.

RM 45412. Brandywine Railroad bridge and viaduct with four 30 ft high by 60 ft span arch sections and earth causeway that raises the 100 year and 500 year flood elevation by 0.6 and 0.7 feet respectively.

Railroad bridge over the East Branch Branch Brandywine Creek in Downingtown Borough. October 22, 2024. Note the two arch sections are partially restricted due to silt accumulation.

RM 46852. Business Route 30/Lancaster Pike bridge in Downingtown with four 60 ft wide by 12 ft rise arch sections raises the 10 year and 50 year flood elevation by 0.7 feet and 0.9 feet respectively and the flood elevation over tops the roadway approach by three feet.

US Route 30 (Business) bridge over the East Branch Brandywine Creek in Downingtown Borough. Photos courtesy of Chester County Planning Commission.

RM 47407. Pennsylvania Avenue Bridge with a 200 ft wide by 8 ft rise and a single concrete pier elevates the 100 year and 500 year flood elevation by 1.1 feet and 1.1 feet respectively and the flood elevation over tops the roadway approach by 3.4 feet.

RM 50557. Route 282 bridge in Downingtown with a 200 foot span and 10 ft rise and a single concrette pier elevates the 100 year and 500 year flood elevation by 2.0 and 1.8 feet respectively.

RM 52186. US Rte 30 bridge above Downingtown with a 200 foot span and 30 ft rise and 3 concrete piers raises the 100 year and 500 year flood elevation by 1.6 and 0.9 feet respectively and the flood elevation over tops the roadway approach by 3.3 feet.

RM 58754. Dowlin Forge Road bridge with a 80 foot span and 10 ft rise and single concrete pier raises the 100 year or 500 year flood elevation by 0.4 feet and 0.8 feet respectively And the flood elevation over tops the bridge deck by 1.4 feet and the roadway approach by 4.6 feet.

RM 68100. Private Drive bridge with a 20 foot span and 8 ft rise plus a 20 ft wide by 3 ft rise elevates the 100 year and 500 year flood elevation by 2.4 feet and 1.8 feet respectively and the flood elevation over tops the bridge deck by 3.8 feet and the roadway approach by 5.1 feet.

RM 72205. Reeds Road bridge a 100 ft span by 10 ft and a single concrette pier elevates the 100 yr and 500 yr flood elevations by 2.1 ft and 1.3 ft respectively and the flood elevation over tops the bridge deck by 1.4 ft and 4.4 ft.

RM 77717. Lyndell Road bridge with a 160 foot span and 8 ft rise elevates the 100 year and 500 year flood elevation by 1.9 feet and 2.3 feet respectively and the flood elevation over tops the bridge deck by 1.1 feet and the over top over tops the roadway approach by 1.5 feet.

RM 99253. Fairview/Creek road bridge with a 60 ft span and 10 ft rise and a single concrete pier raises the 100 year and 500 year flood elevation by 0.8 ft and 3.1 ft respectively and the flood over tops the roadway approach by 2.8 ft.

RM 101800. Rte 282 bridge with a 60 ft span by 8 ft rise and a single concrete pier elevates the 100 year and 500 year flood elevation by 2.9 feet and 4.3 feet respectively and the flood elevation overtops the bridge deck by 1.5 feet and the roadway approach by 3.0 feet.

RM 114392. The North Manor Road bridge with a 100 foot span by 8 ft rise and a single concrette pier raises the 100 year and 500 year flood elevation by 0.5 feet and 1.3 feet respectively and the flood over tops the bridge deck by 0.6 feet and the roadway approach by 1.5 feet.

RM 119783. Wyebrook Road bridge with a three by 25 ft span by 14 ft rise arch culverts elevates the 100 year and 500 year flood elevation by 2.2 feet and 4.8 feet respectively and the flood elevation overtops the roadway approach by 3.2 feet.

RM 124594. Lewis Mills Road bridge with twin 20 ft wide by 8 ft rise arch culverts elevates the 100 year and 500 year flood elevation by 2.5 feet and 2.6 feet respectively and the flood over tops the bridge deck by 0.2 feet and the roadway approach by 2.4 feet.

RM 128625. PA Dam No. 6 thatis 7 ft high and 50 ft wide raises the 100 year and 500 year flood elevation by 8.6 ft and 9.2 ft respectively.

RM 131358. Cupola Road bridge with a 80 ft span by 6 ft high bridge elevates the 100 yr and 500 yr flood elevation by 0.5 ft and 0.5 ft respectively and the flood overtops the roadway approach by 3.9 ft.

RM 135406. Suplee Road bridge that is 40 ft wide and 4 ft rise elevates the 100 year and 500 year flood elevation by 1.0 ft and 1.0 feet respectively and the flood elevation over tops the bridge deck by 1.6 feet and the roadway approach by 2.6 feet.

West Branch Brandywine Creek

RM 4177. Route 842 bridge with a 300 ft span and 12 ft rise and 2 concrete piers raises the 100 year and 500 year flood elevation by 0.9 feet and 1.1 feet respectively and the flood overtops the bridge deck by 1.7 feet and the roadway approach by 7.2 feet.

RM 38567. Brandywine Railroad bridge with a 150 ft span by 20 ft rise ans a single concrette pier elevates the 100 year and 500 year flood elevations by 2.0 feet and 8.1 feet respectively and the flood elevation over tops the bridge deck by 0.2 feet and the road and the railroad approach by 1.1 feet.

RM 40378. Embreeville Road/Rte 162 bridge with three 80 ft span by 8 ft rise arch bridge sections raises the 100 year and 500 year flood elevation by 2.5 feet and 5.3 feet respectively and the flood elevation exceeds the bridge deck by 0.5 feet and over tops the roadway approach by 9.7 feet.

RM 48154. Harvey's Road bridge with a 150 ft span by 16 ft rise with 2 concrete piers ses the 100 year and 500 year flood elevations by 0.4 feet and 1.2 feet respectively and the flood overtops the bridge deck by 5.9 feet and the roadway approached by 14.0 feet.

RM 58505. Brandywine Railroad bridge with a 120 span by 16 ft rise and 6 concrete piers raises the 50 year and 100 year flood elevation by 2.7 feet and 1.2 feet respectively and the flood overtops the bridge deck by 2.9 feet and the railroad approach by 10.3 feet.

RM 71551. Mortonville Road bridge in Modena with a 160 ft span by 15 ft rise and 5 concrete piers raises the 100 yr and 500 yr flood elevation by 2.8 ft and 1.3 ft respectively and the flood overtops the bridge deck by 0.5 ft and roadway approach by 1.7 ft.

RM 73143. Union Street bridge in Modena with a 100 ft span and 10 ft rise raises the 10-year and 50 year flood elevation by 1.0 feet and 0.6 feet respectively and the flood over tops the bridge deck by 3.2 feet and the roadway approach by 5.8 feet.

Union Street Bridge over the West Branch Brandywine Creek in Modena Borough, October 31, 2024.

RM 79889. The pipeline crossing in South Coatesville with a 60 ft span thst is 16 ft above the streambed raises the 100 year and 500 year flood elevation by 0.5 feet and 0.9 feet respectively and the flood over tops the pipeline by 2.7 feet to 4.3 feet.

RM 79956. First Street bridge with a 140 ft span and 14 ft rise raises the 100 year and 500 year flood elevation by 1.3 feet and 1.4 feet respectively and the flood over tops the bridge deck by 4.1 feet and the roadway approached by 5.4 feet.
RM 81718. Cleveland Cliffs railroad bridge with a 150 ft span rand 16 ft rise and 2 concrete piers aises the 10 yr and 100 yr flood elevations by 1.5 ft and 1.9 ft respectively and the flood over tops the bridge deck by 1.2 feet and the over tops the roadway approach by 3.7 feet.

RM 83283. Private Drive bridge with a 50 ft span and 20 ft rise and a single pier raises the 50 yr and 100 yr flood elevation by 0.9 ft and 0.8 feet respectively and flood over tops the bridge deck by 5.0 ft and the road approach by 10.9 ft.

RM 83795. Cleveland Cliffs acces road bridge with a 100 ft span and 12 ft rise and 3 piers raises the 100 year flood elevation by 0.6 feet and the flood elevation over tops the bridge deck by 6.1 feet and the road approach by 6.1 feet.

RM 84010. Railroad Bridge with a 100 ft span and 12 ft rise raises the 50 year and 100 year flood elevation by 1.7 and 1.4 feet respectively and the flood over tops the railroad deck by 6.4 feet.

RM 84755. Railroad Bridge with a 60 ft span by 15 ft rise raises the 50 yr and 100 yr flood elevation by 1.7 ft and 1.3 ft respectively and the flood over tops the railroad deck by 3.2 ft and railroad approach by 9.5 ft.

RM 85003. Access Road to Cleveland Cliffs bridge with a 60 ft span by 18 ft rise elevates the 100 year and 500 year flood elevations by 1.2 feet and 1.0 feet respectively and the flood over tops the bridge deck by 1.4 feet and the road approach by 11.1 feet.

RM 85175. Footbridge at Coatesville with a 80 ft span by 20 ft rise raises the 100 year and 500 year flood elevation by 1.2 feet and 0.7 feet respectively and the flood over tops the bridged act by 1.1 feet and the approach to the footbridge by 9.4 feet

RM 86712. Business Rte 30 bridge in Coatesville with two 50 ft wide by 15 ft high arch sections elevates the 100 yr and 500 yr flood elevation by 1.1 ft and 4.2 ft respectively and the flood over tops the roadway approach by 6.3 ft.

US Route 30 (Business) bridge over the West Branch Brandywine Creek in the City of Coatesville

RM 87569. Pedestrian path bridge with a 160 foot span by 10 ft rise and 3 concrete piers elevates the 100 year and 500 year flood elevation by 3.4 feet and 1.9 feet respectively and the flood elevation over tops the bridge deck by 3.9 feet and the approach to the pedestrian bridge by 5.4 feet.

RM 87799. Coatesville dam that is 5 ft ft high by 100 ft wide elevates the 100 and 500 yr flood elevation by 0.7 ft and 1.6 ft respectively.

RM 88244. Eigencrest Rd. bridge 80 ft rise by 12 ft rise with 2 concrete piers raises the 100 yr and 500 yr flood elevation by 1.5 ft and 1.7 ft respectively and the flood over tops the bridge deck by 1.9 ft and roadway approach by 4.0 ft.

RM 88570. Brandywine Railroad bridge with 80 ft span by 10 ft rise and 3 concrete piers elevates 100 yr and 500 yr flood elevation by 7.7 ft and 6.5 ft respectively and the flood overtops the railroad by 8.0 ft.

RM 90014. Brandywine Railroad bridge with a 110 ft span by 18 ft rise with 3 concrete piers raises the 100 yr and 500 yr flood elevation by 1.7 ft and 4.4 ft respectively and the flood elevation over tops the railroad by 0.9 ft to 2.8 ft.

RM 90718. Wagontown Road bridge with four 30 ft wide by 26 ft high arch sections raises the 50 year and 100 year flood elevation by 0.8 feet and 1.0 feet, respectively.

RM 91123. Brandywine Railroad bridge with a 120 ft span by 12 ft rise and 5 concrete piers raises the 100 yr and 500 yr flood elevation by 0.6 ft and 3.4 ft respectively and the flood overtops the railroad by 4.9 to 6 ft across this span.

RM 92214. Valley Station road bridge with a 60 ft span by 16 ft rise raises the 100 year and 500 year flood elevation by 1.6 feet and 2.0 feet respectively and the flood over tops the bridge deck by 0.6 feet and the roadway approach by 3.9 feet.

RM 96543. US Route 30 bridge with 300 ft span by 50 ft rise and 3 concrete piers raise the 150 ft yr flood elevation by 0.7 ft respectively

RM 98442. Route 340 bridge above Coatesville with a 100 ft span by 14 ft rise and a single pier raises the 100 yr and 500 yr flood elevation by 1.9 ft and 1.1 ft respectively and the flood overtops the roadway approach by 4.0 ft.

RM 107051. Wagontown Road bridge with a 40 ft span and 6 ft rise and single pier elevates the 100 yr and 500 yr flood elevation by 4.4 ft and 4.6 ft respectively and the flood over tops the bridge deck and the roadway approach by 2.9 ft.

Beaver Creek

RM 1388. Manor Ave. bridge with a 60 ft span by 6 ft rise rand a single pier raises the 100 yr and 500 yr flood elevation by 1.0 ft and 2.1 ft respectively and the flood over tops the road approach by 2.6 ft.

RM 6510. The Lloyd Ave. bridge with three 25 ft wide by 8 ft high arch sections raises the 100 yr and 500 yr flood elevation by 1.5 ft and 1.6 ft respectively and the flood over tops the bridge deck by 1.0 ft and the road approach by 1.5 ft.

RM 118. The Fisherville Road bridge 20 ft wide by 10 ft rise elevates the 100 yr and 500 yr flood elevation by 3.6 ft and 3.4 ft respectively and the flood over tops the bridge deck by 1.6 ft and roadway approach by 3.4 ft.

RM 2755. Private Driveway bridge with a 30 ft span by 16 ft rise and a single pier raises the 100 yr and 500 yr flood elevation by 2.0 ft and 3.0 ft respectively and the flood over tops the bridge deck by 1.2 ft and road approach by 2.0 ft.

RM 3574. Private Driveway bridge with a 50 ft wide by 10 ft rise and single pier elevates the 100 yr and 500 yr flood elevation by 3.8 ft and 4.4 ft respectively and the flood over tops the driveway deck bridge deck by 4.2 ft and the driveway approach by 4.5 ft.

RM 4119. Private Driveway bridge with 60 ft wide by 10 ft rise and single pier raises the 100 yr and 500 yr flood elevation by 1.4 ft and 2.0 ft respectively and the flood over tops the bridge deck by 0.6 ft and driveway approach to bridge by 3.8 ft.

RM 6362. Hadfield Road bridge with a 40 ft span by 8 ft rise raises the 100 year and 500 year flood elevation by 0.6 ft and the flood over tops the bridge deck by 0.5 feet and the road approach by 3.1 feet.

RM 9106. Hadfield Road bridge a 40 ft span by 5 ft rise raises the 100 yr and 500 yr flood elevation by 0.9 ft and 1.5 ft respectively and the flood overtops the bridge deck by 0.9 ft and road approach by 1.8 ft.

RM 12545. Private Driveway bridge a 60 ft span by 5 ft rise elevates the 100 year and 500 year flood elevation by 1.1 feet and 0.9 feet respectively and the flood over tops the bridge deck by 3.2 feet and the approach road approach by 5.4 feet.

Beaver Run

RM 10450. Fairview Road bridge raises the 100 yr and 500 yr flood elevations by 1.5 ft and 1.0 ft.

Bennetts Run

RM 880. Brandywine Railroad bridge raises the 100 yr and 500 yr flood elevation by 2.5 ft and 1.0 ft and the flood elevation over tops the bridge deck by 2.0 ft.

RM 1520. Brinton Bridge Road bridge raises the 100 yr and 500 yr flood elevation by 2.5 ft and 1.0 ft .

RM 4960. Chandler Road bridge raises the 100 yr and 500 yr flood elevation by 2.0 ft and 2.0 ft respectively and the flood elevation over tops the bridge deck by 1.0 ft.

RM 6720. Pocopson Road bridge raises the 100 yr and 500 yr flood elevations by 1.0 ft and 1.0 ft respectively and over tops the bridge deck by 1.0 ft

RM 8040. Private Road bridge raises the 100 yr and 500 yr flood elevations by 4.0 ft and 4.5 ft.

RM 10920. Pocopson Road bridge raises the 100 yr and 500 yr flood elevations by 2.0 ft and 2.0 ft respectively and the flood elevation over tops the bridge back by 2.0 ft.
RM 11880. Parkersville Road bridge raises the 100 year and 500 year flood elevations by 2.0 feet and 2.0 feet respectively and the flood elevation over tops the bridge deck by 4.0 feet.

RM 12440. The Bennetts Run dam raises the 100 yr and 500 yr flood elevations by 10.0 ft and 10.5 ft.

Birch Run. No. 1

RM 9400. Martins Corner Road bridge elevates the 100 year and 500 year flood elevations by 3.0 feet and 2.5 feet respectively and the flood elevation over tops the bridge deck by 2.0 feet.

Birch Run No. 2.

RM 10200. The dam raises the 100 year flood elevation by 4.0 feet.

RM 10340. Birch Run Road Bridge raises the 100 year flood elevation by 1.5 feet.

RM 12340. The dam raises the 100 year flood elevation by 3.0 feet.

RM 12700. The Access Road bridge raises the 100 year flood elevation by 2.5 feet.

Boot Road Run.

RM 1600. Springton Lane Bridge raises the 100 year and 500 year flood elevation by 2.0 feet and 2.0 feet respectively and the flood elevation over tops the bridge deck by 2.0 feet.

RM 6200. Green Hill Road bridge raises the 100 year and 500 year flood elevation by 4.0 feet and 4.0 feet respectively and over cops the bridge deck by 1.0 feet.

Buck Run

RM 400. Doe Run Church Road bridge raises the 100 yr and 500 yr flood elevation by 0.5 ft and 1.5 ft.

RM 12700. Doe Run Road bridge raises the 100 year and 500 year flood elevations by 5.0 feet and 6.0 feet respectively and the flood elevation overtops the bridge deck by 1.0 feet.

RM 13,000. The dam raises the 100 yr and 500 yr flood elevations by 7.0 ft and 1.0 ft respectively.

RM 15200. Private Road bridge raises the 100 year and 500 year flood elevations by 2.0 feet and 1.0 feet respectively and the flood elevation over tops the bridge deck by 8.0 feet.

RM 16600. Springdale Road bridge raises the 100 year flood elevation by 9.0 feet and the 500 year flood elevation by 9.0 feet and the flood elevation over tops the bridge deck by 6.0 feet.

RM 21200. Railroad Bridge raises the 100 year and 500 year flood elevations by 4.0 feet and 6.0 feet.

RM 25100. Buck Run Road bridge raises the 100 yr and 500 yr flood elevations by 4.0 feet and 6.0 feet.

RM 28100. Railroad bridge raises the 100 yr and 500 yr flood elevations by 6.0 ft and 8.0 ft respectively.

RM 28200. Private Road bridge raises the 100 yr and 500 yr flood elevations by 6.0 ft and 8.0 ft respectively and the flood elevation overtops the bridge deck by 8.0 ft.

RM 28400. The Wier raises the 100 year and 500 year flood elevations by 5.0 feet and 3.0 feet respectively and the flood elevation overtops the wear were roadway elevation by 7.0 feet.

RM 29100. The Railroad Bridge raises the 100 year and 500 year flood elevations by 7.0 feet and 8.0 feet respectively and the flood elevation overtops the railroad by 6.0 feet.

RM 32300. The Railroad bridge raises the 100 year and 500 year flood elevations by 8.0 feet and 10.0 feet respectively and the flood elevation overtops the railroad deck by 4.0 feet.

RM 34800. West Glen Rose Road bridge raises the 100 year and 500 year flood elevations by 2.0 feet and 2.0 feet respectively.

RM 35800. Railroad Bridge raises the 100 year and 500 year flood relations by 3.0 feet and 3.0 feet respectively and the flood elevation overtops the railroad deck by 1.0 feet.

RM 38200. Railroad Bridge overtops raises the 100 year and 500 year flood elevations by 6.0 feet and 6.0 feet respectively and the flood elevation overtops the bridge deck by 3.0 feet.

RM 40900. Railroad Bridge raises the 100 year and 500 year flood elevations by 1.0 B and 1.0 feet.

RM 42900. Railroad Bridge raises the 100 year and 500 year flood elevations by 1.0 feet and 3.0 feet.

RM 45800. Private Road bridge raises the 100 year and 500 year flood elevations by 2.0 feet and 2.0 feet respectively and the flood elevation over tops the bridge deck by 6.0 feet.

RM 45900. Railroad Bridge raises the 100 year and 500 year flood elevations by 3.0 feet and 5.0 feet.

Colebrook Run

RM 4500. Private Driveway bridge raises the 100 year and 500 year flood elevations by 2.5 ft and 2.0 ft.

RM 5000. US Route 30 bridge raises the 100 year and 500 year flood elevations bye 2.5 feet and 2.0 feet.

RM 5250. Private Driveway bridge raises the 100 year and 500 year flood elevations by 1.0 ft and 1.5 ft.

RM 8050. Colebrook Road Bridge raises the 100 year and 500 year flood elevations by 4.5 ft and 4.5 ft.

Copeland Run

RM 1150. West Pennsylvania Avenue Bridge raises the 100 year and 500 year flood elevations by 2.5 feet and 2.5 feet respectively.

RM 1950. West Lancaster Avenue bridge raises the 100 yr and 500 yr flood elevations by 2.5 ft and 3.5 ft.

RM 2250. Private Drive bridge raises the 100 year and 500 year flood elevations by 3.5 feet and 4.5 feet respectively and the flood elevation over tops the bridge deck by 1.0 feet.

RM 2700. West Prospect Avenue bridge raises the 100 year and 500 year flood elevations by 1.0 feet and 3.5 feet respectively.

RM 3000. Railroad Bridge raises the 100 year and 500 year flood elevations by 14.0 feet and 15.0 fee.

Cossart Run

RM 2360. Private Road bridge raises the 100 year and 500 year flood elevations by 1.5 feet and 1.5 feet respectively and the flood elevation over tops the bridge deck by 4.0 feet.

RM 2480. Dam No. 3 raises the 100 year and 500 year flood elevations by 8.5 feet and 8.5 feet.

Craigs Run

RM 3100. Fairville Road bridge raises the 100 year and 500 year flood elevations by 5.0 feet and 5.0 feet respectively and the flood elevation over tops the bridge deck by 2.0 feet.

Doe Run

RM 9450 Doe Run Road bridge raises the 100 year and 500 year flood elevations by 1.5 feet and 1.5 feet respectively and the flood elevation over tops the bridge deck by 0.5 feet.

RM 16750. North Chatham Road bridge raises the 100 yr and 500 yr flood elevations by 2.5 ft and 2.0 ft.

RM 19400. Springdale Road bridge raises the 100 year and 500 year flood elevations by 6.5 feet and 4.5 feet respectively and the flood elevation over tops the bridge deck by 1.0 feet.

RM 26800. Rock Dam elevates the 100 year and 500 year flood elevations by 3.0 feet and 3.0 feet.

RM 29050. Access Road bridge elevates the 100 year and 500 year flood elevations by 1.5 feet and 1.5 feet respectively and the what elevation over tops the bridge deck by 1.0 feet.

RM 33050. Creek Road bridge raises the 100 year and 500 year flood by 1.0 feet and 1.5 feet respectively and the flood elevation over tops the bridge deck by 1.0 feet.

Indian King Run

RM 500. South Whitford road bridge raises the 100 year and 500 year flood elevations by 1.5 feet and the flood elevation over tops the bridge deck by 2.0 feet.

RM 7050. US Route 30 bridge raises the 100 year and 500 year flood elevations by 3.0 feet and 3.5 feet.

RM 7360. The Railroad bridge raises the 100 year and 500 year flood elevations by 3.0 feet and 2.5 feet.

Little Buck Run

RM 3300. Route 10 bridge raises the 100 year and 500 year flood elevations by 2.0 feet and 2.0 feet respectively and the flood elevation over tops the bridge deck by 1.0 feet.

RM 5000. Route 372 bridge raises the 100 year and 500 year flood elevations by 2.5 feet and 3.5 feet.

RM 6000. Railroad bridge raises the 100 year flood elevation by 1.0 feet.

RM 6250. Main Street bridge raises the 100 yr and 500 yr flood elevation by 5.0 ft and 6.5 ft respectively.

RM 7150. Route 10 bridge raises the 100 yr and 500 yr flood elevations by 1.0 ft and 6.0 ft respectively.

RM 8300. The dam raises the 100 yr and 500 yr flood elevations by 2.0 feet and 2.0 feet respectively.

RM 8700. The north Church Street bridge elevates the 100 year and 500 year flood elevations by 2.5 meat and 2.0 feet and the flood elevation over tops the bridge deck by 2.0 feet.

Parke Run

RM 850. The abandoned Railroad bridge raises the 100 yr and 500 yr flood elevations by 1.5 ft and 2.5 ft.

RM 1100. The railroad bridge elevates the 100 yr and 500 ft elevations by 1.5 ft and 2.5 ft respectively.

RM 2750. The Chestnut Road bridge raises the 100 year and 500 foot elevations by 2.0 feet and 1.0 feet.

Pocopson Creek

RM 200. The railroad bridge raises the 100 year and 500 yr flood elevation by 2.0 feet and 1.0 feet respectively and the flood elevation over tops the bridge deck by 1.0 feet.

RM 3800. Route 926 bridge elevates the 100 yr and 500 yr flood elevations by 0.5 feet and 0.5 feet.

Radley Run

RM 2500. The Railroad bridge elevates the 100 year and 500 foot elevations by 2.0 feet and 1.0 feet respectively and the flood elevation over tops the bridge deck by 1.0 feet.

RM 3300. The Knolls Road bridge elevates the 100 yr and 500 yr flood elevations by 8.0 ft and 7.5 ft.

Ring Run

RM 850. Chaddsford School Rd bridge elevates the 100 yr and 500 yr flood elevation by 1.5 ft and 1.5 ft.

RM 4100. US Route 1 bridge raises the 100 year and 500 year flood elevations by 4.0 feet and 4.0 feet..

RM 4600. Legend Lane bridge elevates the 100 yr and 500 yr flood elevations by 3.0 feet and 2.0 feet.

RM 4900. Constitution Drive bridge raises the 100 yr and 500 yr flood elevations by 3.5 ft and 2.0 ft.

Rock Run

RM 700. Pedestrian Bridge raises the 100 year and 500 year flood elevations by 0.5 feet and 1.0 feet and the flood elevation over tops the footbridge by 7.0 feet.

RM 4000. Private Road bridge raises the 100 year and 500 year flood elevations by 3.0 feet and 1.5 feet.

Shamona Creek

RM 180. Struble Trail footbridge raises the 100 year and 500 year flood elevations by 6.5 feet and 5.0 feet respectively and the flood elevation over tops the footbridge by 1.0 feet.

RM 260. Footbridge raises the 100 year and 500 flood elevations by 1.5 feet and 1.0 feet respectively.

Shiloh Run

RM 840. Conrail bridge raises the 100 year and 500 year flood elevations by 16.5 feet and 18.0 feet respectively and the flood elevation over tops the conrail tracks by 2.0 feet.

Sucker Run

RM 3400. Access Road No. 2 elevates the 100 year and 500 year flood elevations by 3.5 feet and 3.5 feet respectively and the flood elevation over tops the bridge deck by 3.0 feet.

RM 4200. Access Road No. 3 elevates the 100 year and 500 year flood elevations by 6.0 feet and 7.5 feet respectively and the flood elevation over tops the bridge deck by 1.0 feet.

RM 7300. Railroad Bridge elevates the 100 year and 500 year flood ovations by 1.0 feet and 2.0 feet.

RM 8750. South Park Avenue bridge raises the 100 year flood elevation by 1.0 feet and the flood elevation over tops the bridge deck by 1.0 feet.

RM 9400. Grove Ave. bridge elevates the 100 yr and 500-yr flood elevations by 1.5 ft and 1.0 ft respectively.

RM 9800. Footbridge raises the 100 year flood elevation by 0.5 feet and 1.0 feet respectively and the flood elevation over tops the footbridge by 3.5 feet.

RM 10500. Route 372 bridge elevates the 100 year and 500 year flood elevations by 1.5 feet and 1.5 feet.

RM 11800. Mount Carmel Street bridge raises 100 year and 500 foot elevations by 3.0 feet and 3.0 feet.

RM 13500. Red Road bridge elevates the 100 year and 500 year flood elevations by 3.0 feet and 3.0 feet.

Taylor Run

RM 100. Highland Rd. bridge raises the 100 year and 500 year flood elevations by 5.5 feet and 6.0 feet.

Two Log Run

RM 2700. Private road bridge raises the 10 year and 50 year flood elevations by 2.0 feet and 1.5 feet and the flood elevation over tops the bridge deck by 1.0 feet.

Trib. To East Branch Brandywine

RM 1000. Creek Road elevates the 100 year and 500 year flood elevations by 2.0 feet and 2.0 feet.

RM 2200. Off Creek Road bridge elevates the 100 year and 500 year flood elevations by 2.0 feet and 1.5 feet respectively and the flood elevation over tops the bridge deck by 3.5 ft.

RM 2400. Bollinger Road bridge elevates the 100 year and 500 foot elevations by 1.0 feet and 1.0 feet.

Trib to West Branch Brandywine

RM 1000. Private Road bridge elevates the 100 year and 500 year flood by 1.5 feet and 1.5 feet respectively and the flood elevation overtops the bridge deck by 2.0 feet.

RM 2600. Stillwater lane bridge raises the 100 yr and 500 year flood elevation by 1.0 ft and 1.5 feet.

RM 3200. Telegraph Road bridge elevates the 100 year and 500 year flood elevations by 0.5 and 0.5 ft.

Valley Run

RM 4100. Bondsville Road bridge elevates the 100 yr and 500 yr flood elevations by 0.5 ft and 0.5 ft.

Valley Run

RM 4000. Bondsville Road bridge elevates the 100 year and 500 foot elevations by 3.5 8 and 3.0 feet respectively and the flood elevation over tops the bridge deck by 0.5 feet.

RM 5100. Thornridge Drive Bridge elevates the 100 year and 500 year flood elevations by 1.0 feet and 1.0 feet respectively and the flat elevation over top of the bridge deck by 2.0 feet.

RM 8700. Bailey Road bridge elevates the 100 year and 500 year flood elevations by 2.0 feet and 2.0 feet respectively and the flood elevation over tops the bridge deck by 2.0 feet.

RM 9200. George Carlson Blvd bridge raises the 100 yr and 500 yr flood elevations by 2.0 ft and 2.5 ft..

RM 10400. George Carlson Blvd. bridge raises the 100 year and 500 year flood elevations by 4.0 feet ten 5.5 feet respectively and the flood elevation over tops the bridge deck by 1.5 feet.

RM 12400. Barleysheaf Road bridge elevates the 100 yr and 500 yr flood elevations by 1.5 ft and 2.0 ft.

RM 13300. Loomis Avenue bridge elevates the 100 year and 500 foot elevations by 1.0 feet and 1.0 feet.

RM 14500. Setzer Avenue bridge elevates the 100 year and 500 year flood elevations by 1.0 feet and 1.0 feet respectively and the flood elevation over tops the bridge deck by 1.5 feet.

Valley Creek (East Branch Brandywine)

RM 7900. South Whitford Road bridge elevates the 100 yr and 500 yr flood elevation by 0.5 ft and 0.5 ft.

RM 13300. Route 100 bridge elevates the 100 yr and 500 yr elevations by 1.5 feet and 1.0 feet.

RM 14100. Route 30 bridge elevates the 100 yr and 500 yr flood elevations by 1.0 ft and 1.0 ft

RM 14600. Exton Mall access bridge elevates the 100 yr and 500 yr flood elevations by 1.0 ft and 3.0 ft.

RM 17500. Valley Road bridge elevates the 10 yr flood elevation by 2.0 feet.

RM 17700. Locust Lane bridge elevates the 100 year and 500 year flood elevations by 1.0 feet and 0.5 feet respectively and the flood elevation over tops the bridge deck by 1.0 feet.

RM 18900. Ship Road bridge raises the 100 year end 500 year flood elevations by 2.0 feet and 2.0 feet.

RM 20200. Exton Mall Access bridge raises the 100 yr and 500 yr flood elevations by 1.5 ft and 1.5 ft.

RM 20400. Exton Mall Access Road bridge elevates the 100 year and 500 foot elevations by 1.0 feet and 1.0 feet respectively and the flood elevation over tops the bridge deck by 1.0 feet.

RM 21000. Chester Valley Trail bridge elevates the 100 year and 500 year flood elevations by 9.0 feet and 8.5 feet respectively and the flood elevation overtops the trail by 0.5 feet.

RM 21500. Railroad Bridge raises the 100 year and 500 year flood elevations by 5.5 feet and 6.5 feet respectively.
RM 23500. Church Farm Lane bridge elevates the 100 year and 500 year flood elevations by 3.0 feet and 3.0 feet respectively and the flood elevation over tops the bridge deck by 2.0 feet.

RM 24600. Valley Creek Blvd. bridge elevates the 100 yr and 500 yr flood elevations by 4.5 ft and 5.0 ft.

6.6 Stormwater Reduction Measures

Stormwater runoff contributes to local flooding during both small and large storm events. Local improvements and investments made in each municipality provide benefits within nearby neighborhoods as well as to downstream communities. The project team has compiled stormwater infrastructure geospatial data of municipalities in the Brandywine Creek watershed to identify flood mitigation measures to better protect residents living along the Brandywine Creek in Pennsylvania and Delaware. Understanding the current state of local stormwater management including existing infrastructure is a critical component to the development of flood mitigation strategies.

Stormwater infrastructure includes features such as stormwater Best Management Practices (BMPs) including detention basins, wet ponds, and infiltration facilities, stormwater inlets, pipes, and outfalls. These features capture and convey stormwater to control facilities before its release to surface waters throughout the drainage area. Stormwater infrastructure is typically constructed during land development and is regulated by the states and local municipalities. However, local municipalities have the final say as to what is constructed within their jurisdiction and how stormwater is managed. Local municipalities are required to understand and map their stormwater facilities as part of the PADEP Municipal Separate Storm Sewer System (MS4).

Data collection includes stormwater basin data from various available sources to compile a complete, accurate geodatabase of all stormwater basins in the Brandywine Creek watershed. It also includes attribution (the addition of information about the size and capabilities of each feature in the geodatabase) and the connecting infrastructure (inlets, pipes, and outlets) to understand how stormwater is ultimately controlled and conveyed to the streams within the watershed. Typical attributes for basins include ownership, area, depth, storage volume, age, and condition, if available.

Stormwater Basin Retrofits

A desktop analysis identified 1,232 stormwater basins in the Brandywine watershed. These were primarily concentrated in areas that have been developed over more recent decades and therefore, subject to local stormwater management regulations. In total, it is estimated that these basins have a collective maximum capacity of 5.4 million cubic feet, or about 40 million gallons.

That volume is equal to roughly 1% of the capacity of the existing five major flood control facilities in the upper watershed. Therefore, it is unlikely that investments in storage capacity upgrades to these smaller, distributed systems would have any measurable impact on regional flooding. However, in certain areas, retrofitting existing stormwater basins may make very meaningful contributions to localized flood reduction efforts, particularly in areas near the smaller, flood-prone tributaries to the larger mainstem, East Branch, and West Branch stretches of the Brandywine Creek.

The project team plans to work with municipalities to further identify potential stormwater basin retrofit projects, specifically in areas with localized flooding concerns. In addition, municipalities should regularly inspect their stormwater basins, and all stormwater infrastructure, to ensure they are functioning as designed. Faulty or failing basins have the potential to exacerbate community flooding issues, so frequent monitoring and timely repair is important.

Finally, many older developments and communities lack critical stormwater infrastructure, as they were constructed prior to the adoption of stormwater management regulations. Especially in these areas, redevelopment presents opportunities to install stormwater infrastructure that will help address runoff-related challenges, such as flooding.

Reducing Impervious Cover

Rainfall runs off impervious cover contributing to increased stormwater and potentially local flooding. Removing impervious surfaces and replacing with either natural vegetation or pervious pavement or pavers can help reduce the amount of stormwater runoff. Converting existing impervious areas to areas that allow infiltration can help reduce stormwater runoff during small events and during the first few hours of larger storms.

Alternatively, for areas where pervious surfaces are unlikely to be effective (either due to the underlying geology or the nature of typical activity on the site), the addition of underground stormwater storage should be considered. For the sake of efficiency and cost effectiveness, this would typically be considered when the site is undergoing any significant development or redevelopment.

Drainage Improvement Projects

Municipalities are responsible for maintenance of their stormwater drainage system. Inspection of inlets, catch basins, manholes, pipes, and related stormwater infrastructure helps to identify malfunctioning components of the stormwater collection system. Incorporating additional factors, such as useful life estimates and local flood frequency, municipalities can prioritize stormwater infrastructure in need of repair or replacement.

Backflow Prevention Device Installation

During heavy storm events, stormwater infrastructure that is outdated to meet current capacity, under-designed, improperly maintained, or simply overwhelmed for extreme storm events may experience floodwaters backing up through the system, resulting in localized flooding. For example, this can happen when flood elevations in the stream are higher than stormwater outfalls. Backflow prevention devices, like gates, flaps, or valves, may be installed at various points within the stormwater system to prevent backwater from contributing to flooding.

Chapter 7 Non-Structural Recommendations

7.1 Overview

Along with structural solutions to mitigate flood damage, there are non-structural solutions that can be implemented prevent harm to the landscape and community during flood occurrences. Non-structural solutions vary widely, with some more appropriate for areas with significant development, and others better suited for areas with more open space and undeveloped land. This section will review strategies, recognizing that communities may utilize strategies for both categories to achieve maximum flood mitigation and prevention benefits.

7.2 Non-structural Solutions in Developed Areas

Much of the landscape in urban and suburban areas, especially along waterways, is already developed. While this may present challenges for implementing larger scale structural projects, non-structural solutions offer communities the opportunity to reduce flood risks through planning, public education, and emergency management efforts. Many of the non-structural solutions discussed below for developed areas are already being utilized in some capacity by municipalities throughout the Brandywine Watershed. So, expanding these efforts by incorporating new techniques, best practices, and information may be the lowest hanging fruit for many communities to implement.

Emergency Preparedness Planning

Since flooding is often unpredictable, robust emergency preparedness planning is a critical tool to ensuring that first responders are adequately equipped to respond as waters rise. Pennsylvania's Title 35 Emergency Management Services Code dictates that each municipality is responsible for emergency management, response, and recovery within its jurisdiction. This includes developing and updating the local disaster emergency management plan. When it comes to addressing flood hazards, these plans should give special attention to roadways and access points that may be cut-off by flood waters, preventing emergency services from reaching those in need.

Bridge crossings and low-lying roads are particularly vulnerable. In some extreme cases, communities bisected by a waterway may require two emergency response plans: one for each side of the stream, in the event that first responders are unable to cross from one side to the other. Care should be taken to identify these potential problem sites, along with concrete steps to maneuver around them during a flood event.

The same logic should also be applied to evacuation routes. This information should be easily accessible by the public, and communities should promote it regularly to ensure residents are aware of these resources prior to an emergency. Flood simulation tabletop exercises, where local officials run through protocols and procedures to train for addressing real world crises, can also be valuable.

Proactively closing flood-prone roads during a storm is another key strategy for keeping the public safe. According to the Centers for Disease Control and Prevention, more than half of all drownings during flood events happen to people attempting to drive through dangerous flood waters. Less than two feet of rushing water can carry away the average car, and many drivers are likely to underestimate both water depths and the risks they pose. In high hazard areas where cones or standard barricades might not be enough to dissuade drivers, some communities have installed roadway closure gates. Whether manually or automatically managed, these barriers can help reduce some of the most significant safety risks during a flood event.

A critical step that municipalities can take before disaster strikes is to participate in the development process of, and subsequently adopt, the County Hazard Mitigation Plan. In addition, identifying areas of recurrent flooding and mitigation opportunities opens the door for communities to access funding, both before and in the aftermath of a flood event.

Public Alerts and Readiness

Early warnings ahead of major storms saves lives. In Chester County, the County's Department of Emergency Services offers the ReadyChesCo program, where individuals can register for free to receive emergency and non-emergency alerts for their community. These alerts can be received as emails, text messages, and/or automated phone calls for one or multiple locations. Residents can sign up to receive alerts for their home municipality, and also for municipalities they commonly visit or travel. Severe weather and flood alerts are sent out through the ReadyChesCo system.

The Chester County Water Resources Authority hosts a web-based "Flood Tools" portal (www.chesco.org/floodtools) with current and forecasted flood conditions across the County. One of the portal's features includes instructions and links for individuals to sign up for rainfall and stream height and flow alerts for their area based on data directly from the local USGS monitoring network. These alerts are free and available via email and text.

Officials and disaster assistance personnel recommend individuals and families assemble an emergency kit and have an established plan for what to do in a variety of emergency situations. In the case of a flood, this may mean being without electricity for a period of time or evacuating to higher ground. The U.S. Department of Homeland Security maintains the www.ready.gov website, which includes information on what to include in an emergency kit and how to develop an emergency plan.

Finally, ensuring people can get back on their feet after a flood is crucial to both individual and community well-being. Flood insurance through the NFIP can help individuals recover losses and rebuild their lives. Those with federally backed mortgages and other loans may be required a flood insurance policy on their property, and it's sensible for anyone owning property with an elevated risk of flooding to consider getting a policy. Municipal officials and community organizations can help educate the public on the value of flood insurance and dispel related common myths. For example, National Flood Insurance Program (NFIP) flood insurance is available for anyone (even renters), regardless of whether their property is located within Special Flood Hazard Areas (SFHA).

Enforcing and Enhancing Floodplain Regulations

All municipalities in Pennsylvania are required to participate in NFIP and adopt local floodplain ordinances. These ordinances are critical tools to helping build safer, more resilient communities. Floodplain ordinances require municipalities to:

- Designate a Floodplain Administrator to oversee the implementation of the local floodplain management program and enforcement of the ordinance
- Adopt flood maps, as developed by FEMA, which define the official SFHAs, to identify boundaries within which floodplain regulations are enforced
- Develop and implement a floodplain permitting program requiring permits for all development activities (including grading/earth moving, small scale projects, etc.) within the floodplain
- Identify construction standards specific to structures and development within the floodplain,
- Enforce code requirements for new structures and for structures determined to be "substantially improved" (where the market value of improvements to a structure is greater than or equal to 50% of the value of the structure) or "substantially damaged" (where the market value of necessary repairs to a structure after it is damaged is greater than or equal to 50% of the value of the structure)

Ensuring that all municipal officials are aware of the requirements of the floodplain ordinance enables them to better support the designated floodplain administrator and their communities.

All Pennsylvania municipalities are required to implement an ordinance that complies with NFIP requirements. However, some communities choose to implement higher standards to further reduce local flood risk. These higher standards may include provisions such as:

- Increased freeboard requirements in construction standards
- Cumulative substantial improvement rules
- Compensatory storage requirements to offset fill placement in the floodplain

Communities who elect to adopt higher standards may be eligible to participate in FEMA's Community Rating System (CRS) program. This program points to a municipality for activities and regulations that go beyond the minimum requirements, which translate to lowered NFIP insurance premiums for their residents.

Structural Elevations, Floodproofing, and Property Buyouts

Over the past few hundred years, thousands of structures have been built in the floodplains in the Brandywine watershed. These include industrial sites, commercial businesses, and residences. These structures and the people who rely upon them tend to be the most vulnerable to damages from flood events. Table 7.1 lists the total acres within the 100-year floodplain (FEMA designated Special Flood Hazard Area Zones A, AE, AE Floodway, and AO), along with the number of parcels and structures greater than 400 square feet, by municipality.

Table 7.1 Existing Development in the 1% Annual Chance (100-year) Floodplain by Municipality

Municipality	County	State	Total Acres	# of Parcels	# of Structures (> 400 sq. ft)
Birmingham Township	Chester	PA	646.2	215	43
Caln Township	Chester	PA	479.6	324	95
Charlestown Township	Chester	PA	0.0	0	0
Coatesville City	Chester	PA	107.5	83	32
Downingtown Borough	Chester	PA	269.7	433	172
East Bradford Township	Chester	PA	1309.7	501	103
East Brandywine Township	Chester	PA	413.6	213	33
East Caln Township	Chester	PA	132.8	30	5
East Fallowfield Township	Chester	PA	553.9	187	30
East Marlborough Township	Chester	PA	79.7	78	5
East Nantmeal Township	Chester	PA	516.2	70	3
East Whiteland Township	Chester	PA	8.1	6	1
Highland Township	Chester	PA	319.1	85	16
Honey Brook Borough	Chester	PA	0.0	0	0
Honey Brook Township	Chester	PA	1473.5	276	47
Kennett Township	Chester	PA	41.8	42	4
Londonderry Township	Chester	PA	271.6	54	8
Modena Borough	Chester	PA	58.6	82	34
Newlin Township	Chester	PA	976.4	261	70

Municipality	**County**	**State**	**Total Acres**	**# of Parcels**	**# of Structures (> 400 sq. ft)**
Parkesburg Borough	Chester	PA	33.6	40	9
Pennsbury Township	Chester	PA	499.8	153	24
Pocopson Township	Chester	PA	772.2	240	70
Sadsbury Township	Chester	PA	346.2	155	33
South Coatesville Borough	Chester	PA	75.6	16	23
Thornbury Township	Chester	PA	22.0	16	3
Upper Uwchlan Township	Chester	PA	947.7	272	35
Uwchlan Township	Chester	PA	76.4	60	11
Valley Township	Chester	PA	144.5	213	49
Wallace Township	Chester	PA	500.4	130	10
West Bradford Township	Chester	PA	491.5	136	34
West Brandywine Township	Chester	PA	484.3	207	18
West Caln Township	Chester	PA	591.4	126	13
West Chester Borough	Chester	PA	12.0	89	26
West Fallowfield Township	Chester	PA	7.4	3	0
West Goshen Township	Chester	PA	205.3	253	38
West Marlborough Township	Chester	PA	662.5	92	25
West Nantmeal Township	Chester	PA	569.9	153	18
West Sadsbury Township	Chester	PA	32.3	8	0
West Vincent Township	Chester	PA	17.1	6	3
West Whiteland Township	Chester	PA	803.7	565	194
Westtown Township	Chester	PA	33.9	14	2
Bethel Township	Delaware	PA	8.0	2	0
Chadds Ford Township	Delaware	PA	436.0	134	40
Concord Township	Delaware	PA	10.6	18	1
Caernarvon Township	Lancaster	PA	0.0	0	0
Salisbury Township	Lancaster	PA	38.0	11	5
New Castle County	New Castle	DE	528.1	95	52
Wilmington	New Castle	DE	433.9	487	270
TOTAL			**16442.1**	**6632**	**1707**

Sources:
FEMA Flood Map Service Center, https://msc.fema.gov/portal/advanceSearch
DVRPC, https://catalog.dvrpc.org/dataset/impervious-surfaces-2015-chester-county
DVRPC, https://catalog.dvrpc.org/dataset/impervious-surfaces-2015-delaware-county
Lancaster County, https://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=1257
New Castle County GIS Services, https://apps-nccde.hub.arcgis.com/

Two main options for increasing the resilience of buildings already located with the floodplain are structural elevation and floodproofing. For residential properties, the standard protocol is to elevate the house above the base flood elevation (also known as the 100-year flood height). Structural elevation may be achieved in several forms, including elevating the building up on fill or abandoning the bottom floors. For non-residential structures, floodproofing is an acceptable strategy by dry floodproofing (where materials are used to make the exterior of a building watertight) or wet floodproofing (where flood damage-resistant materials are used to minimize damage in the lower portion of a structure, which is intentionally allowed to flood).

Structural elevation and floodproofing have numerous benefits, however, they do not entirely eliminate the risk to life and property. For example, an elevated home might keep the residents high and dry, but first responders may still be cut off from accessing them when the land around the structure floods. For homes subject to frequent, hazardous floods, some communities have chosen to pursue voluntary property buyouts. In these cases, the municipality offers the owner of the flood-prone property to pay fair market value, then the site is completely cleared. This eliminates future risk to loss of life from flooding at the site, and when coupled with floodplain restoration, can even reduce potential flood damage to nearby areas.

Unfortunately, despite the benefits, buyout programs is not without downsides. Many residents may be unwilling to participate, and those who do, may choose to move out of the municipality, which has potential ramifications for the tax base and overall fabric of the community. It can also be an expensive process, although there are several federal and state programs that can provide funding to support property buyouts (particularly after disaster declarations). Ultimately, it is up to the community to weigh the risks and benefits of a buyout program before initiating one.

Municipalities should conduct a comprehensive analysis of residential structures within the delineated 100-yr floodplain and consult with the affected property owners. The analysis should assess the value and structural soundness of the building to determine whether they are fit for elevation or floodproofing, compared to the persistent flood risks and NFIP claims.

Strengthening Steep Slope Ordinances

Steeper slopes generate more stormwater runoff than flatter areas, leading to flooding and problems with erosion. Most municipalities in Chester County have protective ordinances that restrict some or all development activities on slopes with a 15% or higher grade. However, even less steep slopes can generate significant runoff that can damage infrastructure and create risks for the public. To address this issue, a model ordinance should be developed to identify additional stormwater management protections and/or development restrictions for slopes with grades of 10-15%.

Public Education and Engagement

Consistent education and outreach are needed on "blue sky" days to help community members prepare for flood events. Popular ready-made campaigns include the National Weather Service's "Turn Around, Don't Drown®" program, which educates the public on the dangers of trying to drive through floodwaters. NWS offers numerous resources, including emergency sign templates, available online for public use (www.weather.gov/safety/flood-turn-around-dont-drown).

Through the NFIP, FEMA has a High Water Mark Initiative aimed at encouraging community awareness of flood risk and mitigation opportunities through historic high water mark signage (https://www.fema.gov/flood-maps/products-tools/high-water-mark-initiative). In places like Washington D.C. and Carson City, Nevada, communities have gone one step further, enlisting the help of artists to visually depict the impact of floods through public art installations like murals and sculptures. A program like this could be replicated in the Brandywine Watershed with relative ease, as the USGS recorded high watermarks at bridges along the mainstem and the East and West branches of the Brandywine during Hurricane Ida (Table 7.2). For instance, the recorded high watermarks at the US Route 13 bridge in northeast Wilmington (RM 7970) was 9.7 ft and at US Route 1 in Chadds Ford (RM 23,660), the Ida high watermark was found at 171.6 ft. Installing Hurricane Ida high water mark signs or art pieces at some of these locations could serve as a reminder to the public about the historic high water experienced during the largest flood along the Brandywine and its tributaries in two centuries.

Table 7.2 Hurricane Ida high water marks recorded by the US Geological Survey

Bridge	RM (mi/ft)	Thalweg (ft)	Deck (ft)	Ida HWEL	100-yr (ft msl)	500-yr (ft msl)
Mainstem Delaware						
AMTRAK RR	6,548	-14.0	31.3	8.4	5.4	8.1
US Rte 13/NE Blvd	7,970	-10.0	20.2	9.7	9.9	14.1
Jessup St./16th St.	9,929	-14.9	20.0	15.1	12.3	16.7
Market St.	11,351	-7.3	31.8	14.3	12.8	17.1
Van Buren St.	14,449	11.5	40.0	28.4	28.3	31.3
Foot Bridge	16,692	16.7	38.4	34.6	36.0	38.7
Augustine Dam No. 3		26.0	32.0	43.2		
DuPont Exp. Sta. Dam 6	24,490	72.0	80.1	92.4	92.3	93.9
Iron Bridge	6.2	110.0	148.0	130.7	126.0	136.0
Reading Railroad	7.2	117.0	146.5	142.8	137.5	151.0
Rockland Rd	7.3	118.0	148.0	142.9	142.5	155.0
Rockland Dam No. 11	7.3	118.0	130.0	144.7	142.5	155.0
Thompson Bridge Rd.	8.8	124.0	155.0	150.6	149.0	161.0
Smith Bridge Rd.	10.5	134.0	157.0	156.4	155.0	165.0
Mainstem Pennsylvania						
Rte 100	14,470	143.3	168.6	165.7	162.5	165.8
Railroad	22,413	147.0	171.3	171.3	169.7	170.3
US Rte 1	23,660	149.5	170.7	171.6	170.8	172.3
PA Dam No. 1	23,743	151.2	156.4	172.1	171.0	172.5
PA Dam No. 2	31,064	156.0	161.9	175.9	173.6	175.9
Rte 926	38,474	159.1	180.9	180.9	177.2	179.5
Rte 52	44,561	158.0	187.0	184.4	181.0	184.8
East Br. Brandywine						
Rte 322	39,913	213.0	232.0	232.5	224.7	226.1
Pennsylvania Ave	47,407	229.0	239.5	241.5	237.5	238.3
Rte 282	50,557	239.0	254.0	248.0	246.3	247.0
Rte 30	52,186	245.0	270.7	255.1	251.7	253.3
Dowlin Forge Rd	58,754	256.0	270.1	270.8	266.2	268.6
West Br. Brandywine						
Strasburg Rd	61,857	239.4	259.4	257.1	253.3	256.0
Mortonville Rd	71,551	260.3	273.4	273.7	273.8	273.9
Union St.	73,143	264.3	275.0	275.9	276.8	278.2
Rte 30	86,712	299.4	318.0	312.8	312.9	318.0
RR Pedestrian Path	87,386	302.7	385.0	314.2	315.5	318.7
Pedestrian Path	87,569	303.4	317.9	316.5	320.1	321.8

7.3 Non-structural Solutions in Less Developed Areas

In areas with more limited development, a variety of strategies exist to utilize open space as a natural flood mitigation tool to slow, spread, and store floodwaters. Protecting these lands is critical, as development on these lands may exacerbate future flooding. While a complete development moratorium is not permitted under state law, local governments should implement zoning ordinances and policy changes that limit and/or heavily regulate development within floodplains or other flood-prone areas (Northwest Hydraulic Consultants Ltd., 2021). There are opportunities for local governments and conservation organizations to protect open spaces for public and private use, as an effective tactic in protecting communities from flooding, as it prevents development in flood-prone areas and allows landscapes to absorb and slow the flow of water (Open Space Institute (OSI), 2020).

Protecting and enhancing natural floodplains is one of the most cost-effective methods for managing flood risk in downstream communities. The floodplains of Brandywine and its branches have 16.5 billion gallons of potential storage capacity including: 3.6 billion gallons along the mainstem Brandywine in Delaware; 4.3 billion gallons along the mainstem Brandywine in Pennsylvania; 3.0 billion gallons along the East Branch; and 5.7 billion gallons along the West Branch. Table 7.3 summarizes floodplain velocity, width, and volume data from HEC-RAS hydraulic modeling (described in Chapter 3) along the Brandywine River and its tributaries.

Table 7.3 Floodplain volume summary along Brandywine River and tributaries

River Station (ft)	Discharge Total (cfs)	Channel Elevation (ft)	Water Surface Elevation (ft)	Depth (ft)	Velocity (fps)	Width (ft)	Volume (gal)	Vol. Reach (mg)	Vol Reach (mg/mi)	Reach (mi)
	Mainstem Brandywine Del.									
4.5	Rising Sun Lane Bridge							2,700	450	6.0
25,125	47270	72.0	95.2	14.7	9.2	349	853,938,636	625	400	1.6
16,876	47793	18.0	40.0	15.2	14.1	381	559,878,144	229	216	1.1
11,352	Market Street									
11,286	47928	-7.3	16.5	21.0	13.7	198	331,055,094	331	364	0.9
6,548	AMTRAK RR									
	Mainstem Brandywine Pa.									
51,175	39,977	171.0	188.6	17.6	4.4	784	4,270,116,004	983	407	2.4
38,474	Street Road/ State Route 926									
38,426	40,867	159.0	179.1	20.1	3.7	1,751	3,287,504,878	1,414	501	2.8
23,607	Baltimore Pike/ US Route 1									
23,531	44,440	149.0	172.2	23.2	2.8	2,604	1,873,373,734	820	184	4.5
14,471	South Creek Rd/ State Rte 100									
14,382	45,609	143.0	165.7	22.7	5.3	704	1,053,737,722	1,054	387	2.7
	East Branch Brandywine Pa.									
138,551	329	593.6	596.9	3.3	5.3	30	2,972,210,314	1,088	94	11.5
77,777	Lindell Road									

River Station	Discharge Total	Channel Elevation	Water Surface Elevation	Depth	Velocity	Width	Volume	Vol. Reach	Vol Reach	Reach
77,738	6256	320.1	327.3	7.2	11.8	294	1,884,267,950	372	76	4.9
52,108	US Route 30									
52,015	10126	244.6	251.9	7.3	8.2	2,641	1,503,699,912	297	301	1.0
46,852	US 30 Business									
46,795	10186	225.2	236.0	10.8	6.3	572	1,204,589,074	158	29	1.3
39,913	US Rte 322									
39,840	10632	212.8	224.8	12.0	6.2	485	1,044,607,133	512	121	4.2
17,604	Strasburg Road									
17,569	14040	187.1	199.6	12.5	5.5	574	531,426,773	531	160	3.1
988	State Rte. 842									
945	15287	171.7	183.6	11.9	3.1	908	14,336,467			
	West Branch Brandywine Pa.									
107,261	10759	428.0	448.6	20.6	3.9	176	5,683,822,753	213	104	2.0
107,032	Wagontown Rd									
96,544	US Route 30									
96,435	11871	343.1	360.1	17.0	4.3	446	5,466,234,280	101	92	1.1
90,719	Wagontown Rd									
90,669	15260	317.1	337.1	20.0	6.3	238	5,365,520,598	82	107	0.7
86,712	US Rte 30/ Lincoln Hwy.									
86,651	15281	298.6	314.5	15.9	4.0	1071	5,281,000,608	506	310	1.6
78,072	Lower Gap Rd									
78,045	15566	275.7	296	20.3	9.6	433	4,774,239,075	167	134	1.2
71,552	Mortonville Rd									
71,485	16393	259.7	272.9	13.2	5.2	687	4,607,382,146	1,015	229	4.4
48,155	Harveys Br.									
48,108	28918	215.0	238.6	23.6	4.0	556	3,586,951,511	635	349	1.8
38,568	Conrail									
38,509	29270	204.4	223.2	18.8	3.5	1276	2,951,715,682	2,897	397	7.1
777	31505	171.7					54,478,575			

The most impactful opportunities for flood storage and open space conservation are typically found in areas where the floodplain is minimally developed, wide, and mildly sloped. Examples of this in the Brandywine Watershed include the stretch of stream between Chadds Ford and Lenape Park, where the floodplain ranges from 1700 to 2600 feet wide, and along the East Branch below Embreeville, where the floodplain is roughly 900 feet wide.

There is a long legacy of land preservation in the Brandywine watershed by municipalities and conservation organizations. Presently, roughly a third of the watershed in Chester County is permanently preserved as open space or agricultural land. This has been achieved primarily through the use of fee simple land and conservation easement acquisitions, both of which are described in detail in the following sections. A combination of land conservation and active land management can support natural systems which are extremely effective in mitigating flood risk and creating healthier ecosystems.

Fee Simple Acquisition

Fee simple acquisition entails the outright purchase of a parcel of land. Ownership of the land allows a conservation organization more flexibility in how it is managed. Deed restrictions can be placed on the land to prevent certain types of development and protect sensitive environments within the parcel. These restrictions can also limit future land use to prevent commercial, agricultural, or disruptive recreational activities. It can allow for land management techniques that may be prohibited in other forms of land conservation for wetland and floodplain restoration, such as dredging. While fee simple acquisition may be more effective in quickly protecting and managing flood-prone land, it is usually more costly, as the owning entity must have enough funding to make the purchase and provide all equipment and labor necessary for the management and maintenance of these lands.

Conservation Easements

For more than six decades, conservation easements have protected land within the Brandywine Watershed and have helped mitigate flooding within the region. A conservation easement is a legal agreement between a landowner and a conservation organization or government entity that protects the conservation values of a parcels of land in perpetuity. Conservation objectives can vary from uninterrupted public views of open space to the presence of rare habitat types. A conservation easement functions to extinguish some of the development rights held by the original owner and limit the allowable activities, uses, and improvements of the landscape. The easement declarations achieve the protection of their conservation objectives through restrictions and prohibitions on the uses, activities, and reserved rights that can be exercised on a property. Conservation easements can be used to protect many aspects of a landscape, such as its scenic value, a sensitive ecosystem, agricultural soils, and others. The components a landowner and easement holder want protected can be specified within the grant of easement. For example, if a parcel has a large tract of mature growth forest, that area can have special restrictions outlined in the easement to protect it in perpetuity, even if the land is sold.

Once a conservation easement is executed, it can be extremely difficult to make any changes to it. This is very important, as it protects the land from any future landowners who may intend to develop or use the property for other means. However, it can also create difficulties in adequately protecting the land under the easement. Landscapes are dynamic, and more recently are subject to rapid, climate driven change. When significant changes occur, a conservation easement with the best intentions may prevent the easement holder and landowners from being able to properly manage or restore a natural area.

It has been noted in various studies, such as the Open Space Institute's "The Role of Land Protection in Mitigating Fresh Water Flood Hazards Report", that land trusts have not used previously conservation easements or fee acquisition to preserve land specifically for its ability to mitigate flood hazards, even though both of these tools easily provide a means to this goal. While there are flood mitigation benefits that occur along with other conservation values protected in easements, there is a lack of targeted flood-related language (OSI, 2020, p.4). For this reason, it is important to consider the ways in which conservation easements can be written, amended, or restructured in a way that would more effectively protect flood prone land.

Existing Conservation Easement Language

Flood mitigation is a common conservation objective among conservation easements on properties within the Brandywine Watershed. Many conservation easements have been written to restrict activities, uses, and reserved rights associated with a property that would otherwise exacerbate flooding. Restrictions on permitted activities and uses often either loosely resemble Best Management

Practices or outright prohibit certain activities, and these restrictions aim to reduce overall flooding or mitigate the impact of flooding. If agricultural use of a property is permitted, for example, there might be restrictions on plowing steep slopes (which can help to both reduce flooding and mitigate the impact of flooding on water quality). Other restrictions, such as limitations on dumping or storage of manure within a floodplain, primarily mitigate the negative externalities from flooding.

There are, of course, areas where conservation easements fall short in reducing flooding. Primarily, conservation easements do not mandate explicitly proactive flood mitigation activities. Grantors do not have an obligation to remove legacy sediments from floodplains, for example, and many older easements even prohibit the dredging of streams and wetlands. The current WeConservePA Model Grant of Conservation Easement and Declaration of Restrictive Covenants, which places greater emphasis on the conservation objectives of the easement, allows for greater flexibility for management activities that further the conservation objectives, but there is still the issue of an inability to enforce a higher standard of performance for ecosystem services. Further, the limitations set forth in the easement that the easement holder can enforce often exceed what would be optimal for flood mitigation. Many eased properties have not met their impervious coverage limits or exercised all their reserved rights, meaning lands already eased within the watershed may exacerbate flooding. Agricultural conservation easements that follow the Pennsylvania model language, which prioritizes the preservation of the property's agricultural use, often lack restrictions on impervious coverage of agricultural structures and have little to no restrictions on tree cutting.

Examples of Other Easement and Protection Models: Same Easement Model with Flood Specific Language

As demonstrated in some of the region's existing easements, language in the WeConservePA and Pennsylvania state agricultural easement models do allow some protection to, and management of, flood prone areas. However, there are gaps in the protections put on these conserved landscapes. There is potential to strengthen language within this easement model to better protect land for flood mitigation purposes either through the amendment of current easements or by implementing targeted flood protection language in new easements. This would require the drafting and implementation of new standard easement models throughout the state.

Some land trusts and other conservation organizations have already adopted this method in pursuit of protecting flood-prone landscapes. In 2001, the Milwaukee Metropolitan Sewerage District along with The Conservation Fund launched Greenseams, a flood management program that protects important open spaces via land purchases and conservation easements in watersheds where major suburban growth is expected to occur. In their easement model, flood management is identified as one of the main goals of protecting the land (The Conservation Fund, n.d.). For example, their model includes the following clause:

> "WHEREAS, the goals of this Conservation Easement are to preserve the Conservation Values of the Property and to ensure that the Property contributes to the prevention of future flooding risks and the protection of air and water quality and ecological resources of the region as outlined in the Greenseams® Program, adopted on October 31, 2001 by the Commissioners of the Milwaukee Metropolitan Sewerage District" (Greenseams, 2021, p.1).

The easement provisions then expand upon this initial clause by again listing flood management as a goal of the easement under its "Purpose." The easement also explicitly allows for, "The restoration of natural vegetation and natural hydrology including de-channelization of ditches and contouring the land to simulate natural conditions." (Greenseams, 2021, p.3). This allowance means that landowners or easement holder have the capability to actively manage their wetlands and stream channels that would allow for better water absorption, the removal of foreign sediment build up from previous flooding and more. However, the allowance is restrictive, in that the easement specifically notes its use for "restoration purposes," and later prohibits, "alteration or manipulation of water courses other than previously defined," (Greenseams, 2021, p.4). Lastly, the easement language includes an "Exhibit C" that outlines the purposes of the Greenseams program and lists the desired qualities of a parcel that would qualify it for this program. This demonstrates that the property was conserved specifically for its flood management and mitigation potential.

Easement Language Changes: Pros and Cons

Considerations should be made before adding language specific to flood protection to easement language, such as the following (Table 7.4):

Table 7.4 Easement Language Change Considerations

PROS	CONS
New easement language allows for active floodplain management, but limits any other waterway or floodplain alteration.	Allowance of any active management could create potential risk of unwanted alterations by landowners.
Few changes to the easement language as a whole would need to be made. Only certain restrictions, definitions, etc., would need to be added or removed.	While easier to implement on the drafting side, it could be difficult to convince current easement holders to amend their easements with further restrictions and management responsibilities.
Adds the explicit purpose for flood management while retaining a broader set of conservation values.	Current and future landowner may not have the means or desire to implement proper management.
Example language lays out loose guidelines to choosing properties for their flood mitigation qualities.	

River Corridor Easements

Another method used by conservation organizations to protect flood-prone lands is through an altogether different kind of conservation easement. The Vermont Rivers Program, under the Vermont Agency of Natural Resources, works to protect flood-prone land through River Corridor Easements (RCEs). (Vermont Agency of Natural Resources Department of Environmental Conservation (VTDEC), n.d.). While the adoption of a new kind of easement may seem daunting to many conservation organizations and other easement holders, this easement language has seen notable success in Vermont, where flooding has created decades long safety, environmental and agricultural issues.

In the program's sample easement, it states the following Conservation Purposes:

> "The purposes of this grant are to allow the ___________ River to re-establish its natural slope and meander pattern, have banks stabilized by a buffer of native, predominantly woody vegetation, and access to natural floodplains in order to reduce flood and erosion hazards, improve water quality through capture and storage of flows, sediment and nutrients, and to conserve and enhance aquatic and wildlife habitats and the natural processes associated with the Protected Property now and in the future." (Kline, 2010)

This is a passive means of restoration and bars most active management practices within the river corridor. In these easements, the channel management rights are either purchased by the holding entity or donated by the landowner as a standalone easement or as an amendment to another conservation easement (VTDEC, n.d.). A designated area of land adjacent to either side of the river is protected and contains a fifty-foot riparian buffer consisting of native, woody plants. If this buffer does not exist upon acquisition of the easement, it must be planted and managed. The fifty-foot riparian buffer must then be maintained as the river moves, the riparian buffer moves with it, within the designated easement boundaries (Vermont Agency of Natural Resources Department of Environmental Conservation, 2018).

It is important to note that in this easement model, some agricultural and forestry practices are still permitted within the protected area outside of the riparian buffer area. These practices are subject to certain restrictions, but allowances like this can make this easement language more desirable to landowners. The easement, however, restricts subdivision, construction of permanent structures other than certain agricultural structures, and any other commercial or residential activity not explicitly stated in the easement or under the discretion of the holding entity (Kline, 2010).

The project selection criteria used to identify lands eligible for a river corridor easement are more specific than most other conservation easements. In the example of the Vermont Rivers Program, specialized teams of hydrologists and river scientists conducted studies to determine high priority areas in the state. These areas are known as “key attenuation areas,” or areas where flooding and sediment distribution could be in constant conflict with human land uses (Kline, 2010). This can create complications within conservation organizations, which may not have the capacity to conduct more extensive river corridor studies where the information is not already available.

River Corridor Easements: Pros and Cons

River Corridor Easements have been successful in mitigating flooding and creating healthier floodplain ecosystems and should be considered as a potential tool for flood mitigation efforts. This kind of easement would not replace current conservation easements but could be used as a supplementary tool. Currently, WeConservePA has its own model language for Riparian Buffer Easements that follows many of the same principles of the Vermont River Program’s easement but has not been updated since 2017. Whether an organization chooses to use a model like the Vermont River Program’s or incorporate certain ideas and tools it presents. it is important to consider all aspects of River Corridor Easements to determine if they are a viable option. The below pros and cons list highlights some potential positive and negative aspects of this model (Table 7.5):

Table 7.5 River Corridor Easement Considerations

PROS	CONS
Aggressively protects waterways and floodplains while continuing to allow some agriculture and passive recreation activities.	Model is very different from current WeConservePA model and may be difficult to draft.
A more "hands-off" approach; potentially less resource intensive for landowners and easement holders on the back end.	Moving riparian buffers could create stewardship and management challenges that organizations may not be equipped to handle.
Flexible; can be used as a standalone easement or used in conjunction with another easement or conservation plan.	Still requires some level of management, as riparian buffers will likely need to be planted and regularly managed
May be cheaper to purchase for conservation organizations due to generally smaller acreage.	Would need to determine how to deal with permanent structures that fall within the river corridor.
	More restrictive than other models, which may make it less attractive to landowners.

Site Assessment and Prioritization for Conservation Easements

The way an organization determines which properties have the greatest conservation value varies based on their mission and goals. By examining their goals, organizations can decide what aspects of a property make it a valuable conservation project and can better allocate their resources to the most impactful projects. Certain criteria can be used to determine the flood mitigation potential of a property, and many of these criteria overlap with other more general conservation goals. By creating prioritization methods that specify flood mitigation characteristics, local conservation organizations can quickly determine and focus on properties that will have the greatest, and most immediate impact.

For instance, the Brandywine Conservancy relies on a Conservation Interest Project Selection Criteria (CIP) questionnaire to determine if a property meets the criteria necessary to move forward with a conservation project. All prospective projects are evaluated following a preliminary site visit and meeting with the landowner. The CIP includes criteria in the categories of feasibility, qualification under IRS codes for donations, public benefit, and natural, open space, scenic, and historic resources. Within each category, there are criteria that purposely and collaterally target flood mitigation qualities within a landscape. Some of these include intense land development in the surrounding area, contribution to the area's ecological viability, presence of wetlands, steep slopes, floodplain protection areas, and riparian corridors. The Brandywine Conservancy also evaluates potential properties to determine the presence of certain features such as prime agricultural soils, stream classes, steep slopes, endangered or sensitive species habitat and more. This method functions in a similar way to the CIP model but makes it easier to find more specific information and identify where various criteria overlap in a landscape.

Other organizations working to conserve land for flood mitigation incorporate additional criteria to identify high priority lands for conservation. For example, in a project conducted by a Duke University graduate student in conjunction with the Land Trust for Central North Carolina, identified land for riparian buffer conservation based on potential nutrient retention, significant natural area protection, and ease of funding (McNamara, 2011). One criterion from this work that may be considered is stream bank control, or whether the same owner owns both sides of a stream bank. This is important as it determines the level of control the conserving entity may have on the stream banks, their stabilization, restoration, and wandering ability. A parcel containing both sides of the stream bank may be considered a more worthwhile project.

In another example, the Nature Conservancy, as part of the Fresh Water Network, created a Flood Plain Prioritization Tool for the Mississippi River Basin. The tool contains various data layers and specifications that allow users to search within the Mississippi River Basin for properties with the desired criteria. The "Flood Prioritization Tool Cheat Sheet" breaks down each of these data layers and specifications (The Nature Conservancy (TNC), n.d.). Notable criteria in this model include:

- 1 in 5-yr floodplains (areas subject to more frequent flooding, which may become both more frequent and more intense as precipitation patterns shift)
- Management actions required by the property (passive preservation only versus active restoration recommended)

WeConservePA has a vast resource library containing materials and guidance for use by land trusts throughout the state. One of their articles titled, "Prioritization of Conservation Resources," outlines the different paths a land trust may take to develop and implement their prioritization process (Billett et al., 2017). One of the recommendations mentioned in this resource is using swing weighting to score potential projects based on the prioritization criteria they meet. Higher values are assigned to criteria that are more important in a conservation project. How criteria are weighted depends on an individual municipality or conservation organization's goals.

Developing Municipal Open Space Funds

An extremely useful tool that many municipalities in the region already employ to fund both land acquisition and easements is municipal open space funding programs. These programs are implemented by local governments through a small increase in Earned Income Taxes. An example of this can be seen in Elk Township (Chester County, PA), which, in 2006, proposed an open space funding referendum and passed by a vote of township residents. The referendum allowed a 0.5% Earned Income Tax increase for resident wage earners to be used to fund the purchase of agricultural lands and open space in the township (Brandywine Conservancy, 2016). Between 2006 and 2016, the township's protected lands grew from 14% to 37% and raised about $90,000 each year, at very little cost to individual residents.

Open space funds allow municipalities to prioritize their own land conservation goals, such as prime agricultural soils or recreational spaces. Hence, municipalities may use open space funds to protect lands for other public benefits, such as flood mitigation. Overall, the implementation of an open space fund is an effective tool that municipalities may use for flood management initiatives.

Chapter 8 A Path Forward

8.1 Recognizing Study Limitations and Need for Further Analysis

While this study involved a robust assessment of flood hazards and potential mitigation opportunities within the Brandywine Watershed, it is not without its limits. In particular:

- results included in this report are based on best available data, public/partner input, and computer modeling software used;
- study partners worked with available HEC-RAS models from FEMA, which were not available for many of the smaller tributaries; and
- generally speaking, the scale of analysis was based on subwatersheds and not at an individual site/project scale.

Structural recommendations included in Chapter 6 are conceptual in nature and project design was not within the scope of this study. For this reason, the development of cost estimates for mitigation projects was also omitted. Engineering designs and their associated site analyses will need to be completed as projects are selected for implementation. Future partners for implementation are welcome to the available data and models used in this study, which can be accessed through the Chester County Water Resources Authority.

Fortunately, further analyses of potential localized mitigation projects are currently underway in several areas of the watershed. Ongoing studies in the City of Coatesville, Downingtown, and Wilmington will likely produce additional sites to supplement those identified in this study. The Flood Study partners are committed to supporting these efforts as they come to fruition.

8.2 Suggested Roles for Implementation

Achieving full implementation of this study's potential will require engagement from individuals, municipalities and organizations throughout the watershed. This section outlines potential implementation roles for different stakeholders based on the recommendations outlined in Chapters 6 and 7. While not exhaustive, this list is meant to serve as a starting point for those looking to reduce flood risks in their communities.

Chester County Water Resources Authority

- Begin the preliminary stages of design and preparation for the rehabilitation of Barneston Dam in the East Branch Brandywine watershed to comply with updated state requirements and improve flood storage capacity
- Coordinate with County Facilities to assess opportunities for impervious cover reduction and stormwater control/flood storage projects on County-owned properties within the watershed
- Identify opportunities to support municipalities with the implementation of floodplain ordinances and participation in the FEMA Community Rating System (CRS)
- Maintain operations of Struble Lake, Beaver Creek Dam, and Hibernia Dam to ensure ongoing flood control benefits for downstream communities

- Maintain the FloodTools website to provide public information on current and forecasted flooding conditions

County Departments of Emergency Services/Emergency Management

- Coordinate with municipalities throughout the watershed to identify and incorporate flood hazards and projects into the updated County Hazard Mitigation Plans
- Support municipal and multi-municipal emergency preparedness and planning efforts
- Support municipal and multi-municipal grant applications for pre-disaster mitigation funding
- For Chester County, continue to broadcast storm and flood alerts to subscribers of the Ready ChesCo alert system

Municipalities

- Inspect, maintain, rehabilitate, and upgrade stormwater infrastructure to improve flood storage capacity
- Prioritize replacement or upgrades of municipally owned bridges, culverts, or other obstructions identified in Chapter 6 to reduce local flood risks
- Identify properties in the floodplain subject to high risk to life and damages and consider offering voluntary property buyouts
- Work with the County Planning Commission/Department and/or regional metropolitan planning organization to submit bridge repair and replacement projects to the state Transportation Improvement Program (TIP) list
- Participate in the County's Hazard Mitigation Plan update process and adopt the plan upon its completion to ensure future eligibility for state and federal hazard mitigation funding
- Review community emergency response plans to ensure they account for major flood scenarios, especially in streamside communities or those bisected by waterways
- Educate community members on flood preparedness tools and resources like Ready ChesCo and Chester County's FloodTools website
- Educate municipal staff, elected officials, and the public about the importance of proper enforcement of the local floodplain ordinance
- Consider participation in the FEMA CRS program to reduce local flood insurance premium costs and encourage residential participation in the NFIP

PennDOT/DelDOT

- Prioritize replacement or upgrades of state-owned bridges, culverts, or other obstructions identified in Chapter 6 and design beyond the 100-year storm to reduce long-term local flood risks
- Inspect, maintain, rehabilitate, and upgrade stormwater infrastructure to improve flood storage capacity

Conservation organizations

- Prioritize parcels with natural floodplains for preservation
- Explore floodplain restoration on owned and/or eased lands to improve flood storage, particularly in areas where floodplains are flat, wide, and vertically disconnected from the stream channel
- Educate municipal representatives and the public about the importance of floodplain protection
- Provide technical assistance for municipalities, homeowners associations, and others on issues related to stormwater management, riparian buffers, etc.
- Coordinate with academic and local government partners as opportunities arise to seek funding for project implementation

Community groups

- Help identify strategies to improve community preparedness and prevention, including accessing and interpreting information about flooding before and after storm events
- Elevate local concerns about the impacts of flooding to municipal and county officials, including areas of chronic flooding, barriers to individual or community resilience, etc.
- Coordinate with municipalities to support waterway cleanups to reduce litter and debris that can contribute to flooding obstructions
- Coordinate with county, state, and federal disaster response efforts after a flood to improve the efficiency of recovery efforts

Individuals

- Sign up for early warning alerts, like those provided by Ready ChesCo, USGS, or the National Weather Service
- Maintain a personal emergency preparedness kit and be aware of local evacuation routes
- For property owners and renters, consider purchasing federal flood insurance for properties within the designated floodplain and close to waterways with flood potential (even if they are not along streams with a mapped floodplain)
- Consider elevating structures within the floodplain to reduce flood risk
- Be aware of and prepared to comply with substantial improvement and substantial damage requirements in the local floodplain ordinance as they apply to properties in the special flood hazard area
- Remember to never drive or walk through floodwaters, even if they do not seem too deep

8.3 Potential Funding Opportunities for Implementation

Funding is often one of the largest hurdles to implementing flood mitigation and risk reduction strategies. Fortunately, there are local, state and federal grant funding opportunities that communities can pursue to offset the costs of these efforts. For some non-flood related grants, flood protection and mitigation may be incorporated as a secondary or co-benefit to the primary focus of the grant (e.g., habitat restoration or infrastructure repair).

Table 8.1 highlights potential grant funding opportunities that may be relevant in the implementation of this study's recommendations. It is important to note that some grants are only open to local governments or nonprofits, while others may have broader applicant eligibility. Generally speaking, projects involving partnerships across sectors or jurisdictional boundaries tend to rank higher with grant funders, and so collaboration is strongly encouraged.

Table 8.1 Potential Grant Funding Opportunities for Flood Mitigation Planning and Projects

Funding Entity	Grant Name	Grant Subgroup	Purpose	Description
Chester County Department of Community Development	Community Revitalization Grants	NA	Project implementation	Chester County's boroughs and the City of Coatesville are eligible applicants. Eligible activities include urban revitalization efforts for municipally-owned infrastructure, including stormwater improvements, floodplain management, etc. A 25% match is required unless otherwise indicated under the program guidelines.
Chester County Parks and Preservation	Preservation Partnership Program	Municipal Acquisition Grant	Acquisition	Funds 50% of appraised value of fee simple land purchases and conservation/trail easements for that preserve significant natural, recreational, agricultural, historic, and cultural land resources. Acquisitions must enhance public access and public benefit. Available only to local government within Chester County.
Chester County Parks and Preservation	Preservation Partnership Program	Conservancy Acquisition Grant	Acquisition	Funds 50% of appraised value of fee simple land purchases, conservation/trail easements that preserve significant natural, recreational, agricultural, historic, and cultural land resources. Acquisitions must enhance public access and public benefit. Available only to nonprofit land conservation organizations in Chester County.
DE DNREC	Outdoor Recreation Parks and Trails Program	NA	Acquisition	Local governments and park districts may apply. Grants may be awarded for 50% of eligible project costs for fee simple acquisition of parkland, open space or conservation areas, planning and design of parks or trails, and outdoor recreation facility construction in the state of Delaware.
FEMA	Hazard Mitigation Grant Program	NA	Acquisitions, planning, project implementation	Local governments are eligible to apply when funding becomes available after a presidentially-declared disaster. Eligible projects include planning and enforcement of hazard mitigation plans, acquisition of hazard prone properties, flood control structure construction, elevation, drainage improvements, and retrofits to structures, utilities, and infrastructure.

FEMA	Flood Mitigation Assistance Grant Program	NA	Planning, project implementation	Local governments are eligible as sub-applicants under the Commonwealth's application to FEMA. Projects eligible for funding may include capacity building activities, mitigation planning, project scoping, localized flood risk reduction projects, individual flood mitigation projects, enhancing local floodplain management, and repetitive loss strategy development. Typically, a 25% match is required.
National Fish and Wildlife Foundation	Delaware Watershed Conservation Fund	Implementation Grants	Project implementation	Eligible entities include nonprofits, governmental organizations, and academic institutions. Eligible projects are those which are shovel-ready within six months and result in quantifiable benefits for fish, wildlife, and people within the Delaware River Watershed. A 1:1 non-federal match is required.
National Fish and Wildlife Foundation	Delaware Watershed Conservation Fund	Planning Grants	Planning	Eligible entities include nonprofits, governmental organizations, and academic institutions. Eligible projects include: engagement, planning, and prioritization; feasibility, suitability, or alternatives analyses; site assessment and conceptual design; and final design and permitting. A 1:1 non-federal match is required.
PA DCED	Act 13 Marcellus Legacy Fund	Flood Mitigation Program	Project implementation	Eligible entities include municipalities, academic institutions, watershed organizations, and businesses. Projects authorized by a flood protection authority, PADEP, USACE, NRCS, or identified by a local government for flood mitigation are eligible for the program. A 15% match is required.
PA DCED	Act 13 Marcellus Legacy Fund	Watershed Restoration and Protection Program	Project implementation	Eligible entities include municipalities, academic institutions, watershed organizations, and businesses. Projects which involve the construction, improvement, expansion, repair, maintenance or rehabilitation of new or existing watershed protection BMPs are eligible. A 15% match is required.

PA DCED	Municipal Assistance Program	Community Planning	Planning	Counties and municipalities are eligible to apply. This program provides funding to assist local governments with the development of multi-municipal plans. A 50% match is required.
PA DCED	H2O PA	Water Supply, Sanitary Sewer, and Stormwater Projects	Project implementation	Municipalities and municipal authorities are eligible entities. The program provides single or multi-year funding to assist with the construction of drinking water, sanitary sewer, and stormwater projects. A 50% match is required.
PA DCED	H2O PA	High Hazard Unsafe Dam Projects	Project implementation	Municipalities, municipal authorities, independent agencies, and the Commonwealth are eligible entities. Single or multi-year projects which involve the repair, rehabilitation, or removal of all or a part of a high hazard unsafe dam are eligible. A 25% match is required.
PA DCED	H2O PA	Flood Control Projects	Project implementation	Municipalities, municipal authorities, independent agencies, and the Commonwealth are eligible entities. Single or multi-year projects which involve construction, improvement, repair or rehabilitation of all or part of a flood control system are eligible. The applicant must provide easements and rights-of-way, relocation of buildings and utilities, alterations or rebuilding of inadequate bridges, and operation and maintenance of the completed project.
PA DCED	Greenways, Trails, and Recreation Program	NA	Planning, acquisition, project implementation	Eligible entities include municipalities, academic institutions, watershed organizations, and businesses. Projects which involve planning, acquisition, development, rehabilitation and repair of greenways, recreational trails, open space, parks and beautification projects are eligible. A 15% match is required.

PA DCNR	Community Conservation Partnerships Program	Community Recreation and Conservation Planning Grant	Planning	Funds planning projects that study the needs, benefits and opportunities for future land acquisition, development and/or management of parks and facilities, critical habitat, open space, natural areas, greenway, and river/watershed corridors. Open to county or municipal governments, educational institutions, and nonprofits in PA.
PA DCNR	Community Conservation Partnerships Program	Land Acquisition and Conservation	Acquisition	Funds the purchase or donation of land for park and recreation areas, greenways, critical habitat areas, and open space. Open to local governments, educational institutions, and non-profit land trusts in PA. Acquisitions can be projects that enhance public access, or that protect open space and critical habitat for important species and ecosystems.
PADEP	Growing Greener Plus	Watershed Restoration	Project implementation	Eligible entities include watershed associations, local governments, conservation districts, nonprofits, municipal authorities, and educational institutions. Floodplain restoration for flood mitigation and stormwater management projects are among the eligible project types. A 15% match is required.
PEMA	Building Resilient Infrastructure and Communities	Capacity and Capability Building	Planning	Local governments are eligible as sub-applicants under the Commonwealth’s application to FEMA. Eligible projects include building code activities, project scoping, and mitigation planning. There is a 25% non-federal match requirement (10% non-Federal match for identified Small and Impoverished Communities).
PEMA	Building Resilient Infrastructure and Communities	Mitigation Projects	Project implementation	Local governments are eligible as sub-applicants under the Commonwealth’s application to FEMA. Eligible projects include acquisition, demolition, relocation, elevation, and other floodproofing measures. There is a 25% non-federal match requirement (10% non-Federal match for identified Small and Impoverished Communities).

PennVEST	NA	NA	Project implementation	While not usually a source of grant funding, PennVEST offers low interest loans for construction or improvements to stormwater management facilities.
The Land Trust Alliance and Open Space Institute	Land and Climate Catalyst Planning Grants	NA	Planning	Funds the development of climate-informed land conservation, stewardship, or communications plans that address habitat resilience, community adaptation to climate impacts such as stronger storms, flooding, drought, fire or extreme heat, and more. Open to LTA members and affiliate state land trust associations for LTA funding. OSI funding is open to non-profits and state/federally recognized Tribes within the Delaware River Watershed.
U.S Fish and Wildlife Service	North American Wetlands Conservation Act	Standard Grant	Acquisition	Supports public-private partnership projects that further the goals of the North American Wetlands Conservation Act. These projects must involve long-term protection, restoration, and/or enhancement of wetlands and associated uplands habitats for the benefit of all wetlands-associated migratory birds. For projects requesting between $250,000 and $3,000,000.
U.S Fish and Wildlife Service	North American Wetlands Conservation Act	Small Grant	Acquisition	Funds public-private partnership projects that further the goals of the North American Wetlands Conservation Act. Projects must involve long-term protection, restoration, and/or enhancement of wetlands and associated uplands habitats for the benefit of wetlands-associated migratory birds. For projects requesting $250,000 or less.
U.S Fish and Wildlife Service	Acres for America	NA	Acquisition	Funds projects that conserve critical wildlife habitat and lands that connect existing protected lands, and projects that provide public access. Open to nonprofits, state and local government agencies, Tribal governments and organizations, and educational institutions. Prioritizes larger scale conservation projects.

U.S. Army Corps of Engineers	Southeastern Pennsylvania and Lower Delaware River Basin Environmental Improvements Program (566 Program)	NA	Design & Construction	Funding for this authority is provided to the Corps through appropriated funding under Environmental Infrastructure and distributed to specific projects through the annual Work Plan or Congressional Earmark. The 566 Program allows USACE to provide design and construction assistance to non-Federal interests for carrying out water related environmental infrastructure, resource protection and development projects in southeastern Pennsylvania.
U.S. Department of Transportation	Rebuilding American Infrastructure with Sustainability and Equity (RAISE) Program	NA	Planning, project implementation	State and local governments, transit agencies, and publically chartered authorities are eligible. Eligible applications for funding may include planning and implementation of highway, bridge, rail,and roadway projects, along with culvert or stormwater management projects that improve aquatic habitat.
U.S. Fish and Wildlife Service	National Fish Passage Program	NA	Project Implementation	Eligible entities include nonprofits, governmental organizations, businesses, individuals, and academic institutions. Eligible projects will remove instream barriers and restore aquatic organism passage and aquatic connectivity. This includes but is not limited to dam removals, culvert replacements, floodplain restoration, and the installation of fishways.
USDA NRCS	Small Watershed Program (PL566)	Structural Watershed Projects	Flood control operations & construction	Require a state, county, or local government sponsor. Eligible projects include flood control structures (dams, levees, channels, etc.) or agricultural water supply reservoirs. Cost share amount is variable depending on project purpose.
USDA NRCS	Emergency Watershed Protection Program	NA	Easement acquisition, project implementation	Require a state, county, local government, or conservation district sponsor. Eligible activities include providing financial and technical assistance to remove debris from streams, protect destabilized streambanks, establish cover on critically eroding lands, repairing conservation practices, and the purchase of flood plain easements. The program is designed for installation of recovery measures. Generally, a 25% match is required.

8.4 Final Thoughts

Anywhere there is water, there is the potential for flooding. Even with unlimited financial and technological resources, it would be impossible to eliminate all flood risks. However, the Flood Study partners are confident that implementation of the recommendations laid out in this report can meaningfully reduce future flood risks to communities throughout the Brandywine watershed. The partners are committed to supporting municipalities, stakeholders, and others in implementing these strategies, and to continually assessing new opportunities to reduce localized and regional flooding in the future.

References

Brandywine State of the Watershed, 2018.

Federal Emergency Management Agency, 2015. Flood Insurance Study, New Castle County, Delaware.

Federal Emergency Management Agency, 2017. Flood Insurance Study, Chester County, Pennsylvania.

Federal Emergency Management Agency, 2017. Flood Risk Report, Chester County, Brandywine Christina Watershed, 02-040205. Report No. 01.

U.S. Army Corps of Engineers, 1962, Delaware River Basin, New York, New York, New Jersey, Pennsylvania, and Delaware. Letter from the Secretary of the Army. Volume Vi.

U.S. Army Corps of Engineers, 1973. Floodplain Information, Brandywine Creek, New Castle County, Delaware. Prepared for the New Castle County Department of Planning.

Brandywine Valley Association, 2005. State of the Watershed Report, Brandywine Valley.

Senior, L. A. and E. H. Koerkle, 2003. Simulation of Stream Flow and Water Quality in the Brandywine Creek Subbasin of the Christina River Basin, Pennsylvania and Delaware, 1994-98. Water Resources Investigations Report 02-4279. U. S. Geological Survey.

(Smith, Chatman-Royce Associates, 1972)

Stuckey, M.H., Conlon, M.D., and Weaver, M.R., 2023, Characterization of peak streamflows and flooding in select areas of Pennsylvania from the remnants of Hurricane Ida, September 1–2, 2021 (ver. 1.1, September 28, 2023): U.S. Geological Survey Scientific Investigations Report 2023–5086, 28 p., https://doi.org/ 10.3133/ sir20235086.).

(ver. 1.1, September 28, 2023): U.S. Geological Survey Scientific Investigations Report 2023–5086, 28 p., https://doi.org/ 10.3133/ sir20235086.).

Delaware River Basin Commission, Docket No. D-64-15 CP

(Smith et al. 2022). Smith, J. A., M. L Baeck, Y. Su, M. Liu, and G. A. Vecchi, 2022.

www.usgs.gov. 2. Ries, K. G. and J. A. Dillow, 2006. Magnitude and Frequency of Floods on Nontidal Streams in Delaware. U. S. Geological Survey. Scientific Investigations Report 2006-5146.

US Army Corps, 2001
(Open Space Institute (OSI), 2020).

(Greenseams, 2021, p.1).

(Kline, 2010)

Vermont Agency of Natural Resources Department of Environmental Conservation (VTDEC), 2018

List of Abbreviations

ac	Acre	ft	
BC	Brandywine Conservancy	ac	
BRC	Brandywine Red Clay Alliance	yr	
CBR4	Christina-Brandywine River Remediation Restoration Resilience	gal	Gallons
cfs	Cubic Feet Per Second	mg	Million gallons
EPA	Environmental Protection Agency		
FAQ	Frequently Asked Question	**msl**	Mean Sea Level
FEMA	Federal Emergency Management Agency	**MS4**	Municipal Separate Storm Sewer System
FIS	Federal Insurance Study	**NB**	Northbound
ft	Feet		
HOA	Homeowners Association	**NOAA**	National Oceanic and Atmospheric Administration
		PRP	Pollution Reduction Plan
		RM	River Mile
		SB	Southbound
		USACOE	United States Army Corps of Engineers
		yr	Year

List of Appendices

All appendices are provided as attachments to this report. The complete list of appendices is as follows:

Appendix 1: Municipal Flood Inventory and Assessment

Appendix 2: Hurricane Ida Precipitation and Flood Data Report

Appendix 3: H&H Study Technical Report and Documentation

Appendix 4: Climate Analysis and Storm Frequency Analysis Memo

Appendix 5: Watershed Buildout Data and Methodology

Appendix 6: Public Engagement Resources and Feedback

Appendix 7: Brandywine Flood Study Website Materials

Appendix 8: Analysis of Structural Opportunities Beyond Bridges and Culverts

Appendix 9: Conservation Easement Resources and Tools