Brandywine-Christina

State of the Watershed Report

2018

Brandywine-Christina State of the Watershed Report

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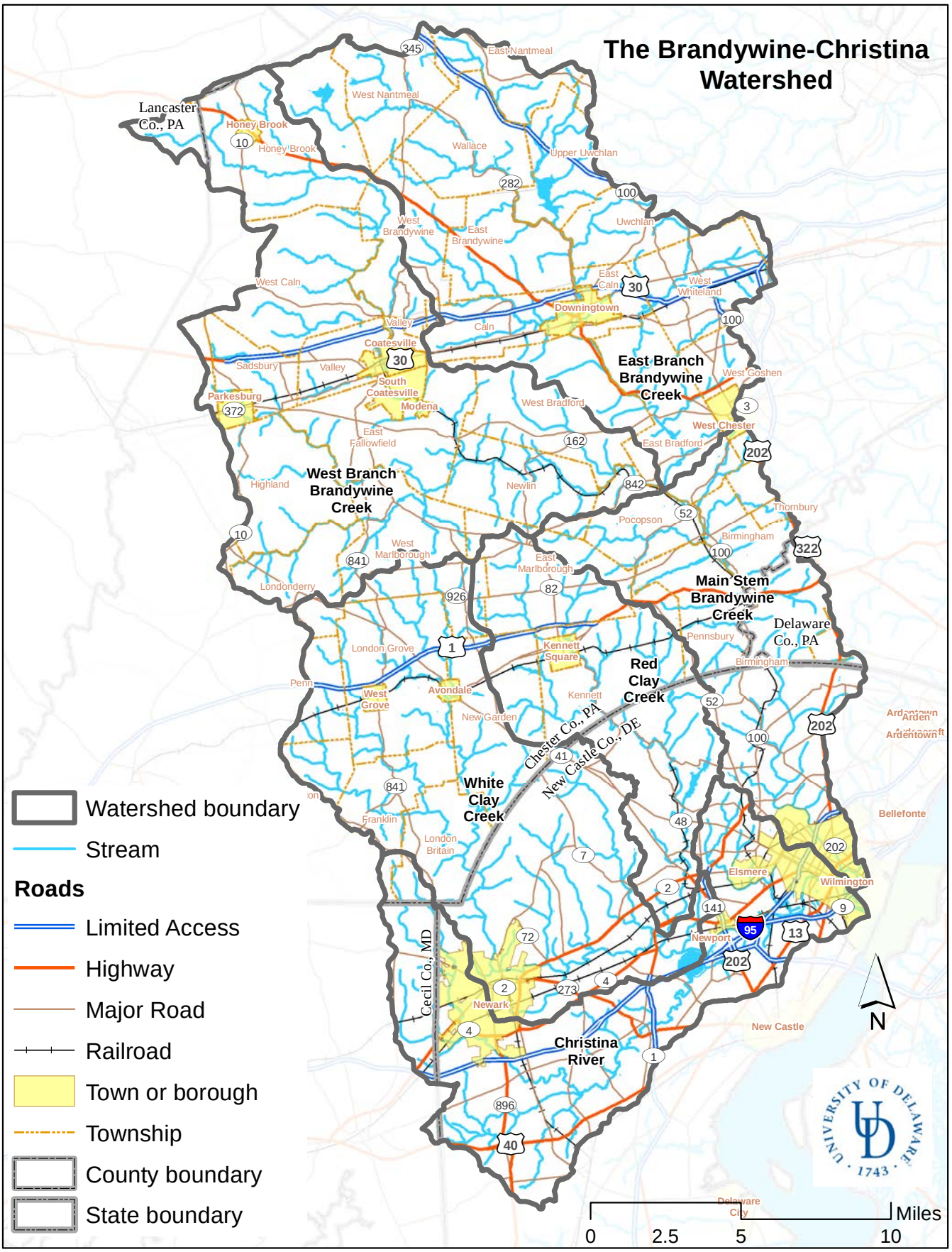

The Brandywine-Christina Watershed
Lancaster Co., PA
East Nantmeal
West Nantmeal
Honey Brook
Wallace
Upper Uwchlan
Uwchlan
West Brandywine
East Brandywine
West Caln
East Caln
West Whiteland
Downingtown
Caln
Valley
Coatesville
Sadsbury
South Coatesville
Parkesburg
Modena
West Bradford
East Fallowfield
West Chester
East Bradford
East Branch Brandywine Creek
West Goshen
West Branch Brandywine Creek
Highland
Newlin
Thornbury
Pocopson
Birmingham
West Marlborough
East Marlborough
Londonderry
Main Stem Brandywine Creek
Delaware Co., PA
Pennsbury
London Grove
Kennett Square
Red Clay Creek
Penn
West Grove
Avondale
Kennett
New Garden
Chester Co., PA
New Castle Co., DE
Ardentown
Arden
White Clay Creek
Franklin
London Britain
Bellefonte
Elsmere
Wilmington
Newport
Cecil Co., MD
Newark
New Castle
Christina River
Delaware City
N
Miles
0
2.5
5
10
Watershed boundary
Stream
Roads
Limited Access
Highway
Major Road
Railroad
Town or borough
Township
County boundary
State boundary

Contents

Acknowledgements

The University of Delaware Water Resources Center would like to acknowledge the following organizations for their partnership in preparing the *Brandywine-Christina State of the Watershed* report. The following organizations have contributed to the data and content provided in this report:

- Brandywine Conservancy
- Brandywine Red Clay Alliance
- Chester County Conservation District
- Chester County Water Resources Authority
- Delaware Department of Natural Resources and Environmental Control
- Delaware Environmental Observation System
- Delaware Geological Survey
- Delaware Nature Society
- Delaware River Basin Commission
- Natural Lands
- New Castle Conservation District
- Partnership for the Delaware Estuary
- Pennsylvania Department of Environmental Protection
- Stroud Water Research Center
- The Land Conservancy of Southern Chester County
- The Nature Conservancy in Delaware
- United State Geological Survey (USGS)
- White Clay Wild & Scenic River Program

It is important to recognize all of the organizations and individuals that are committed to water quality improvement in the Brandywine-Christina watershed. This includes nonprofit, government, academic and private organizations. The Christina Basin Clean Water Partnership has also been an important bi-state voluntary partnership in the watershed. Since its inception in 1993, this bi-state collaborative has demonstrated the benefits of working together and across state lines to improve water quality.

The report team would also like to acknowledge the William Penn Foundation for its support of the *Brandywine-Christina State of the Watershed* report and their commitment to restore and protect the Brandywine-Christina watershed and the entire Delaware River Basin.

Executive Summary

Goal

This report provides an overview of the trends and conditions of the Brandywine-Christina watershed. It is funded through a grant from the William Penn Foundation through the Delaware River Watershed Initiative (DRWI).

Overview

Several partners in Delaware and Pennsylvania have been working for decades on an integrated approach to water resources and land management in the Brandywine-Christina watershed. Governments, nonprofits, academic institutions, and the private sector have all played a significant role in restoring and protecting the Brandywine-Christina watershed through cooperative agreements, regulations, restoration, and land preservation programs. Many of these partner organizations within this area have worked to produce this report, which has also been informed by the many prior reports produced by these organizations and others.

In 2013, the William Penn Foundation launched the DRWI to help focus the efforts of numerous organizations across the Delaware Basin to improve watershed health and water quality. To date, over $40 million has been distributed to over 50 nonprofits. The Brandywine-Christina Partnership, one of eight groups spread across the Basin, consists of six partners: Brandywine Conservancy & Museum of Art, Stroud Water Research Center, Natural Lands, Brandywine Red Clay Alliance, The Nature Conservancy in Delaware, and the University of Delaware Water Resources Center. The initial phase of this effort was directed toward six specific focus areas located across the watershed. A second phase of this initiative refines the geographic focus areas and extends the success from the earlier phase.

The Brandywine-Christina watershed is composed of four smaller watersheds—Brandywine Creek, White Clay Creek, Red Clay Creek and Christina River—covering 565 square miles extending from the tidal reaches of the lower Christina River in Delaware to the headwaters in the foothills of the valley and ridge system of southeastern Pennsylvania, more than 40 miles to the north. The Brandywine-Christina is one of the most historic small watersheds in the nation, two-thirds of the land area lies in Pennsylvania, and it is home to over 600,000 people producing up to 100 million gallons per day (MGD) to serve northern New Castle County, Delaware and southeastern Pennsylvania.

Straddling Pennsylvania, Delaware and Maryland and two physiographic provinces – the Piedmont and the Coastal Plain, the Brandywine-Christina watershed begins at an elevation well over 1,000 feet above sea-level, through the fall line at the edge of the Piedmont and from there to the Delaware River at the northern edge of the Coastal Plain. The region is characterized by loamy soils which are suitable for farming and have a relatively high infiltration rate.

Most of the land in the study area lies in Pennsylvania while more than half (56%) of the current population of 613,000, is in Delaware. The Brandywine-Christina watershed has seen an 8% increase in population between 2000 and 2015, growth has occurred in most areas of Pennsylvania while in Delaware the growth rate has been somewhat lower. It is projected that by the 2030 census the majority of the population will reside in the Pennsylvania portion of the area. The governance structure of the watershed, with three states, five counties and 55 municipalities, creates a challenge in its complexity, yet affords ample opportunity for collaboration and coordination in efforts to protect and restore its waters.

The region has a rich and varied history from settlement by the Lenni Lenape, its discovery by the Swedes in the 17th century, the site of the largest battle of the Revolutionary War in 1777 and later the DuPont gun powder mills along the Brandywine at the turn of the 19th century. It provides opportunities for heritage tourism, outdoor recreation, and the exploration of its artistic legacy and agricultural tradition. The many parks and preserved open land throughout the watershed provide an abundance of destinations for residents and visitors to enjoy the outdoors. Activities throughout the watershed contribute $4.9 billion and over 100,000 jobs to the economy of the region.

Key Findings of the Report

Precipitation: Over the period from 1960 to the present, precipitation has increased across the Brandywine-Christina watershed. Average annual rainfall has risen from 40-45 inches to approximately 50 inches. Generally, higher rainfall is seen in the northerly, more elevated portion of the study area.

Air Temperature: The record of temperature data goes back to the 1890s. Since that time there has been an increase in the average ambient air temperature, with the number of days over 90 degrees Fahrenheit more than doubling.

Streamflow/Mean Daily Flow/7Q10: Along with increased temperatures and precipitation, as well as urbanization in the watershed, there has been an overall increase in both peak stream flows (i.e., flooding), along with lower base stream flows in dry periods. Three major droughts since the 1960s saw low-flow extremes, but the past 15 years have seen higher flows due to wetter conditions.

Peak Events: The watershed has 19 continuously operating stream gages that measure stream flow and other parameters. It was determined that there was not a significant trend in the frequency or number of storm events resulting in the overtopping of streambanks at the Pennsylvania stream gages. In Delaware, peak streamflows have increased at the Brandywine, Red Clay and White Clay Creeks' stream gages over the last 20-30 years.

Impaired Streams: Pollutants, such as nutrients (nitrogen and phosphorus), bacteria and sediment, have caused waterways to be designated impaired (for a given use, such as swimming, use as a drinking water source, or as aquatic habitat). As of 2016, the Delaware portion of the watershed has 51.4 miles of stream impaired for nutrients and 116.5 miles impaired for bacteria, and the Pennsylvania portion has 135.5 miles impaired for nutrients, 68.7 miles impaired for bacteria, and 308.1 miles impaired for sediment.

Pennsylvania has 142.6 miles of stream designated "High Quality"; of those, 41 miles are also designated as "Exceptional Value" waters. Delaware has designated certain streams in the watershed, totaling 98.5 miles, as of Exceptional Recreational or Ecological Significance (ERES). The ability to support trout populations is also an indicator of water quality. In Pennsylvania there are 189 miles of designated cold-water fishery streams and 92 miles of naturally-reproducing trout streams.

Sea-Level: Approximately 40 square miles of the downstream portion of the watershed is tidally influenced, and therefore subject to impacts of sea-level-rise, including inundation and increased salinity. Peak high tides recorded along the two Christina River gages began to increase in 2000 and peaked in 2012 and declined in the four years since then.

Groundwater Levels: There are 12 monitoring wells that indicate groundwater levels throughout the watershed. Since the 1950s Chester County saw a 0.22 foot per year increase in groundwater levels at a key monitoring well. Delaware saw a nearly 5 foot average rise at the Wilmington monitoring well, with a slight decrease in levels at a monitoring well near Newark.

Macroinvertebrates: A long term macroinvertebrate monitoring program in Chester County, PA has been established by the USGS and the Chester County Water Resources Authority (CCWRA), and the Delaware Nature Society (DNS) runs a sampling program in Delaware. Of the nine monitoring sites in Chester County, three indicate good water quality, three indicate fair water quality and three indicate poor water quality. In Delaware 21 sites were monitored between 2011 and 2015. Of these nine were found to be of "good" water quality, and the remaining 13 "fair."

Birds: Changes in land use and water quality in the watershed can have a significant impact on native nesting species. Of six species considered: Eastern Meadowlark, American Kestrel, Common Yellowthroat, Kentucky Warbler, Louisiana Waterthrush, and Northern Parula, all except Northern Parula experienced a decline in breeding populations. Of particular concern are the two grassland-dependent species—Eastern Meadowlark and American Kestrel—which saw the largest declines, and are reliant on one of the most threatened habitats in the region.

Freshwater Mussels: The Partnership for the Delaware Estuary (PDE) has found that in some areas of the lower Brandywine Creek there are relatively abundant. In the Red Clay and White Clay Creeks mussels are not currently present, but the stream habitat appears suitable to host re-introduction.

Fish: Several migratory species of interest have historically been found within the watershed, and there are efforts to encourage their reestablishment—Striped Bass, American Eel, and American and Hickory Shad. Along with the focus on water quality improvements, a key to reintroduction of these species is the removal of dams. To date only one dam, on the White Clay Creek,

has been removed, but the farthest downstream dam on the Brandywine Creek is scheduled for removal in the fall of 2018.

Dissolved Oxygen (DO): The USGS and CCWRA maintain six stations that monitor DO in Chester County, and DNREC operates four stations in the Delaware portion of the watershed. Since the early 1970s, the percentage of days in Chester County that DO levels stayed above healthy levels has increased, and at all monitoring stations, DO levels have increased and improved.

Phosphorus: Orthophosphate is the form of phosphorus that runs off into streams from fertilizer and promotes plant and algal growth in streams. Orthophosphates are measured at ten USGS, CCWRA and DNREC monitoring stations in the watershed. Orthophosphate levels have improved since 1998 at three stations in Pennsylvania and all four stations in Delaware. Orthophosphate levels have remained constant at two stations in Pennsylvania and have increased along the East Branch Brandywine.

Nitrogen: Nitrogen is a nutrient of concern that can lead to excessive algal growth and drops in DO levels. Since 2000, nitrogen levels have improved at two water quality monitoring stations in Pennsylvania and four stations in Delaware. Nitrogen levels have increased, or become worse, at four water quality monitoring stations in PA.

Total Suspended Sediment (TSS): TSS is a pollutant of concern in the watershed, and can come from many sources, including instream erosion. USGS and CCWRA have established continuously operating turbidity sensors which can help determine TSS concentrations. Since 2008, sediment loads have declined somewhat at two stations in Pennsylvania. Sediment loads have declined at all four stations in Delaware since 2000.

Chloride/Salinity: The streams of the watershed have experienced increasing chloride concentrations (salinity) due primarily to winter road salting. These recent trends have raised concerns about stream health across the watershed.

Bacteria: Pennsylvania monitors fecal coliform levels in streams. Levels in winter were found to be below the swimming standard for this pollutant, while in the summer, that threshold is exceeded in the warmer months, June through September. Delaware, where *Enterococcus* bacteria levels are monitored, has seen varying trends since 2000, with slight declines in the Brandywine and Red Clay Creeks, and no trend in the White Clay Creek and Christina River.

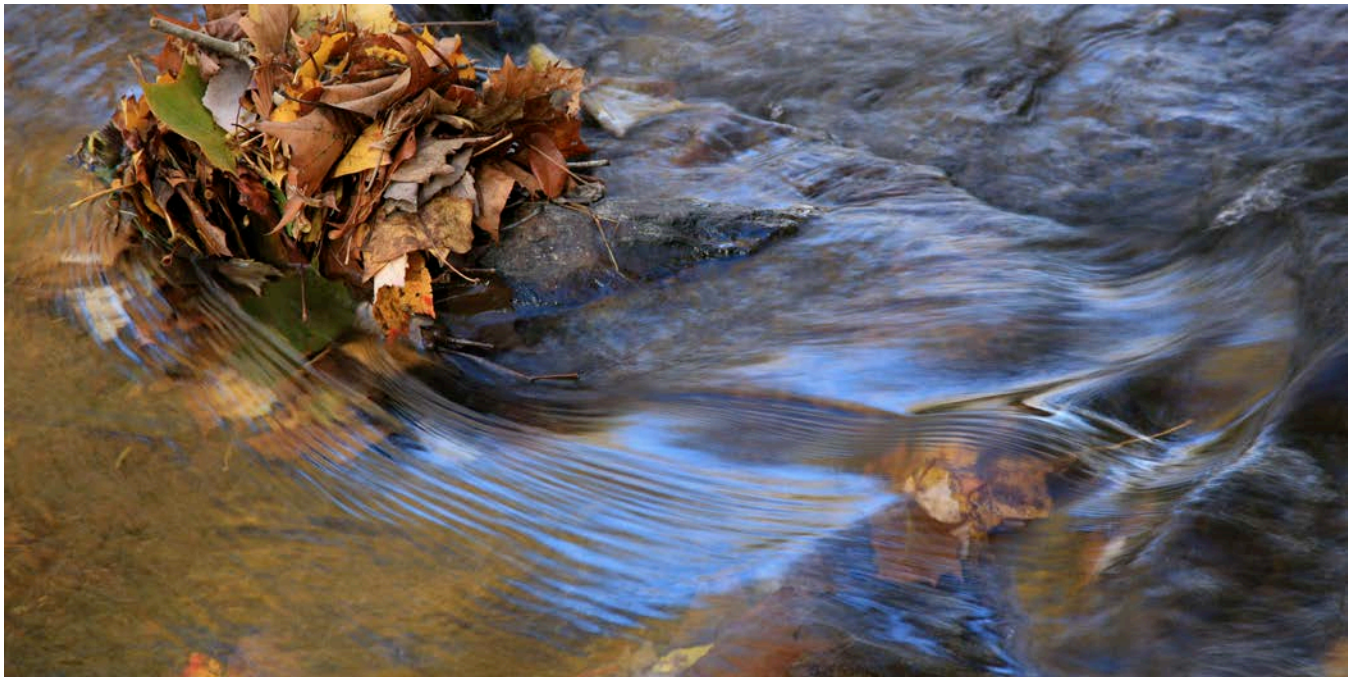
Water Temperature: The USGS has found statistically significant increases in water temperature in Chester County, while there appears to be no trend in Delaware. This may be caused by global changes in temperature, or more localized effects such as increased urbanization or reduction of riparian tree cover.

Land Cover: The watershed is characterized by a diversity of land types, with roughly equal amounts of urbanization, agriculture, and natural lands (e.g., forests and wetlands). In general the lower portions of the watershed are more urbanized, with agriculture concentrated upstream in the Brandywine, White Clay, and Red Clay Creek watersheds. Significant increases in developed land since the mid-1990s have occurred in the watersheds of the Brandywine-Christina, with a concomitant decrease in agriculture and natural lands. Future scenarios developed by the Shippensburg University Center for Land Use and Sustainability (CLUS) and others show that land cover characteristics of the Brandywine-Christina watershed will be affected by the planning and management decisions by regulators and policy makers.

Impervious Cover: Impervious cover has increased along with development in the watershed in recent decades. This trend has implications for water quality in streams and for overall watershed health. In the ten years from 2001 to 2011 many watersheds saw imperviousness levels approaching the critical 10% threshold above which they are considered negatively impacted.

Natural Resources Ordinances: Planning efforts dating back decades have helped Chester County develop strategies to guide growth and foster natural resource protection in the watershed. For instance, to date over half of the municipalities in the Chester County portion of the watershed have rigorous riparian buffer ordinances. Funding provided by the William Penn Foundation through the DRWI has allowed partners to provide technical assistance to municipalities in implementing further ordinances specifically to protect and enhance water quality. In Delaware, research by the University of Delaware Water Resources Center has found a similar level of ordinance-based protection for the waters of the watershed in New Castle County as that found in Pennsylvania.

Protected Lands: Protected lands can include local, county, state or national parks and preserves, agricultural easements, purchased development rights, deed-restricted lands such as open space within residential developments, or land owned outright by conservancies or other conservation organizations. Within the Brandywine-Christina watershed the Brandywine Creek watershed has the highest percentage of protected land



(31%), followed by the White Clay Creek (28%), the Red Clay Creek (27%), and the Christina River (15%).

Agricultural Restoration and Riparian Buffers: Many programs of the US Department of Agriculture Farm Service Agency (FSA) and Natural Resources Conservation Service (NRCS) provide funding assistance to reduce agricultural runoff. In Pennsylvania, in recent years, nearly 26 miles of protected riparian buffers, 10.3 miles of stream fencing, and over 7,100 acres of farmland are being stewarded with conservation plans. Delaware has implemented over 10 acres of riparian forest planting, 1,600 linear feet of stream fencing, and over 4,300 acres of land under nutrient management plans.

Stream Restoration: The Brandywine Red Clay Alliance has undertaken several stream restoration projects in the watershed. To date, over five miles of stream have been restored through 17 projects in the Brandywine and Red Clay Creek watersheds. Ongoing monitoring by Stroud Water Research Center and others is being used to determine the long-term effects on stream health.

Fish Passage: Fish passage research has been conducted on the Delaware portions of the Brandywine-Christina watershed, specifically in the Brandywine Creek and White Clay Creek watersheds. Successes include the removal of Dam No. 1 on the White Clay Creek and the potential removal of the West St. Dam (Dam No. 1) in Wilmington.

Fish Consumption Advisories: DNREC and the Pennsylvania Fish and Boat Commission publish annual Fish Consumption Advisories for waterbodies in the watershed. Many Delaware waters have consumption advisories for legacy pollutants such as PCBs, DDT and dioxins. Mercury is increasingly a source of impairment of concern in Pennsylvania. In 2018 DNREC reinstated the Red Clay Creek as a stream suitable for trout, evidence of improvement.

Water Supply: The data show water demand is declining in both states in the period from 2001-2017 (for Delaware) and 2006 to 2016 (for Pennsylvania). Factors which explain the trends could include reduction in water loss due to leakage, increased water conservation measures, pricing water rates rising and loss of some industrial water users in the watershed.

Wastewater Dischargers: Wastewater dischargers in the watershed are largely located in Pennsylvania. The Brandywine Creek watershed has the largest number of wastewater dischargers. The 20-year trend for the dischargers in the Brandywine Creek and Red Clay Creek watersheds (1995-2015) show generally lower levels of discharge, due to some dischargers closing and some converting to spray irrigation Others factors influencing this trend may be water conservation by commercial, industrial and residential users, and reduction of groundwater infiltration into sewer pipes. ■

Chapter 1
Introduction

Report Background

This report provides an overview of the Brandywine-Christina watershed and a snapshot of the trends and conditions of the watershed. This report is funded by the William Penn Foundation through the *Delaware River Watershed Initiative* (DRWI). The primary author of this report is the University of Delaware Water Resources Center. The Brandywine Conservancy provided formatting and graphics expertise. The Brandywine-Christina watershed partners, as well as the numerous nonprofit, private and government entities working in the watershed have contributed significantly to the content of this report by providing data, maps, text and review at all stages of the report-writing process.

Prior Watershed Studies and Planning Documents

Management plans and reports for the Brandywine-Christina watershed have been comiled by a robust group of organizations working within the watershed over the past several decades. The plans and reports listed in **FIGURE 1-1** detail the numerous reports compiled since 1952. Many of these reports and plans were developed for a specific purpose such as assisting with county-wide planning processes, providing a snapshot of the conditions of a specific watershed within the Brandywine-Christina watershed or providing data and recommendations for future watershed management efforts. Several groups have

FIGURE 1-1 Watershed management and planning reports for the Brandywine-Christina watershed.

Community Watershed Soil and Water Conservation Work Plan for Brandywine Creek (Chester County, PA and New Castle County, DE) (1952); Supplements: 1966, 1974, 1977, 1986, 1991, 1994, 2014, 2014. U.S. Department of Agriculture, for Chester County Soil Conservation District and New Castle County Soil Conservation District. 1952-2014

Work Plan Brandywine Creek Watershed. Chester County Commissioners, Chester County Soil Conservation District, New Castle Soil Conservation, Chester County Water Resources Authority, PA Department of Forests & Waters, PA Fish and Boat Commission, U.S. Department of Agriculture, U.S. Department of Interiorr, and approved by U.S. Congress. April 1962 (as amended 1962, 1966, 1974, 1987, 1991, 1995 and 2014)

The Plan and Program for the Brandywine Technical Report and Summary. University of Pennsylvania and USGS. 1968

The Brandywine Plan: A Plan for the Upper East Branch Brandywine Creek. Institute for Environmental Studies, University of Pennsylvania, Chester County Water Resources Authority. 1968

Preliminary Study of the Brandywine Creek Sub-basin – Final Report. USEPA Region 3. 1983

Regional 537 Plan Update Drinking Water Study, Part One. Downingtown Area Regional Authority. 1990

Red-White Clay Creeks: Final Watershed Protection Plan & Environmental Assessment. USDA Natural Resources Conservation Service, USDA Forest Service, Chester County Conservation District, New Castle County Conservation District. 1996

State of the Watershed Report, Brandywine Valley. Brandywine Valley Association. 1997, 1998, 1999 and 2005

White Clay Creek and Its Tributaries Watershed Management Plan. White Clay Creek Wild and Scenic River Task Force, National Park Service, Northeast Region. 1998, Amended 2001

Phase I and II Report – Christina River Basin Water Quality Management Strategy. Water Resources Agency for New Castle County NCC, Chester County Conservation District, Chester County Water Resources Authority. 1998

Red Clay Valley State of the Watershed Report. Red Clay Valley Association. 1998, 1999, 2005

Final Report: Governor's Water Supply Task Force. University of Delaware Water Resources Agency. 1999

Phase III Report: Christina Basin Water Quality Management Strategy. Water Resources Agency for New Castle County NCC, Chester County Conservation District, Chester County Water Resources Authority. 1999

Watershed Action Plan – White Clay Creek. Chester County Water Resources Authority, Chester County Planning Commission, Camp Dresser, and McKee, Gaadt Perspectives, LLC. 2002

Watershed Action Plan – Red Clay Creek. Chester County Water Resources Authority, Chester County Planning Commission, Camp Dresser, and McKee, Gaadt Perspectives, LLC. 2002

Watershed Action Plan – Brandywine Creek. Chester County Water Resources Authority, Chester County Planning Commission, Camp Dresser, and McKee, Gaadt Perspectives, LLC. 2002

Watersheds: An Integrated Water Resources Plan for Chester County, PA and Its Watersheds. Chester County Board of Commissioners. 2002

Brandywine Creek Watershed Conservation Plan. Brandywine Valley Association, Chester County Water Resources Authority, Gaadt Perspectives, LLC. 2003

A Watershed Restoration Action Strategy (WRAS) for the Delaware Portion of the Christina Basin "A Clean Water Strategy to Protect and Restore the Watersheds of the Brandywine, Red Clay, and White Clay Creeks and Christine River in Delaware". Christina Basin Clean Water Partnership (University of Delaware Water Resources Agency). 2003

Watershed Restoration Action Strategy (WRAS): State Water Plan Subbasins 03H and 03I; Christina River Basin. Pennsylvania Department of Environmental Protection. 2003

Upper East Branch Brandywine Creek Watershed Conservation Plan. Brandywine Conservancy. 2004

Honey Brook Authority Wellhead Protection and Management Plan. Honey Brook Borough Authority. 2008

Restoration Plan for Radley Run Watershed, Chester County, PA. Brandywine Valley Association. 2008

State of the Delaware River Basin Report. Delaware River Basin Commission. 2008

White Clay Creek State of the Watershed Report. University of Delaware, Water Resources Center. 2008/2016

White Clay Creek Watershed Reforestation Plan. Taproot Native Design and Brandywine Conservancy. 2009

City of Wilmington Source Water Protection Plan. Crockett Consulting. 2010

Christina Basin Pollution Control Strategy. Delaware Tributary Action Teams, University of Delaware, Delaware Department of Natural Resources and Environmental Control. 2011

Concept Plan for the Brandywine Creek Greenway. Brandywine Conservancy. 2012

PA American Water—Coatesville Source Water Protection Plan. PA American Water. 2013

County-Wide PA Act 167 Stormwater Management Plan for Chester County, PA (and Model Municipal Stormwater Ordinance). Chester County Water Resources Authority, Chester County Planning Commission, Chester County Conservation District. 2013

Implementation Plan for the Christina Basin, PA Stormwater TMDLs. Brandywine Valley Association (now known as BRC). 2014

Brandywine-Christina Healthy Water Fund: Preliminary Feasibility Study. University of Delaware and The Nature Conservancy in Delaware. 2015

Technical Report for the Delaware Estuary and Basin. Partnership for the Delaware Estuary. 2017

also worked to compile a series of *State of the Watershed* reports on the Brandywine Creek, Red Clay Creek and White Clay Creek watersheds. Using these prior *State of the Watershed* reports as a model, this report serves as a comprehensive update on the current conditions and trends in the entire Brandywine-Christine watershed.

Watershed Conservation Restoration and Efforts

The Brandywine-Christina watershed has a robust group of academic institutions, nonprofit organizations, commercial and industrial entities, and federal, state, county and municipal governments that have been working both collaboratively and independently for many years to improve water quality and bring awareness to the importance of preserving the water resources in the watershed. The many contributions of these entities are briefly summarized below. This list is not exhaustive yet demonstrates the extensive investments and activities that have taken place and the range of organizations involved in efforts to improve overall health within the Brandywine-Christina watershed.

Land and Water Conservation Organizations

The watershed benefits from a rich history of pro-active nonprofit land and watershed conservation organizations, which includes the first small watershed association in America (the Brandywine Valley Association, now known as the Brandywine Red Clay Alliance) and the two oldest small watershed conservation organizations, the Brandywine Valley Association and the Red Clay Valley Association. The thirty-eight watershed and conservation nonprofit organizations in **FIGURE 1-2** work extensively in the Brandywine-Christina watershed and educate stakeholders, conduct research and assist property owners to implement best management practices (BMPs) that have helped to make improvements in the Brandywine-Christina watershed.

Here are a few examples of activities conducted by some of the nonprofit organizations listed in **FIGURE 1-2** and the efforts to improve the Brandywine-Christina watershed:

- Red Streams Blue Program of Brandywine Red Clay Alliance is designed to move impaired streams to unimpaired status. It has leveraged over $200,000 from the City of Wilmington and Pennsylvania local governments to bring in over $5 million from the Pennsylvania's Growing Greener program, The William Penn Foundation and

FIGURE 1-2 **Nonprofit land and water conservation groups in the Brandywine-Christina watershed.**

PENNSYLVANIA	DELAWARE
Brandywine Conservancy	Christina Conservancy, Inc.
Brandywine Red Clay Alliance	Coalition for Natural Stream Valleys
Buck and Doe Trust	Delaware Audobon Society
Cheshire Hunt Conservancy	Delaware Center for Horticulture
Ducks Unlimited	Delaware Chapter of the Sierra Club
French and Pickering Creeks Conservation Trust	Delaware Greenways
Friends of Marsh Creek Watershed	Delaware Nature Society
Friends of White Clay Creek Preserve	Fairfield Watershed Association
Guardians of the Brandywine	Friends of White Clay Creek State Park
Longwood Gardens	Green Delaware
Natural Lands	Mount Cuba Center
S.A.V.E.	The Nature Conservancy in Delaware
Save Our Water	Partnership for the Delaware Estuary
Stroud Water Research Center	Sierra Club
The Land Conservancy of Southern Chester County	Urban Environmental Center
Trout Unlimited	Waterfront Watch of Wilmington
West Chester Fish Game & Wildlife Association	White Clay Creek Watershed Association
White Clay Creek Wild and Scenic Management Committee	Widener Environmental and Natural Resources Law Clinic
White Clay Flyfishers	

private funders for 17 stream restoration projects in the Brandywine-Christina watershed.

- The White Clay Wild & Scenic River Program implemented The White Clay Creek Wild and Scenic River Restoration Fund (WCRF) in Delaware, a voluntary tax check-off to enhance water resource restoration and management programs within the White Clay Creek watershed, Delaware's only federally designated Wild and Scenic River. Specifically, funds have been used to increase water quality monitoring, implement research and restoration projects including rebuilding freshwater mussel beds and installing green infrastructure, as well as supplementing educational programming on watershed stewardship. Initiated in 2012, to date it has generated $42,890 (2012-2017).

- Stream clean ups are a popular management and education practice throughout the Brandywine-Christina watershed. Nonprofit organizations as well as neighborhood, civic and religious groups host clean ups throughout the watershed. The larger clean ups hosted by nonprofit organizations in the watershed include: the Red Clay Valley Clean Up, the Christina River Watershed Cleanup, the First State National Historical Park Clean Up and Brandywine Clean Ups. Several of these clean ups have been ongoing for many years. For example, the Christina River Watershed Cleanup began in 1992 and over this time period more than 360 tons of tires, appliances, household items and other trash have been cleared from within the watershed. Similarly, the Brandywine Conservancy has been organizing a clean up on the Brandywine River since 1994 and has collected 31 tons of trash and debris from the adjacent floodplain during its annual river clean up in the spring. In 2017 alone, the clean ups listed below, which are not an exhaustive list of the clean ups in the watershed, have collected and removed over 36 tons of trash from the watershed:

    - Christina River Clean Up (Christina Conservancy)–over 18 tons
    - Brandywine Clean Up (Brandywine Red Clay Alliance)–3 tons
    - Brandywine Clean Up (Brandywine Conservancy)–0.9 tons
    - First State Historical Park (The Nature Conservancy)–1.7 tons (2,670 lbs in April/690 lbs in October)
    - Red Clay Valley Clean Up (Brandywine Red Clay Alliance)–13 tons

  As an aside, several of the clean up host organizations have reported that the total haul from year-to-year has tapered off due to the prior success of clean up efforts and public education.

- Other significant conservation and restoration work in the watershed comes from the charity and generosity of individual donors through direct financial contributions, and memberships in the organizations working in the area. Further, the watershed benefits immeasurably from the countless hours volunteers donate for stream cleanups and tree planting efforts.

Christina Basin Partnerships

In addition to the efforts of these nonprofit organizations, an inclusive network of organizations, agencies and private entities in the Brandywine-Christina watershed have been working together collaboratively since 1994. For over 20 years, the states of Pennsylvania and Delaware, the U. S. Environmental Protection Agency (USEPA), the Delaware River Basin Commission (DRBC), local co-coordinators from Chester County Water Resources Authority (for PA) and the University of Delaware Water Resources Center (for DE), and numerous partners in the watersheds have been working together through the Christina Basin Clean Water Partnership to advance restoration efforts within the Brandywine Creek, Red Clay Creek, White Clay Creek and Christina River watersheds in Delaware and Pennsylvania. The vision of the Partnership was to make the waters of the Basin fishable, swimmable and potable as per the Federal Clean Water Act. The partnership benefits from active and committed participation of the PA and DE environmental agencies, county health, planning and environmental agencies, federal and interstate agencies (NRCS, USGS, USEPA, DRBC), land and water conservation organizations, water and wastewater purveyors, municipal governments and interested individuals.

The group's goals have been to assist EPA and the states in developing high flow and low flow Total Maximum Daily Loads (TMDLs) and to conduct voluntary collaborative improvement projects and outreach. In 2003 the Christina Basin Clean Water Partnership was selected as the number one rated watershed grant and received $1 million dollars from the USEPA's Targeted Watersheds Grant (TWG). Through continued interactions, all of these municipal, county, state and

federal governments, private and nonprofit organizations in the watersheds are continuing to make investments in restoration in the Brandywine-Christina watersheds.

Christina Watersheds Municipal Partnership

Since 2009, Brandywine Red Clay Alliance, the Chester County Water Resources Authority and the Chester County Conservation District have worked together with the Chester County municipalities in the Christina Basin to improve runoff and pollutant reduction from urban and agricultural lands. Originally known as the Christina TMDL Implementation Partnership (CTIP), the CWMP has broadened its efforts to address water quality restoration of impaired streams across the Chester County portion of the Christina Basin, and beyond the geographic limits of the TMDLs. Of the 45 Chester County municipalities in the Basin, 38 are participating in the CWMP. Recent efforts of CWMP have focused on pilot collaborative planning in three clusters of municipalities – an urban cluster (Coatesville, South Coatesville, Modena and Valley), a rural cluster (Honey Brook Borough and Honey Brook Township) and a suburban cluster in the East Branch White Clay Creek. The work included substantial Basin-wide modeling of nonpoint source loading for sediment and phosphorus, GIS mapping and collaborative planning for developing pollution reduction plans and TMDL implementation plans to meet NDPES MS4 requirements. The draft plans are currently under review by Pennsylvania Department of Environmental Protection (PADEP). The Honey Brook cluster prepared a collaborative plan, including collaborative restoration projects. The other watershed partners collaborated on planning, and although no collaborative projects could be identified, they will continue to work together to find other aspects of implementation that can benefit from collaborative efforts.

Federal, Interstate and State Agencies

The Brandywine-Christina watershed has many challenges and resources at risk to water quality degradation with implications for environmental and ecological resources and the health and economic viability of the communities of the watershed. The federal, interstate and state agencies have recognized these challenges, and have worked closely with the watershed's local governments, organizations and entities to advance restoration and preservation efforts. Some key roles of these agencies are briefly highlighted in FIGURE 1-3 on the right.

County and Municipal Governments

Pennsylvania encompasses 71% of the Delaware River Basin with 51 municipalities located within three counties (Lancaster, Chester and Delaware Counties). An additional

FEDERAL

USDA Natural Resources Conservation Service (NRCS and formerly as Soil Conservation Service) has been actively engaged in planning and implementing improvements in the Basin since the 1950's. Millions of dollars of NRCS technical and financial assistance have been directed into carefully planned and targeted efforts in the Basin for water quality and flood improvements over the past seven decades.

U.S. Geological Survey (USGS) has been conducting water resources monitoring, modeling and investigations in the Basin since the 1960s through its cooperative program with Chester County and the Chester County Water Resources Authority.

U.S. EPA established the federal regulations for and oversees the implementation of the Clean Water Act NPDES programs by the states of DE and PA. USEPA also provided the Christina Basin Targeted Watershed Grant funding as well as ongoing Clean Water Act Section 319 funding, which both states rely upon for work in the Christina Basin.

INTERSTATE

The Delaware River Basin Commission (DRBC) implements its interstate regulatory responsibilities for ensuring activities within the Delaware Basin including service as convener and coordinator for the Christina Clean Water Partnership, providing technical support for development of the Christina TMDLs, implementation of the high flow TMDLs through its wastewater discharge dockets, and administrator of the Christina Targeted Watershed Grant.

The White Clay Wild and Scenic Program is managed by a bi-state Watershed Management Committee composed of local citizens, representatives of various organizations or interest groups, and delegates from local and state government. The National Park Service provides technical and financial support. Together with partner organizations and municipalities, the committee and the National Park Service are working to carry out the White Clay Management Plan.

STATE

Delaware Department of Natural Resources and Environmental Control (DNREC) has contributed in multiple ways to the improvement of the Basin's watersheds. For example, DNREC provided funding for installation of demonstration agricultural water quality improvement projects in the PA headwaters of the Basin, through its commitment to the "inclusive interstate collaboration" of the interstate Christina Clean Water Partnership. DNREC also maintains ongoing water quality monitoring programs, in conjunction with the DE Geological Survey, within the Basin.

Pennsylvania Department of Environmental Protection (PADEP) continues its strong role in advancing water quality improvements in the PA portion of the Christina Basin. PADEP was directly involved with USEPA and DNREC in development of the Christina Basin TMDLS, implements the Clean Water Act NPDES programs (wastewater and stormwater) within Pennsylvania, and has invested millions of dollars of funding for installation of numerous agricultural and urban BMPs, stream restoration, stream enhancement and other water quality improvement projects within the PA portion of the Basin, and in collaboration with PA Department of Conservation and Natural Resources, has invested significant funds in watershed outreach and education, trails and land preservation within the Basin. PADEP also maintains ongoing water quality monitoring programs within the Basin, in collaboration with USGS.

FIGURE 1-3 Agencies

28% of the Basin lies within Delaware and is comprised of four municipalities (including the Cities of Newark and Wilmington), and unincorporated areas of New Castle County. A small portion of the Basin also lies within Maryland's unincorporated area of Cecil County. Thus, for water quality restoration to occur in an effective and sustainable manner requires the direct efforts of five counties and 55 municipalities through their land development and growth management planning, regulations and programs. The summaries below focus on the local government efforts in Chester and New Castle Counties, given they collectively comprise 94% of the Basin.

Municipal Governments

As described in the programs below, Pennsylvania municipalities in the Brandywine-Christina watershed have taken actions to establish land development and land use management plans, policies and regulations that promote land development to occur in a manner that allows for preservation and protection of natural and water resources within the watershed. While the net cumulative actions of each municipality may vary, all municipalities in Chester County have adopted plans, policies and codes consistent with Chester County's *Landscapes2* comprehensive plan to promote land use and growth management in a manner that protects natural and cultural resources. Many of these efforts have benefited from technical and/or financial assistance from Chester County and/or local nonprofit land and water conservation organizations.

The municipalities in the Delaware portion of the watershed include: Elsmere, Newark, Newport and Wilmington. The Delaware municipalities in the watershed must meet federal standards in their jurisdictions to comply with the federal and state Clean Water Act National Pollutant Discharge Elimination System (NPDES) requirements. The City of Wilmington is also required to comply with the NPDES Combined Sewer Overflow (CSO) Control Policy and the City has invested over $10 million and installed million gallon underground tanks to reduce combined sewer overflows. In 2007 the City of Wilmington became the first government in Delaware to adopt a stormwater utility to fund sewer improvements and in 2017 the City of Newark adopted a stormwater utility. The municipalities in the watershed have also implemented policies and codes for landuse development and redevelopment in a manner that protects natural resources and considers source water protection in the watershed. The cities of Newark and Wilmington have also invested upstream in the Pennsylvania headwaters to implement BMPs and protect northern Delaware's sources of drinking water supply.

County Governments

Chester County, PA–Since 1989, the Chester County Board of Commissioners has demonstrated the commitment of the County and its constituents to sustainable land use and growth management with land and water preservation through several proactive and progressive programs. Through these programs, the County has created and funded one of the most comprehensive and sustained efforts in the country to promote a high quality of life, vibrant economies and healthy communities and environment. **FIGURE 1-4** briefly highlights accomplishments achieved within the Brandywine-Christina as a result of Chester County's programs carried out in close partnership with municipalities, nonprofit conservation organizations and other stakeholders.

New Castle County, DE–The Brandywine-Christina watershed contains unincorporated areas of New Castle County. These areas lie within the watershed but outside of the jurisdiction of the four municipalities and are governed by New Castle County. County and state government policies and programs, as highlighted in **FIGURE 1-4**, have established protections for the natural resources of the Brandywine-Christina watershed through land use planning, source water protection and water supply programs in the southern part of the watershed.

Public Water Suppliers and Private Industry

Six public water purveyors withdraw source water from the streams of the Brandywine-Christina watershed for public water supplies. Several of these purveyors have prepared source water protection plans for their systems, and some have implemented actions in conjunction with the Brandywine-Christina partners. Private water use industry has also invested in water quality restoration and protection in the Brandywine-Christina watershed. The following are examples of such activities:

- In 2010, the City of Wilmington adopted its Source Water Protection Plan. The city has spent $279,850 for source water protection projects since its adoption (Miller 2014).
- SUEZ, formerly United Water, an investor-owned water purveyor in the White Clay Creek watershed, committed $700,000 from 2012 through 2017 to watershed restoration projects as part of its Long Term 2 (LT2) Enhanced Surface Water Treatment Rule permit (Hubbard 2014).
- Victory Brewing Company, headquartered in Downingtown, PA, founded the Headwaters Grant Pro-

CHESTER COUNTY

- Chester County Land Use Planning and Management Programs
  - *Landscapes* and *Landscapes2*–implementation of county-wide comprehensive land use planning including conservation and preservation policies and principles since 1996
  - Landscapes Vision Partnership Municipal Grant Program–$3,200,000 County funding and $800,000 staff services to all 46 municipalities in the Brandywine-Christina for comprehensive plans, ordinances, and special studies related to improved land use and water and natural resources protection since 1996
- Open Space Preservation Programs
  - Agricultural Land Preservation – approximately $38,000,000 County funding to perBrmanently preserve 16,400 acres of agricultural land in Brandywine-Christina since 1990; and Brandywine Headwaters Preservation Program
  - Preservation Partnership – approximately $32,100,000 County funding for permanent preservation of 6,300 acres of land in the Brandywine-Christina since 1990
  - Park and Recreation Spaces – approximately $19,600,000 County funding for permanent protection of 3,600 acres of municipal parks and public recreational spaces since 1989
- Community Revitalization Programs
  - Approximately $18,500,000 combined County funding and County-managed block grant funding to 9 boroughs and the City of Coatesville for 39 projects in the Brandywine-Christina to improve stormwater and drainage to encourage redevelopment of existing urban centers within the Brandywine-Christina as a strategy to help protect rural lands from new development since 2002
- Integrated Water Resources Planning and Management
  - Adoption and implementation of *"Watersheds – A County-Wide Integrated Water Resources Management Plan for Chester County and Its Watersheds"* since 2002
- Stormwater Management Planning and Coordination
  - Adoption and implementation of "County-Wide Act 167 Stormwater Management Plan for Chester County, PA" since 2013, including adoption of the model stormwater ordinance by all 46 municipalities within the Brandywine-Christina
- Floodplain Management
  - Close coordination with FEMA restudy and implement new flood risk maps for the Brandywine-Christina and assist all 46 municipalities within the Brandywine-Christina to adopt floodplain ordinances that meet or exceed current FEMA standards in 2017.
- Soil and Water Conservation
  - The Chester County Conservation District (CCCD), in coordination with partnering agencies, has conducted a comprehensive on-the-ground effort to promote and implement the Regional Conservation Partnership Program (RCPP). The program has provided a number of opportunities for BMP implementation in the Delaware River watershed of Chester County since 2015. These efforts in the past year alone have resulted in numerous conservation practices being installed as well as setting up leads for future high quality conservation work. The work this year has resulted in 15 contracted projects totaling $1,312,493 on 570 acres in Chester County. This work includes ten waste storage facilities, 8,352 feet of riparian and animal exclusion fencing, 51,985 square feet of heavy use area protection, four stream crossings, and over 100 acres of nutrient management planning in high priority Red Clay Creek, White Clay Creek, and the Brandywine Creek watersheds.

NEW CASTLE COUNTY

- Unified Development Code (UDC)
  - New Castle County's Department of Land Use regulates planning for all new and existing development in unincorporated New Castle County and enforces the laws governing building and zoning codes and property maintenance. New Castle County, Delaware adopted its Unified Development Code (UDC) in December 1997. The purpose of the UDC is to establish standards, procedures, and minimum requirements, consistent with the Comprehensive Development Plan, which regulate and control land use development in the unincorporated areas of New Castle County.
- Water Resource Protection Area (WRPA) Program
  - Since 1987, the University of Delaware has administered the WRPA Program for New Castle County. The purpose of the WRPA ordinance in the New Castle County UDC is to protect environmentally-sensitive areas that are very important to the state's water supply and water quality. Under the UDC, all development within recharge, wellhead, Cockeysville formation, and reservoir water resource protection areas are required to meet maximum impervious cover thresholds (20% to 50%) and may require groundwater recharge facilities, water monitoring, and water management facilities. Presently, over 20% of New Castle County land area is protected by the WRPA provision of the Unified Development Code.
- NPDES Municipal Separate Stormwater System (MS4) Permit
  - Over the last decade and a half, watershed strategies such as the New Castle County and the Delaware Department of Transportation (DelDOT) NPDES MS4 Permit Program required by the Federal Clean Water Act, have improved or preserved water quality along the streams in the County that fall within the Brandywine-Christina watershed.
- Water Supply Coordinating Council (WSCC)
  - The mandate of the WSCC is to work cooperatively to achieve water-supply self-sufficiency in northern New Castle County (eliminate dependence on out-of-state water supplies) by 2010. Water purveyors in northern New Castle County have developed over two billion gallons in reserve water supplies since the drought of 1999 to provide a healthy surplus of supply to meet peak demands during the next drought and providing a reserve to meet new economic development in Delaware.
- New Castle Conservation District (NCCD)
  - Under the oversight of DNREC, the NCCD is responsible for conservation work within the boundaries of New Castle County. Initially financial and technical assistance was primarily provided to agricultural producers and other landowners interested in conserving soil and protecting water quality. As the county developed, programs and priorities also became directed to non-agricultural drainage, streambank erosion, and flood control projects. Both agricultural and nonagricultural projects have been implemented in the Brandywine-Christina watershed.

FIGURE 1-4 PA and DE County programs impacting the Brandywine-Christina watershed.

gram. For every bottle of Headwaters purchased, a portion is donated to the Headwaters Grant Program. Victory has donated nearly $58,000 to local watershed conservation groups.

- DuPont's Clear into the Future® initiative works with the community to preserve the Delaware Estuary by providing grants for research and restoration projects in the estuary, including the Brandywine-Christina watershed.
- Arcelor Mital has supported watershed stewardship efforts of the Brandywine Red Clay Alliance (BRC) for many years.
- The Dockstader Foundation, associated with the Southern Chester County Solid Waste Authority, has provided funding for public awareness projects and has sponsored annual watershed education programs of the BRC for many years.

Academic Institutions

The following colleges' and universities' main campus or satellite campuses are located in the Brandywine-Christina watershed. These include:

- Delaware County Community College
- Delaware Technical Community College
- Delaware State University
- Lincoln University
- Penn State
- University of Delaware
- University of Pennsylvania
- West Chester University
- Widener Law School
- Wilmington University

These academic institutions have conducted research projects on a variety of important water resource related topics in the watershed. Through this research valuable data has been collected. Additionally, the results of this research help to inform BMP implementation and policy initiatives that impact the watershed.

As detailed above, the Brandywine-Christina watershed benefits from a dedicated array of organizations and individuals working to improve water quality. Many of these projects and programs are successful because of the collaborative nature of the partners working in the watershed. These efforts will continue to grow and be effective in improving water quality as collaboration continues among the academic institutions, nonprofit organizations, commercial and industrial entities and federal, state, county and municipal governments.

William Penn Foundation DRWI

In 2013, the William Penn Foundation of Philadelphia launched an ambitious strategic project to focus a significant portion of its environmental grant making activities on its *Delaware River Watershed Initiative* (DRWI) with the intent of aligning over 50 leading nonprofit organizations in a coordinated and collaborative effort to protect and restore water quality in the Delaware River Basin.

Through a science-informed process, the Foundation identified eight sub-watershed areas where there were known key water quality stressors (loss of forested headwaters, agricultural runoff, polluted stormwater and aquifer depletion) and institutional capacity to make a significant impact at addressing these stressors. The Brandywine-Christina watershed was one of the designated areas.

The Brandywine Conservancy was selected to be the coordinator of a six-member team of nonprofit organizations for the Brandywine-Christina watershed. The other members of the team are Stroud Water Research Center, Natural Lands, Brandywine Red Clay Alliance, The Nature Conservancy in Delaware and the University of Delaware Water Resources Center. Since the inception of the DRWI, the Brandywine-Christina Watershed Partners have been working together with a renewed sense of coordination and collaboration.

Between 2013 and 2017, the William Penn Foundation awarded grants totaling over $40 million to over 50 nonprofits involved in the DRWI. The Brandywine-Christina Watershed Partners have focused their efforts in six geographic "focus areas" in Chester County, PA where work is being concentrated – the Brandywine Headwaters, Little Buck Run, Red Clay Creek Headwaters, Plum Run, Sharitz and White Clay Creek Headwaters. The principal strategies being employed by the Partners to address the watershed's stressors involve conserving farmland, implementing agricultural BMPs, reforesting stream corridors, instream restoration, securing municipal adoption of land use regulations, providing technical assistance to municipalities on stormwater management and developing a sustained funding mechanism for underwriting water quality protection and restoration activities. In this first phase of the DRWI the Partners

protected 19 farms encompassing 1,244 acres with 9.1 miles of streams; planted 34,507 trees to create 22.35 miles of forested stream buffers; installed 8.75 miles of stream bank fencing; and implemented 185 separate agricultural BMPs on 44 farms. The partners also secured the adoption of six Riparian Buffer Ordinances by local municipalities.

Water quality monitoring to measure the results of the Partners' work is a key component of the DRWI. Sampling stations have been set up in strategic stream locations in each focus area since 2014, and water quality monitoring by the Stroud Water Research Center and the Academy of Natural Sciences has been ongoing. The goal is to restore the Brandywine-Christina watershed to provide clean, sufficient water for a healthy ecosystem and human communities.

This financial commitment was only a fraction of the estimated $190 million needed to continue this important work over the next six years. In early 2018, the William Penn Foundation announced its commitment to continue funding the DRWI by approving an additional $40+ million in grants for the entire Delaware River watershed to the involved partner organizations. These Phase II grants will run through 2020.

In Phase II, the Brandywine-Christina Watershed Partners will eliminate Little Buck Run as a focus area and concentrate its work on an expansion of three of the original focus areas to include more of the subwatersheds' headwater streams **(FIGURE 1-5)**. The Partners will deploy four main strategies: land protection (purchasing agricultural and conservation easements); agricultural restoration (taking a whole-farm approach to land and nutrient management); stream restoration (helping landowners restore impaired streams to health); and municipal innovation (promoting water quality protection through regulations and policies, low-impact development, pollutant reduction plans, green stormwater infrastructure, and separate stormwater and sewer systems). The projected outcomes for Phase II include preserving from development 17 farms covering 890 acres and buffering 10.5 miles of streams. A full suite of agricultural BMPs are expected to be implemented on 41 farms. Approximately 1½ miles of streams are expected to be restored. Dozens of municipalities will receive planning and technical assistance.

The Partners are seeking to raise over $9.7 million in non-William Penn Foundation funding from public and private sources. In addition, a new conservation funding mechanism is proposed—the Brandywine-Christina Healthy Water Fund, which is projected to bring an additional $1–10 million, and under which the watershed's downstream beneficiaries will invest in upstream land restoration and protection measures that ensure water quality. The fund will initially be managed by The Nature Conservancy with technical support by the DWRC and guidance from the other Partners.

Work on the DRWI by the Brandywine-Christina Watershed Partners is also being generously supported by grants from numerous other organizations including the National Fish and Wildlife Foundation; Open Space Institute, City of Wilmington, DE; City of Newark, DE; and the Pennsylvania Department of Environmental Protection. ■

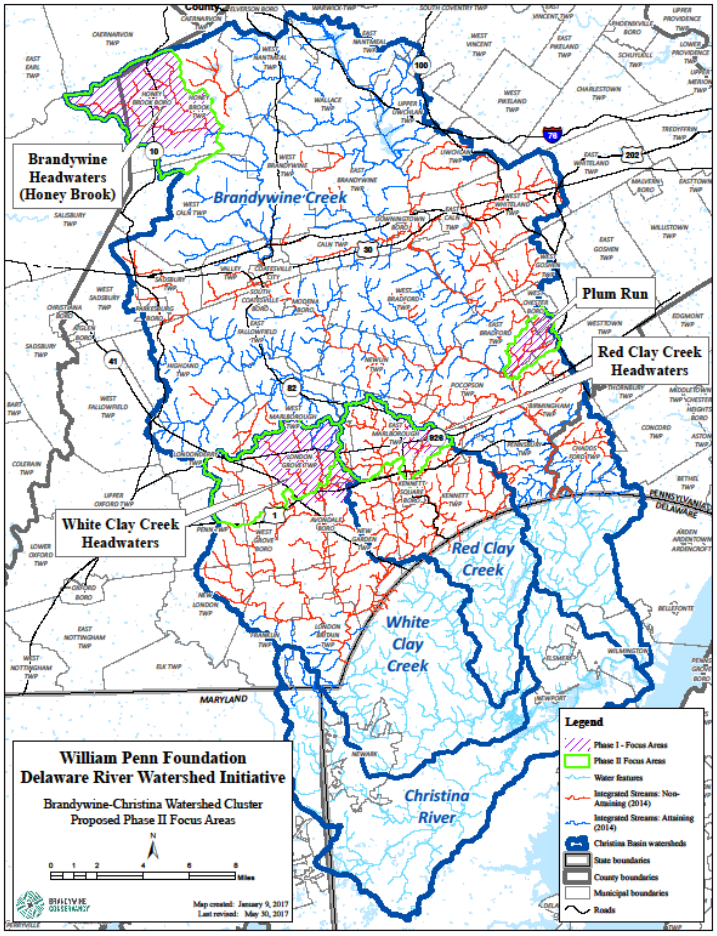


Figure 1-5 Brandywine-Christina Watershed Proposed Phase II and Phase I Focus Areas. (Brandywine Conservancy)

Chapter 2

Study Area Description

Watershed Overview

The Brandywine-Christina watershed, also referred to as the Christina Basin, is an integral part of the larger 13,000-square-mile Delaware River Basin which flows from the Catskill Mountains of New York through Pennsylvania and New Jersey, and into the Atlantic Ocean at the Delaware Bay. The Brandywine-Christina is only one of two interstate watersheds in the entire Delaware River Basin, adding complexity to the management of the watershed; it is also the second-largest watershed draining to the Delaware Estuary (after the Schuylkill River watershed).

The Brandywine-Christina watershed is one of the most historic small watersheds in the nation. It covers more than 565 square miles and is home to more than 590,000 people (U.S. Census 2010). The watersheds serve an essential role in meeting the drinking water and water supply needs of the residents and industries in northern Delaware and southeastern Pennsylvania. The Brandywine-Christina can supply up to 100 million gallons per day of drinking water from surface and groundwater sources for over 600,000 people in Delaware and Pennsylvania.

The watershed includes the Brandywine Creek, Red Clay Creek, White Clay Creek, and the Christina River watersheds (FIGURE 2-2). The headwaters and two-thirds of the land area of the watersheds are in Pennsylvania while the majority of the population is in Delaware. The Brandywine Creek watershed is the largest of the four watersheds spanning 324 square miles (93% in PA and 7% in DE). The Red Clay Creek watershed is the smallest of the four watersheds (55 square miles) with the largest portion in Chester County, PA (61%). The Red Clay Creek flows into the White Clay Creek and the combined flow empties into the tidal Christina River near Churchmans Marsh in New Castle County, DE. The White Clay Creek is the second largest watershed spanning 107 square miles. The White Clay Creek spans three states (PA, DE and MD) yet the land area is almost evenly split between Pennsylvania (57%) and Delaware (43%) with only a very small portion in Maryland. The Christina River has the third largest geographic footprint by land area, also spanning three states, and is the only watershed with the largest portion of land area in Delaware (86%). The remaining land area spans Maryland (10%) and Pennsylvania (3%). The Christina River watershed, which lies almost entirely in Delaware is the furthest downstream point in the entire Brandywine-Christina watershed. The relative proportions of land use are roughly similar in the Brandywine, White Clay and Red Clay Creek watersheds with agriculture, forest and wetlands, and suburban and urban land use groupings, each comprising approximately one-third of each watershed. The Christina River watershed is significantly more suburban and urban and less agricultural than the other watersheds.

Overall, 71% of the watershed lies in PA, 28% in DE, and 1% in MD. The entire 28% of the watershed that lies within DE is within New Castle County. Sixty-six percent of the watershed is in Chester County, PA. The remaining portions of the watershed are within Lancaster and Delaware Counties, PA and Cecil County, MD. Thus, 94% of the watershed is geographically contained within two counties – Chester County, PA and New Castle County, DE.

STATE	WATERSHED	SQUARE MILES	% IN STATE	% OF TOTAL
PA	Brandywine Creek	301	93%	
DE	Brandywine Creek	23	7%	
		324		**58%**
MD	Christina River	8	10%	
DE	Christina River	67	86%	
PA	Christina River	2	3%	
		78		**14%**
PA	Red Clay Creek	33	61%	
DE	Red Clay Creek	21	39%	
		54		**10%**
PA	White Clay Creek	61	57%	
DE	White Clay Creek	46	43%	
MD	White Clay Creek	0	0%	
		107		**19%**
	TOTAL	**564**		**100%**

Figure 2-2 Watersheds within the Brandywine-Christina watershed.

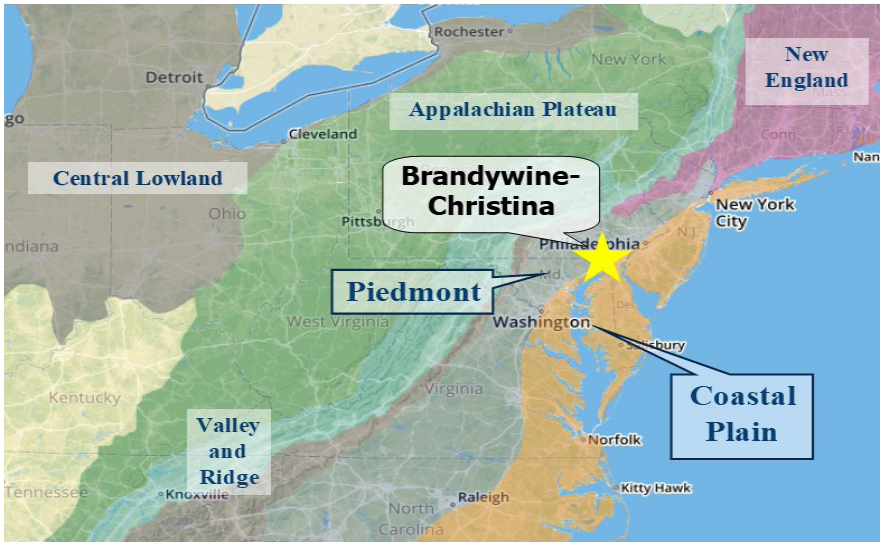


Figure 2-3 Physiographic provinces of the mid-Atlantic. (National Park Service, 2018)

Geology, Soils, Topography

The Brandywine-Christina watershed straddles three states, southeastern Pennsylvania, the northern tip of Delaware, and a small portion of Maryland. Most of the basin lies in the Piedmont physiographic province in Pennsylvania, while the southern portion lies in the Coastal Plain province in Delaware. The Brandywine, Red Clay, and White Clay Creeks flow through the rolling hills of the Piedmont before joining the Christina River in the Coastal Plain at the fall line, or transition zone between the upland Piedmont and low-lying Coastal Plain. The Christina River lies almost entirely in the Coastal Plain, and runs parallel to the fall line. Much of the early human development in the Brandywine-Christina watershed occurred along the fall line, as settlers harnessed hydraulic power for their mills and factories. **FIGURE 2-3** shows the location of the physiographic provinces of the mid-Atlantic and location of the Brandywine-Christina watershed.

The geology and topography of a watershed determines many of its surface flow and groundwater characteristics. The Brandywine-Christina watershed extends into the central part of Chester County, to the Welsh Mountains, with an elevation of over 1400 feet above sea level. The Brandywine flows for over 60 miles to the confluence with the Christina River at Wilmington, near the outlet to the Delaware River. The Red and White Clay Creeks have their headwaters in Pennsylvania, near Kennett Square and Avondale, respectively. They flow into Delaware, with the White Clay Creek heading east at Newark, and the Red Clay Creek joining the White Clay Creek near its confluence with the Christina River, and the head-of-tide.

Topographically, the Brandywine-Christina watershed is characterized by a transition from high rolling hills in the north to very flat Coastal Plain topography in the south. The Brandywine Creek defines the largest watershed within the Brandywine-Christina watershed, arising nearly sixty miles from its mouth, in the rolling farmland of northern Chester County, through the east-west limestone valley of the central Brandwine Creek watershed (the so-called Great Valley or Chester Valley), to the steep rocky outcrops of the fall zone in northern Delaware. The narrow stream valley in the lower reaches of the Brandywine provided ample hydraulic power for the mills of the early industrial period in the region. The White and Red Clay Creeks begin just a few miles north of the Pennsylvania border with Delaware, in gently rolling terrain, flowing down to converge near their confluence with the Christina River, just west of Wilmington, DE. The flat terrain of the Coastal Plain gives the Christina River a slow moving, meandering character, except in its headwaters to the west. This river is navigable even beyond its confluence with the White Clay Creek, and is tidal up to that point. The map in **FIGURE 2-4** represents the topography of the Brandywine-Christina watershed.

Several significant geologic formations affect the hydrology of the Basin. The upper basin is underlain by metamorphic bedrock (diabase, gneiss, and marble), while the Great Valley, cutting across the central Brandywine Creek watershed is characterized by limestone. Farther down are hard, metamorphic formations such as Wissahickon Schists and Brandywine Blue Gneiss (also known as Wilmington Blue Rock), while throughout the basin critical aquifer recharge areas, such as the Cockeysville formation, are characterized by limestone marble bedrock.

The Columbia and Potomac sediments of the Coastal Plain form the base for the tidal, navigable portion of the Brandywine-Christina watershed, which boasts an economically vital deep water port in Wilmington. **FIGURE 2-5** presents the geology of

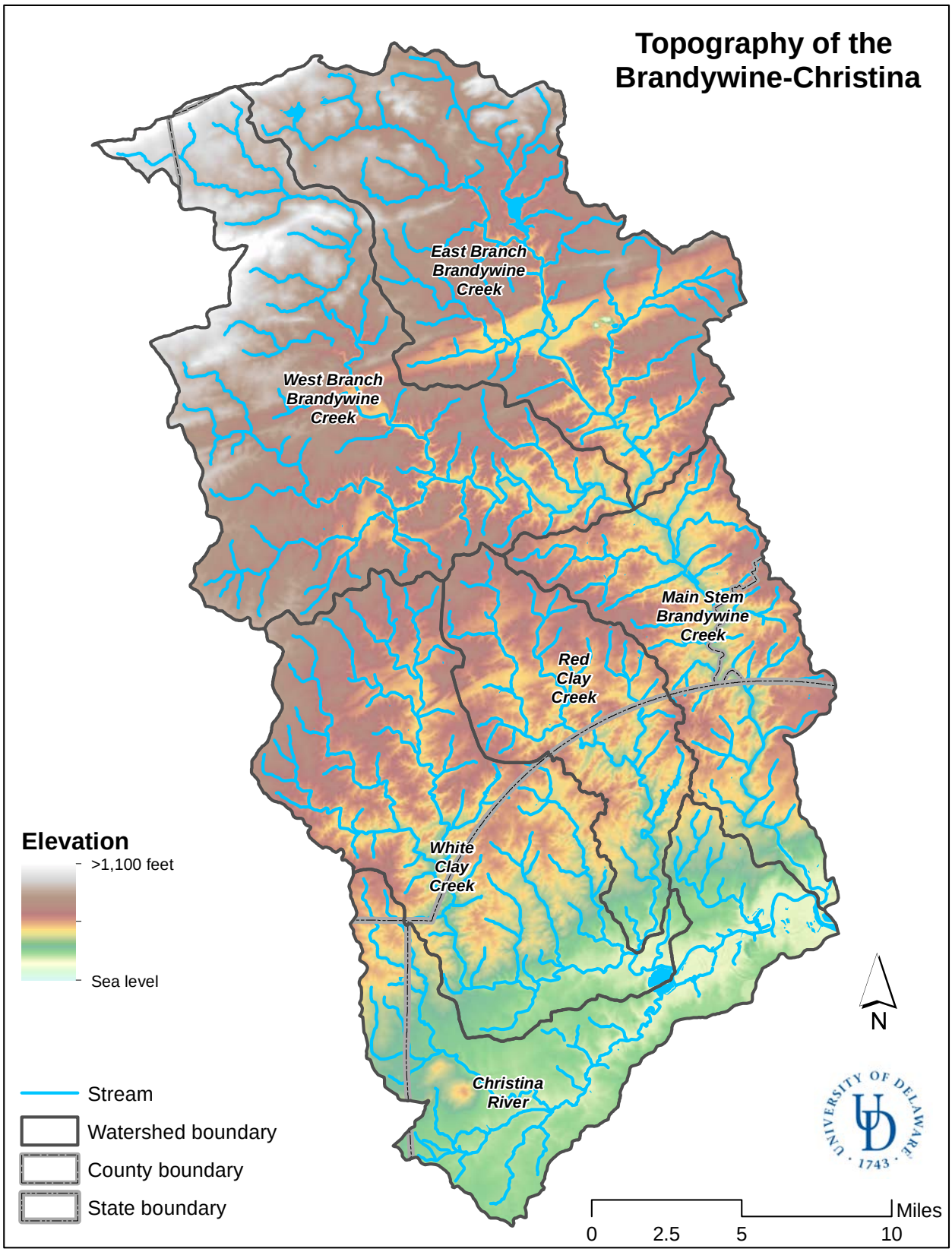


Figure 2-4 Topography of the Brandywine-Christina Watershed. (National Elevation Dataset)

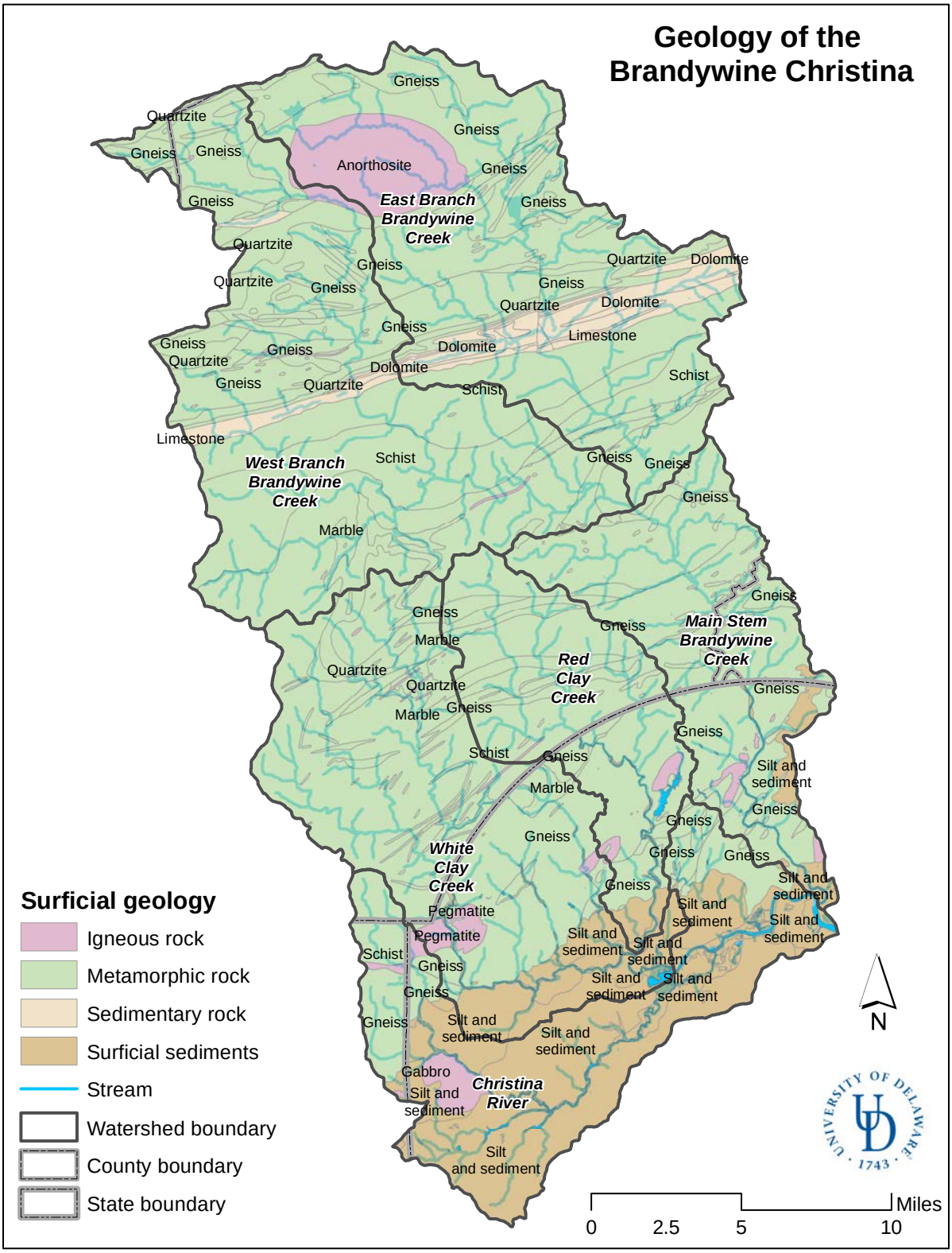


Figure 2-5 Geology of the Brandywine-Christina watershed. (Delaware Geological Survey, Maryland Geological Survey, Pennsylvania Geological Survey)

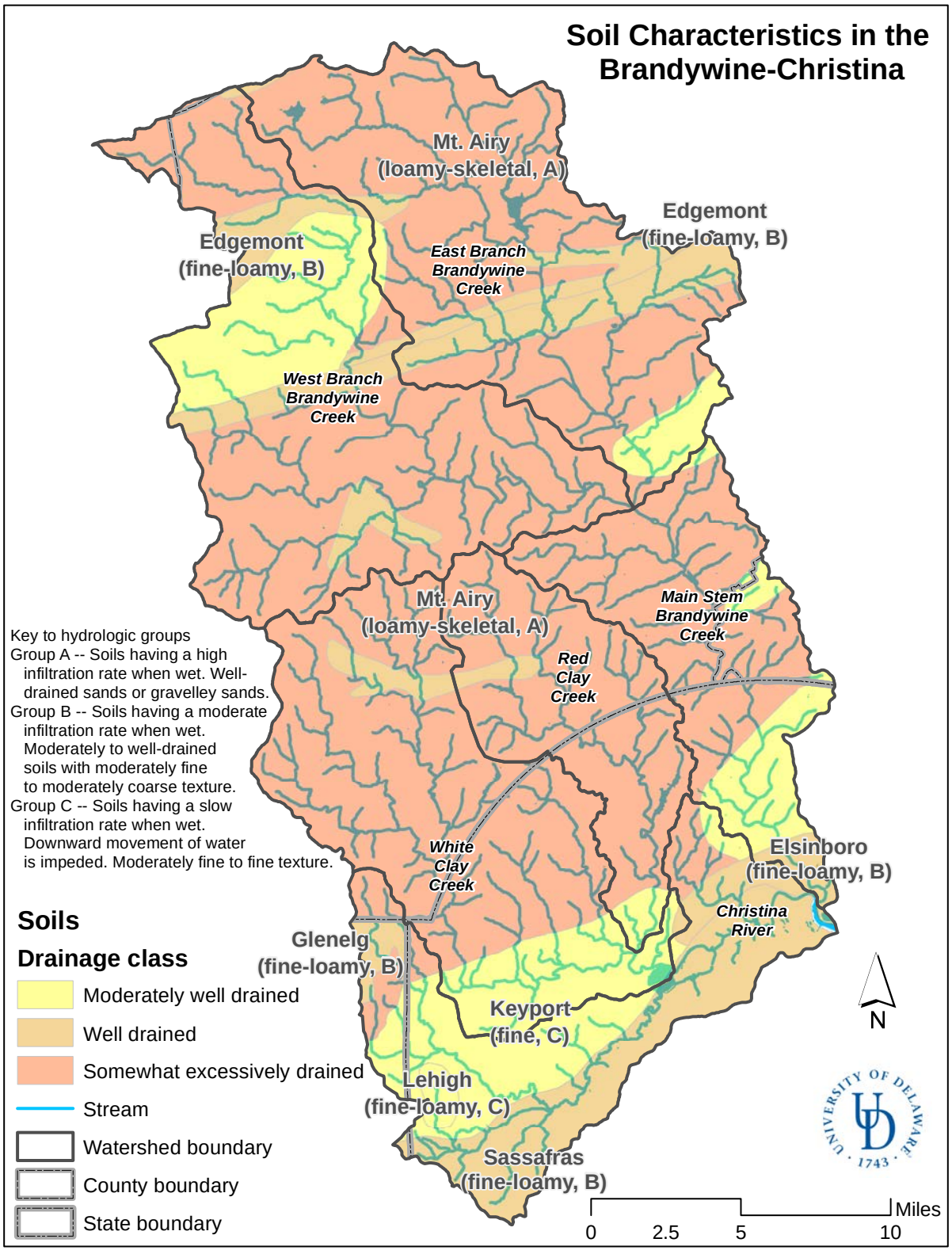


Figure 2-6 Soils characteristics in the Brandywine-Christina. (NRCS STATSGO Soils map)

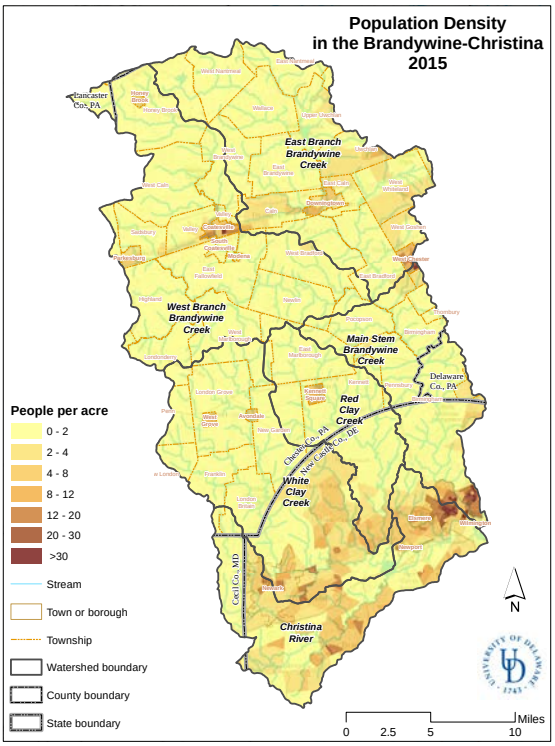


Figure 2-7 Population density in the Brandywine-Christina watershed, based on 2015 ACS 5-year population estimates. (US Census Bureau)

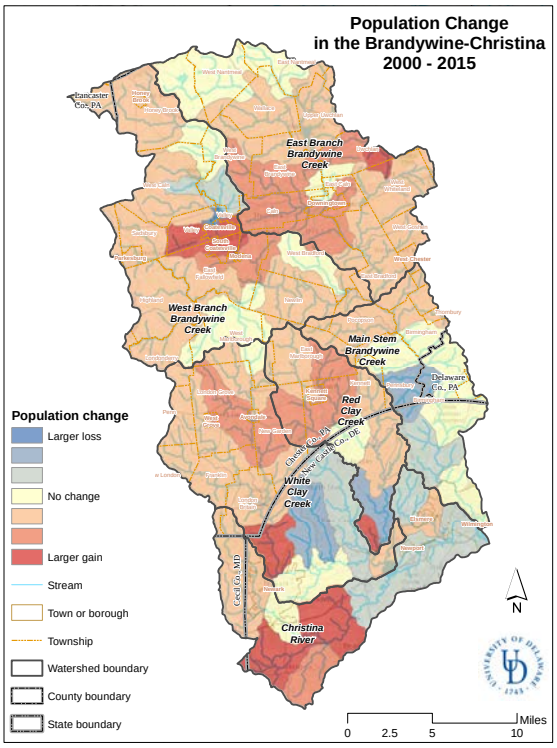


Figure 2-9 Population change by sub-watershed in the Brandywine-Christina watershed, between 2000 and 2015. (US Census Bureau)

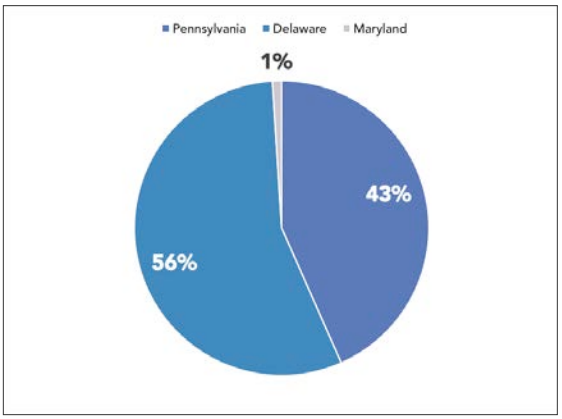


Figure 2-8 Proportion of population by state in the Brandywine-Christina watershed, 2015. (US Census Bureau)

WATERSHED	2000	2015
Brandywine	232,625	257,763
DE	44,866	45,392
PA	187,760	212,370
Christina	176,365	186,134
DE	170,479	179,164
MD	5,201	6,166
PA	686	805
Red Clay	41,520	45,834
DE	23,515	23,500
PA	18,005	22,334
White Clay	118,834	124,759
DE	95,210	93,769
MD	3	4
PA	23,621	30,986
Grand Total	***569,345***	***614,489***

STATE	2000	2015
Pennsylvania	230,072	266,494
Delaware	334,069	341,825
Maryland	5,204	6,169
Total	***569,345***	***614,489***

Figure 2-10 Population in 2000 and 2015 in the Brandywine-Christina watershed, by state and watershed. (US Census Bureau)

Figure 2-11 Population by state, 2000 and 2015 in the Brandywine-Christina watershed. (US Census Bureau)

the Brandywine-Christina watershed, showing underlying rock formation types.

Soil characteristics such as permeability and drainage are important within a watershed to determine hydrologic characteristics such as groundwater recharge, erodibility, and flood plain characteristics. Clay or silty soils are generally less permeable, and promote more runoff, while coarser, grainier soils promote infiltration. Within the Brandywine-Christina watershed Piedmont soils are generally well drained (hydrologic soil group A or B), while in the Coastal Plain they are somewhat less well drained (hydrologic soil group B and C). **FIGURE 2-6** presents the soils of the Brandywine-Christina watershed, based on the USDA Natural Resources Conservation Service (NRCS) State Soil Geographic (STATSGO) dataset, showing drainage characteristics (Soil Service Staff, 2018). The labels indicate soil series, with texture type and hydrologic group in parentheses.

Population

The Brandywine-Christina watershed is composed of roughly equal portions of three land cover types: urbanized, agricultural and natural lands (i.e. forest and wetlands). The more populous, urbanized areas are concentrated in the Delaware portions of the White Clay Creek, Brandywine Creek and Christina River watersheds, as well as the US Route 30 corridor in the Pennsylvania portion of the Brandywine Creek watershed. **FIGURE 2-7** illustrates the distribution of the population in the watershed, based on the U.S. Census Bureau American Community Survey five-year estimates from 2015. While the American Community Survey (ACS) 5-year estimates refer to a specific five year period, and not the population in 2015, data derived from this dataset are referred to as "2015" data in this report. See U.S. Census Bureau website for a fuller explanation of the American Community Survey data.

While most of the land area of the basin lie in Pennsylvania, Delaware has more population based on 2015 totals, with 56% of the basin's inhabitants living in that state, compared to 43% in Pennsylvania, see **FIGURE 2-8**.

Population in the Basin has grown in the period from 2000 and 2015 (based on the Decennial Census and the American Community Survey), with the greatest gains seen in the urbanized corridor of the Brandywine watershed, and in the greater Newark area in Delaware. The Pennsylvania portions of the Red and White Clay Creek watersheds also saw growth in population. Some of the older urbanized areas in Delaware saw small declines in population over the period. **FIGURE 2-9** shows the population change between 2000 and 2015, summarized by watershed.

FIGURE 2-10 shows the change between 2000 and 2015, by watershed and by state, of population in the basin, and **FIGURE 2-11** shows the change over the same period summarized by state.

FIGURE 2-12 shows the change in population, by watershed, between 2000 and 2015. The largest increase occurred in the Brandywine Creek watershed, concentrated in the urban corridor running from the City of Coatesville to Exton.

FIGURE 2-13 presents the total population for 2015, by watershed and state.

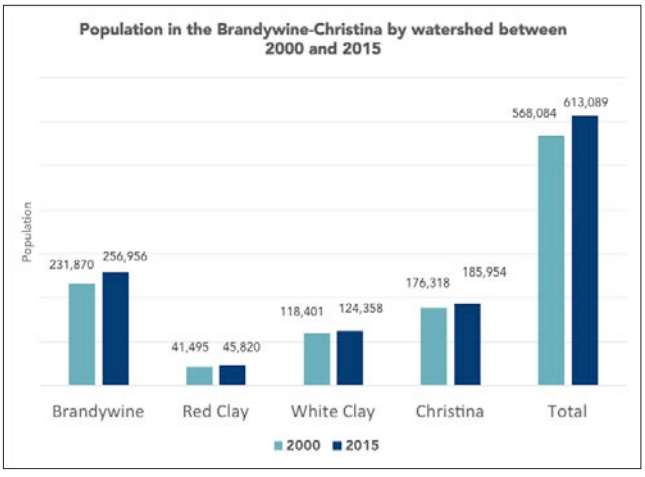


Figure 2-12 Population in 2000 and 2015 by watershed in the Brandywine-Christina watershed. (US Census Bureau)

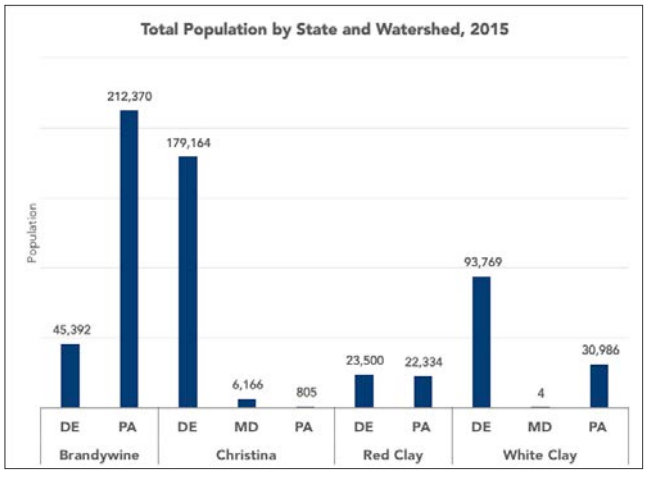


Figure 2-13 Population by state and watershed in the Brandywine-Christina watershed, 2015. (US Census Bureau)

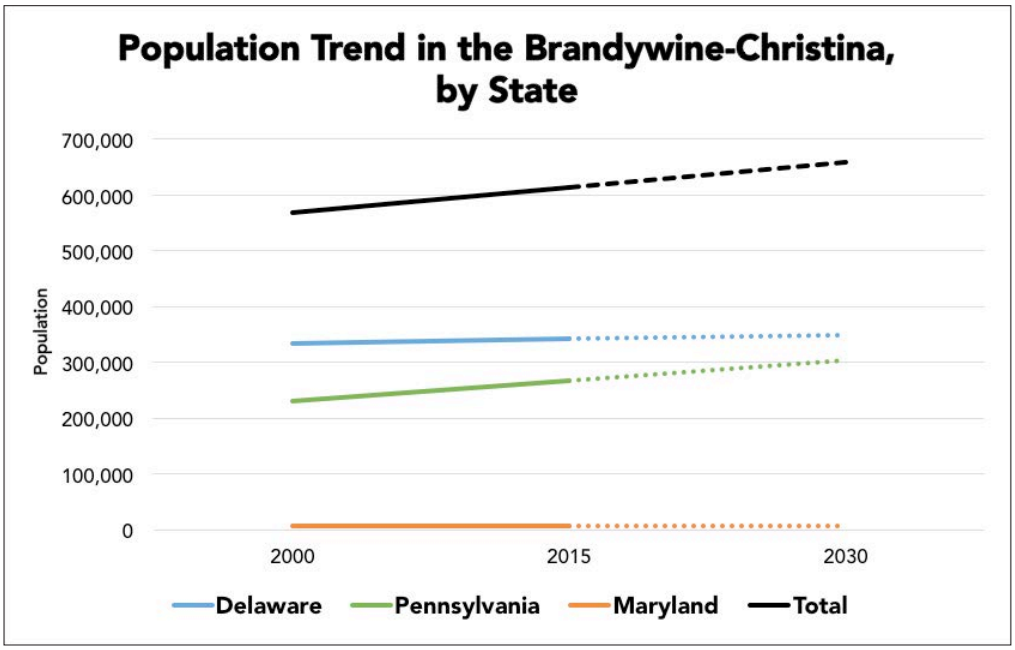


Figure 2-14 Population change, 2000 to 2030 by state. Dotted line indicates projection. (US Census Bureau)

Projected Growth

It is predicted that the population in the Brandywine-Christina watershed will increase, with much of the gain seen in the Pennsylvania portion, based on recent population trends. Of the four watersheds in the Brandywine-Christina the Brandywine Creek watershed is projected to see the most growth.

FIGURE 2-14 shows the actual and projected population by state in the Brandywine-Christina, from 2000 to 2030.

FIGURE 2-15 shows the actual and projected population by watershed in the Brandywine-Christina, from 2000 to 2030.

Governance

The interstate nature of the watershed and the numerous governing bodies and regulations create a complex operating environment. Even with these complexities, this robust network of governing bodies and organizations have worked together and improved the water quality due to their hard work and coordination. The watershed includes the following governing entities:

- Three states: Delaware, Pennsylvania and Maryland
- Five counties: Chester, Lancaster and Delaware counties in Pennsylvania; New Castle County in Delaware; and Cecil County in Maryland
- Fifty-five municipalities (51 in PA, 4 in DE) **(FIGURE 2-16)**

In addition to the governance as discussed above, the counties, and some municipalities must meet federal standards in their jurisdictions to comply with the federal and state Clean Water Act NPDES requirements.

Water quality improvements are occurring due to the regulatory and voluntary actions of these governing bodies as well as the efforts of the Christina Basin Clean Water Partnership, the Christina Municipal Watershed Partnership, private water purveyors, nonprofit organizations, and academic institutions in the watersheds.

Cultural and Recreational Resources

The Brandywine-Christina watershed provides numerous ecological and natural functions while also serving as a recreation destination. The White Clay Creek is designated by the U.S. Congress as a National Wild and Scenic River and is one of only two wild and scenic rivers in the United States designated on a watershed basis. The Brandywine-Christina watershed also enjoys a deep historic and cultural character including:

- Lenni Lenape settled along the White Clay Creek.
- It was discovered by the Swedes in the 17th century.
- It is the site of two Revolutionary War battlefields: Brandywine near Chadds Ford, PA, and Cooches Bridge near Newark, DE.

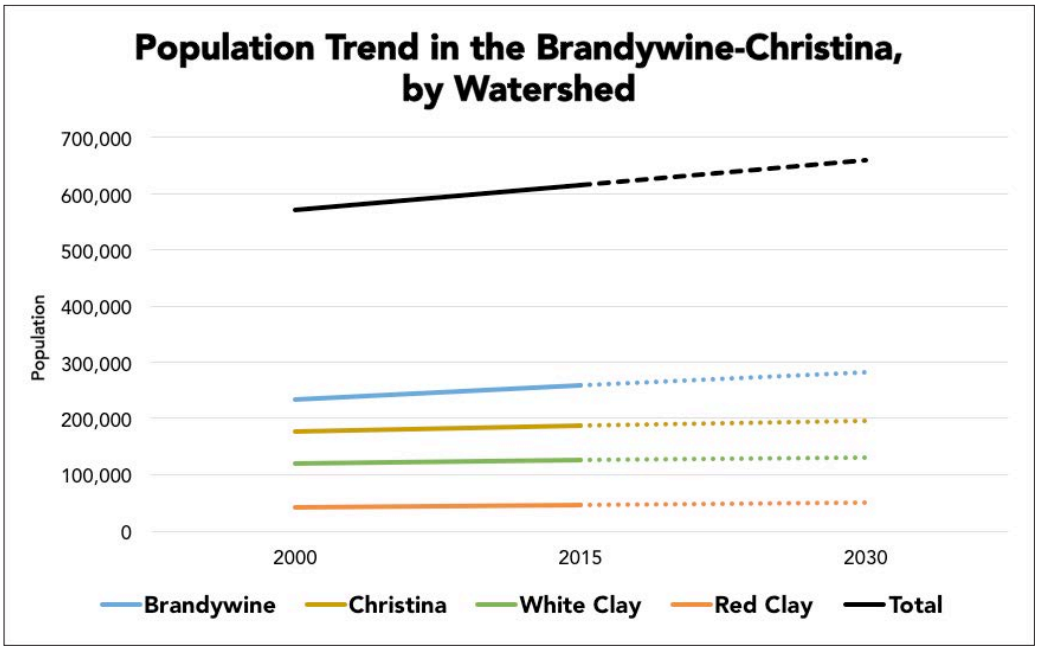


Figure 2-15 Population change, 2000 to 2030 by watershed. Dotted line indicates projection. (US Census Bureau)

- The rolling hills and productive soils are conducive to horse farming near the University of Pennsylvania Veterinary College, customary small grain and produce farming, plus hay and mushroom production. The area is also experiencing increasing settlement by Amish and Mennonite farmers, whose agricultural operations concentrate on dairy, small grains, and specialty crops.
- The old water-powered mills along the Brandywine Creek (such as the Hagley Museum in Wilmington and the Brandywine River Museum of Art in Chadds Ford) are popular tourist destinations.
- The Brandywine Valley is the inspiration for and home of the Brandywine School and Wyeth family artists.
- The temperate and humid mid-Atlantic climate is conducive to some of the most productive public gardens in the world at Winterthur Museum and Longwood Gardens.

The watershed has a robust and growing ecotourism industry and is an important attraction for a variety of popular tourism and recreational activities in the mid-Atlantic region, such as fishing, hiking, cycling and bird watching while the streams of the watershed provide a variety of primary and secondary recreational opportunities. The First State National Historical Park is a 1,100-acre property along the banks of the Brandywine. Several state parks and preserves are also located in the watershed, including the White Clay Creek State Park (DE), Brandywine Creek State Park (DE), White Clay Creek Preserve (PA) and Marsh Creek State Park (PA) and numerous municipal and county parks provide hiking and biking trails, fishing, water sports and camping for the community and visitors. The Brandywine Creek and its lakes hosts many canoe and kayak enthusiasts at public boat landings and commercial liveries. Delaware mariners own 8,400 registered boats that may ply the tidal waters of the Christina River and lower Brandywine Creek. The Brandywine Creek is truly a unique stream from an angling perspective with three distinct fisheries and over 14 target species available along its 60 mile length. The upper reaches of the Brandywine, particularly along the east branch, is a cold water fishery providing good habitat and conditions for freshwater trout; the middle and largest section is a warm water fishery with small mouth bass being the most targeted species; the lower portion from the City of Wilmington to its confluence with the Christina is a tidal fishery offering anglers opportunities to catch American shad, Hickory shad and Striped bass. The watershed also functions as protected-species habitat for the bald eagle, brook trout (the state fish of Pennsylvania), cerulean warbler and bog turtle.

Economic Value

The water, natural resources and ecosystems in the Brandywine-Christina watershed contribute an estimated economic value of $900 million to $4.9 billion annually to the Delaware and Pennsylvania economies. This value range is calculated through three different examinations, discussed below (**FIGURE 2-17**) (Narvaez and Kauffman, 2012).

BRANDYWINE-CHRISTINA MUNICIPALITIES

Delaware

Elsmere
Newark
Newport
Wilmington

Pennsylvania

Avondale
Birmingham
Caernarvon
Caln
Chadds Ford
Coatesville
Concord
Downingtown
East Bradford
East Brandywine
East Caln
East Fallowfield
East Marlborough
East Nantmeal
Franklin
Highland
Honey Brook Borough
Honey Brook Township
Kennett Township
Kennett Square
London Britain
London Grove
Londonderry
Modena
New Garden
New London
Newlin
Parkesburg
Penn
Pennsbury
Pocopson
Sadsbury
Salisbury
South Coatesville
Thornbury (Chester County)
Thornbury (Delaware County)
Wallace
West Bradford
West Brandywine
West Caln
West Chester
West Goshen
West Grove
West Marlborough
West Nantmeal
West Whiteland
West Sadsbury
Westtown
Upper Uwchlan
Uwchlan
Valley

Figure 2-16 Municipalities in the Brandywine-Christina watershed.

- **Economic value directly related to the Brandywine-Christina watershed's water resources and habitat:** The Brandywine-Christina watershed contributes $1.6 billion in annual economic activity from water quality, water supply, fish/wildlife, recreation, agriculture, forests and parks benefits. When accounting for navigation benefits at the Port of Wilmington, the watershed contributes $4.5 billion annually.
- **Value of goods and services provided by the Brandywine-Christina watershed's ecosystems:** Using natural capital as a measure of value, habitat in the Brandywine-Christina watershed provides $900 million annually in ecosystem goods and services in 2010 dollars, with a net present value (NPV) of $29 billion calculated over a 100-year period.
- **Employment related to the Brandywine-Christina watershed's resources and habitats:** Using employment as a measure of value, natural resources within the Brandywine-Christina watershed directly and indirectly support 125,000 jobs with $4.9 billion in annual wages.

The Brandywine-Christina watershed provides real and significant economic benefits to Delaware and Pennsylvania—benefits that are worthy of investment to keep these natural resources healthy and productive. Estimates were made by taking values from existing literature and studies and applying them to the Brandywine-Christina watershed using ecological economics and benefits-transfer techniques. Values are converted to 2010 dollars based on the change in the Northeast Region Consumer Price Index except where noted. ■

WATERSHED	ECONOMIC ACTIVITY[1] ($ MILLION)	ECOSYSTEMS SERVICES ($ MILLION)	JOBS	WAGES ($ MILLION)
Brandywine Creek	890	560	50,000	2,000
Red Clay Creek	145	84	10,000	425
White Clay Creek	420	165	25,000	1,000
Christina River[1]	190	99	40,000	1,500
Brandywine-Christina[1]	**1,645**	**908**	**125,000**	**4,925**

[1] Excludes navigation benefits from Port of Wilmington.

Figure 2-17 Annual economic value of the Brandywine-Christina watershed. (Narvaez and Kauffman, 2012)

Chapter 3

Natural Resources

Precipitation

Annual precipitation at weather stations in Chester County, PA and New Castle County, DE has increased since the early 1960s (FIGURES 3-1 AND 3-2). Annual precipitation measured by the National Weather Service at Wilmington Airport in Delaware ranged from 24.9 inches in 1965 to 56.7 inches in 2004. Annual precipitation measured by the U.S. Geological Survey (USGS) and Chester County Water Resources Authority (CCWRA) at Brandywine Creek at the Chadds Ford stream gage in Pennsylvania ranged from 34.5 inches in 1965 to 69.7 inches in 1996. Precipitation tends to be higher up in the Piedmont plateau of Chester County, PA due to the orographic effect where the weather stations are situated at higher elevations than the stations in New Castle County, DE.

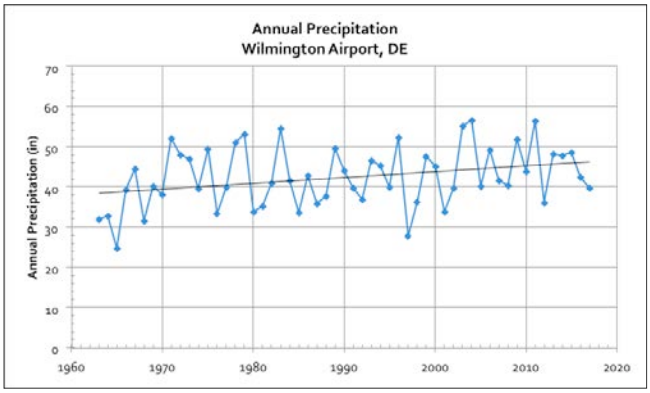


Figure 3-1 Annual Precipitation at Wilmington Airport, DE. (National Weather Service)

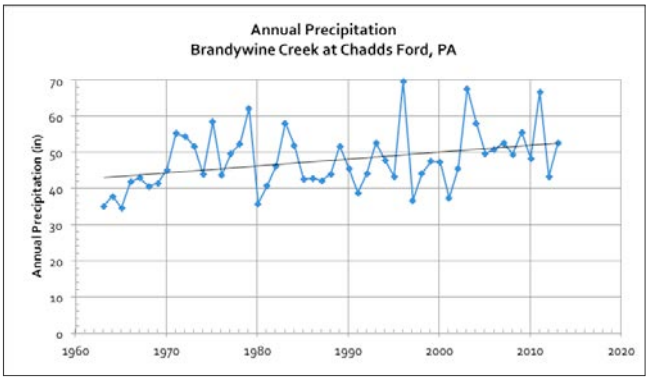


Figure 3-2 Annual Precipitation at Brandywine Creek at Chadds Ford, PA. (National Weather Service)

Air Temperature

Air temperatures recorded at weather stations in Chester County, PA and New Castle County, DE have increased over the last century (FIGURES 3-3 AND 3-4). The number of days per year with maximum air temperatures greater than 90°F in Chester County, Pennsylvania have increased from 10 to 20 in the 1890s to over 40 by 2013 (Sloto and Reif 2017). Maximum air temperatures as measured by the National Weather Service at Wilmington Airport in Delaware have increased since 1960 with a peak of 103°F in 2010.

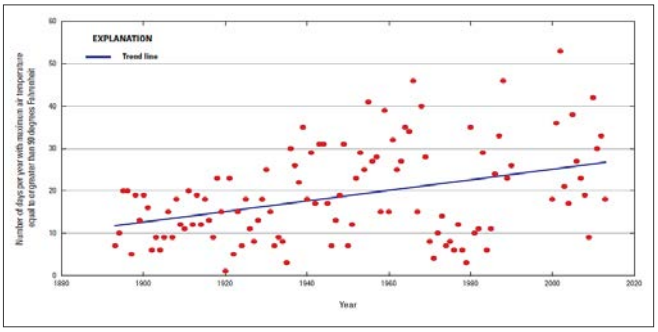


Figure 3-3 Number of days per year with maximum air temperature greater than 90°F in Chester County, Pennsylvania, 1893-2013. (Sloto and Reif 2017)

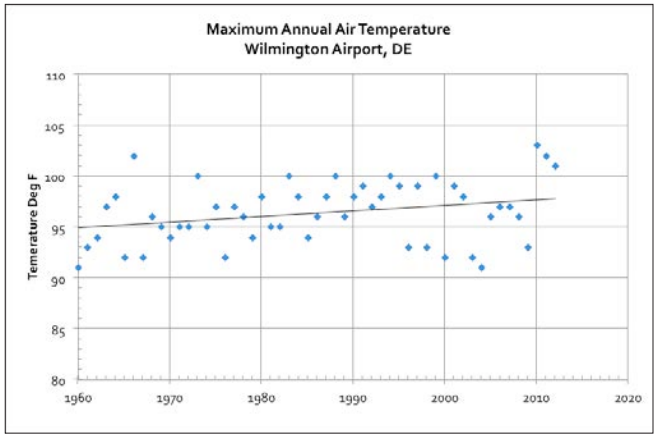


Figure 3-4 Maximum annual air temperature at Wilmington Airport, DE. (National Weather Service)

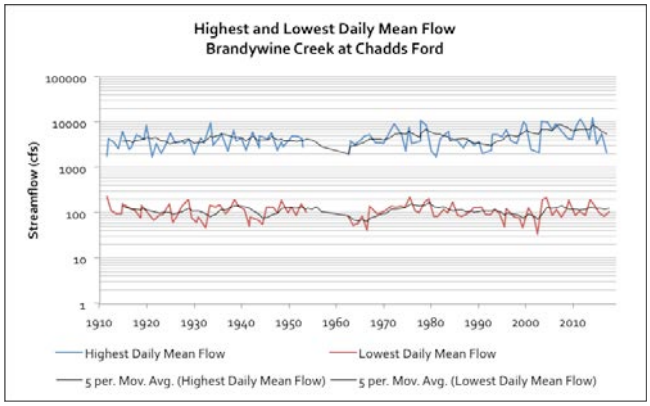


Figure 3-6 Peak and low streamflow at Brandywine Creek at Chadds Ford, PA since 1913. (USGS)

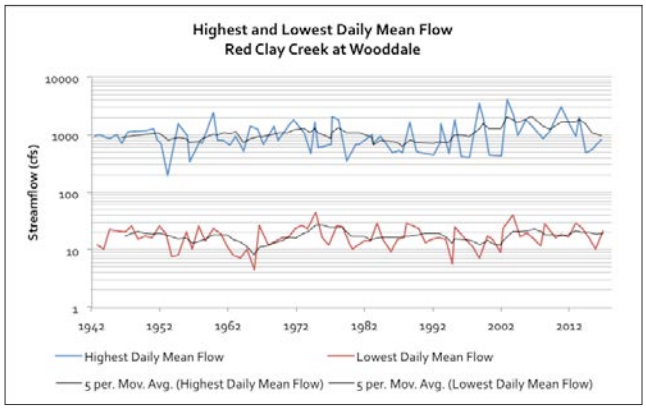


Figure 3-7 Peak and low streamflow at Red Clay Creek at Wooddale, DE since 1946. (USGS)

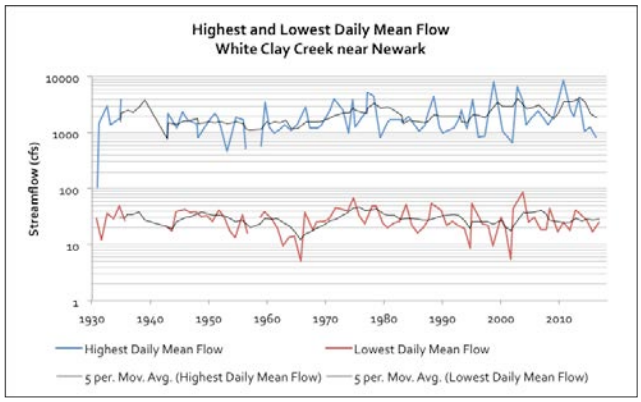


Figure 3-8 Peak and low streamflow at White Clay Creek near Newark, DE since 1930. (USGS)

Surface Hydrology

Streamflow

With the onset of watershed urbanization and warming air temperatures, peak streamflows (floods) have increased since the 1960s along the Brandywine Creek at Chadds Ford, PA and Red Clay Creek at Wooddale and White Clay Creek near Newark, DE **(FIGURES 3-7 & 3-8)**. Low flows (drought flows) at all three drinking water streams declined since the wet 1970s, bottomed out during the droughts of 1995-2002 and have since recovered over the last 15 years since the last drought.

Peak Discharge Events

There are 19 USGS continuous stream gage stations located in the Brandywine-Christina watershed, 13 in Pennsylvania operated under the cooperative USGS/Chester County/CCWRA program, and 6 in Delaware. USGS monitors and collects peak flow data for these gages, and the data are published online by the National Water Information System (NWIS). The peak streamflow data published by USGS is the highest median daily flow for each water year, and therefore is not the highest instantaneous flow for that date. Thus, the instantaneous peak flow will be higher than the median flow for these events.

As part of the USGS/Chester County/CCWRA cooperative program, the USGS evaluated flow data to determine if any statistically significant trends of change were evident over the entire periods of record. For this evaluation, USGS reviewed data from one station in the Red Clay Creek watershed and eight stations in the Brandywine Creek watershed with respect to the bankfull discharge (also referred to as the two-year recurrence for their entire periods of record). The USGS concluded that there were not statistically significant trends of change for the magnitude of peak streamflow equal to or greater than the two-year recurrence interval or the number of annual peak streamflows equal to or greater than the two-year recurrence interval. (Sloto and Reif, 2017)

The Delaware Geological Survey (DGS) and the Center for Environmental Monitoring and Analysis (CEMA) have compiled peak discharge data from the period of record for nine of these USGS stream gage stations in northern Delaware and southern Chester County. Information describing historic peak flow events and volumes are listed below for these nine stations in the lower Basin as well as an additional three stations in the upper portion of the Brandywine Creek watershed is presented in the following tables **(FIGURE 3-9)**.

GAGE STATION	LOCATION	PERIOD OF RECORD
USGS 01478000	Christina River at Coochs Bridge	April 1943-current year
USGS 01478245	White Clay Creek near Strickersville, PA	August 1996 to current year
USGS 01478650	White Clay Creek at Newark, DE	March 1994 to current year
USGS 01479000	White Clay Creek near Newark, DE	October 1931 to September 1936, June 1943 to September 1957, October 1959 to current year
USGS 01479820	Red Clay Creek near Kennett Square, PA	January 1988 to current year
USGS 01480000	Red Clay Creek at Wooddale, DE	April 1943 to current year
USGS 01480015	Red Clay Creek near Stanton, DE	October 1988 to current year.
USGS 01481000	Brandywine Creek at Chadds Ford, PA	August 1911 to September 1953, October 1962 to current year. Prior to October 1911, monthly discharge only
USGS 01481500	Brandywine Creek at Wilmington, DE	October 1946 to current year. Prior to December 1946, monthly discharge only
USGS 01480300	West Branch Brandywine Creek at Honey Brook	1960 to present
USGS 01480870	East Branch Brandywine Creek below Downingtown	1972 to present
USGS 01480617	West Branch Brandywine Creek at Modena	1970 to present

Figure 3-9 USGS Gage Stations in the Brandywine-Christina watershed.

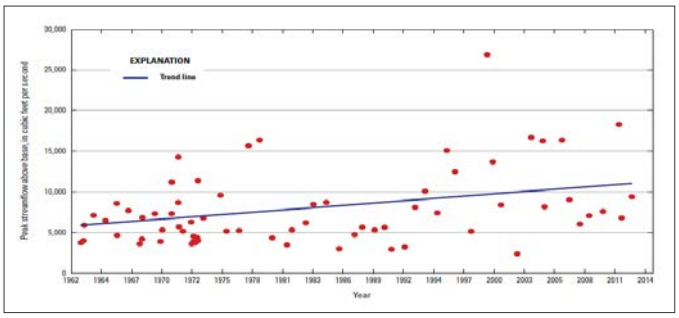


Figure 3-5 Peak streamflow at Brandywine Creek at Chadds Ford, PA, 1962-2012. (Sloto and Reif 2017)

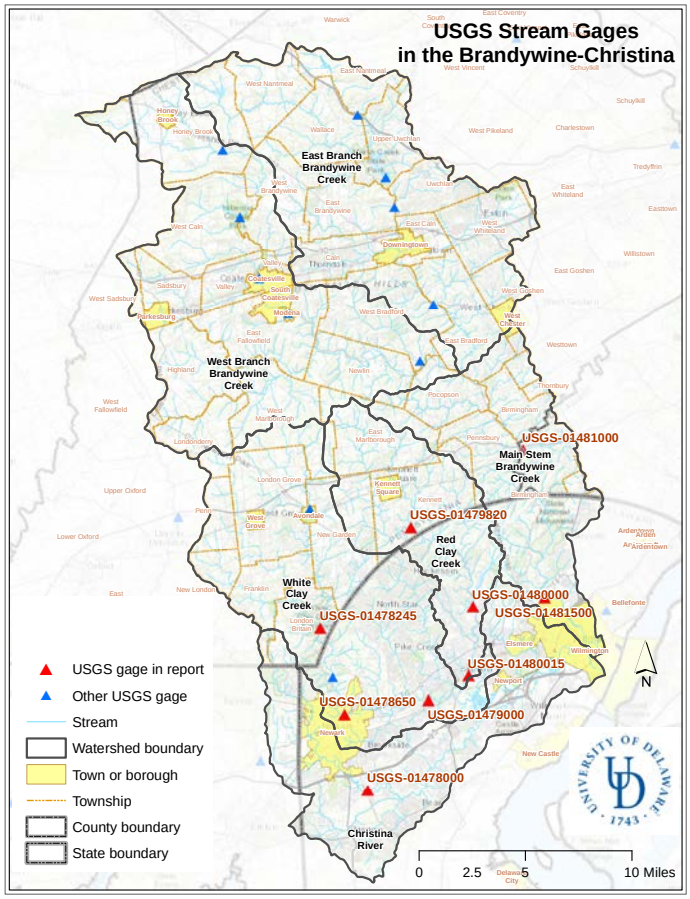


Figure 3-10 USGS stream gages in the Brandywine-Christina watershed. USGS stream gages referenced in this report are shown in red; other USGS stream gages are shown in blue.

Christina River Watershed

Highest storm of record at this station was Hurricane Irene in August 2011 at 7,780 cfs (FIGURE 3-11). The period of record is 1943 to the current year.

CHRISTINA RIVER AT COOCHS BRIDGE			
Date	Peak Discharge (cfs)	Named Storm	Flood Frequency
8/28/11	7,780	Irene	>100-yr
9/16/99	7,050	Floyd	>100-yr
7/5/89	5,530	4th of July	>50-yr
9/28/04	5,430	Jeanne	>50-yr
5/1/47	4,330	Unnamed	25-yr
6/22/72	3,320	Agnes	10-yr
9/12/60	3,300	Donna	<10-yr
8/18/55	3,250	Unnamed	<10-yr
10/1/10	2,970	Unnamed	<10-yr
10/10/71	2,870	Unnamed	<10-yr

Figure 3-11 Mean Daily Peak Discharge at Christina River at Coochs Bridge. (USGS 01478000)

White Clay Creek Watershed

In the White Clay Creek the highest storm of record was constant across all three gage stations and was Hurricane Floyd in September 1999 (FIGURE 3-12). The White Clay at Strickersville, PA peaked at 14,400 cfs. The period of record for this station is 21 years. The White Clay Creek at Newark, DE peaked at 16,800 cfs. The period of record for this station is 24 years. The White Clay Creek near Newark, DE peaked at 19,500 cfs, the period of record at this station is 77 years.

WHITE CLAY CREEK NEAR NEWARK, DE			
Date	Peak Discharge (cfs)	Named Storm	Flood Frequency
9/16/99	19,500	Floyd	>100-yr
8/28/11	17,000	Irene	>100-yr
9/29/04	15,000	Jeanne	100-yr
4/30/14	14,600	Unnamed	>50-yr
9/15/03	13,900	Henri	>50-yr
7/5/89	11,600	4th of July	>25-yr
10/1/10	9,600	Unnamed	>10-yr
1/19/96	9,150	Blizzard of '96	>10-yr
6/22/72	9,080	Unnamed	>10-yr
3/22/00	7,130	Unnamed	<10-yr

Figure 3-12 Mean Daily Peak Discharge at White Clay Creek near Newark, DE. (USGS 01479000)

WHITE CLAY CREEK AT NEWARK, DE			
Date	Peak Discharge	Named Storm	Flood Frequency
9/16/99	16,800	Floyd	>10-yr
9/28/04	12,100	Jeanne	10-yr
8/28/11	10,300	Irene	<10-yr
9/15/03	9,980	Henri	<10-yr
5/1/14	8,410	Unnamed	<10-yr
1/19/96	7,540	Blizzard of '96	<10-yr
1/28/94	5,370	Unnamed	<10-yr
3/10/94	4,780	Unnamed	<10-yr
10/19/96	4,780	Josephine	<10-yr
10/1/10	4,580	Unnamed	<10-yr

Figure 3-13 Mean Daily Peak Discharge at White Clay Creek at Newark, DE. (USGS 01478650)

WHITE CLAY CREEK NEAR STRICKERSVILLE, PA			
Date	Peak Discharge (cfs)	Named Storm	Flood Frequency*
9/16/99	14,400	Floyd	-
8/28/11	9,910	Irene	-
9/15/03	9,750	Henri	-
9/28/04	9,390	Jeanne	-
4/30/14	7,570	Unnamed	-
10/1/10	5,250	Unnamed	-
6/28/13	4,580	Unnamed	-
3/22/00	4,220	Unnamed	-
10/19/96	3,940	Josephine	-
6/3/06	3,840	Unnamed	-

Figure 3-14 Mean Daily Peak Discharge at White Clay Creek near Strickersville, PA. (USGS 01478245) **USGS does not provide flood frequency information for this station.*

Red Clay Creek Watershed

In the Red Clay Creek, Hurricane Henri (2003), Jeanne (2004) and Irene (2011) were the most significant storms for this period of record at the first, second, and third highest discharges respectively (FIGURE 3-13 & 3-14). The Red Clay Creek near Kennett Square, PA peaked at 19,700 cfs, based on 30 years of record. The Red Clay Creek at Wooddale, DE peaked at 16,000 cfs, based on 73 years of record. The Red Clay Creek near Stanton, DE peaked at 17,400 cfs, based on 28 years of record at this station.

RED CLAY CREEK NEAR STANTON, DE			
Date	Peak Discharge (cfs)	Named Storm	Flood Frequency
9/15/03	17,400	Henri	>50-yr
9/29/04	10,900	Jeanne	>10-yr
8/28/11	10,500	Irene	>10-yr
9/16/99	8,260	Floyd	>10-yr
4/30/14	6,000	Unnamed	<10-yr
1/19/96	5,330	Blizzard of '96	<10-yr
7/5/89	5,320	4th of July	<10-yr
1/28/94	5,110	Unnamed	<10-yr
6/28/06	5,000	Unnamed	<10-yr
6/20/03	4,730	Unnamed	<10-yr

Figure 3-15 Mean Daily Peak Discharge at Red Clay Creek near Stanton, DE. (USGS 01480015)

RED CLAY CREEK AT WOODDALE, DE			
Date	Peak Discharge (cfs)	Named Storm	Flood Frequency
9/15/03	16,000	Henri	>100-yr
9/28/04	8,280	Jeanne	>50-yr
8/28/11	7,690	Irene	50-yr
9/16/99	7,650	Floyd	50-yr
4/30/14	5,830	Unnamed	>10-yr
10/1/10	5,530	Unnamed	>10-yr
6/28/06	5,490	Unnamed	>10-yr
7/21/75	5,010	Unnamed	>10-yr
6/20/03	4,820	Unnamed	>10-yr
9/12/60	4,780	Donna	>10-yr

Figure 3-16 Mean Daily Peak Discharge at Red Clay Creek at Wooddale, DE. (USGS 01480000)

RED CLAY CREEK NEAR KENNETT SQUARE, PA			
Date	Peak Discharge (cfs)	Named Storm	Flood Frequency
9/15/03	19,700	Henri	>50-yr
9/28/04	6,080	Jeanne	<10-yr
8/28/11	5,470	Irene	<10-yr
6/28/06	4,780	Unnamed	<10-yr
9/16/99	4,680	Floyd	<10-yr
10/1/10	4,250	Unnamed	<10-yr
4/30/14	3,820	Unnamed	<10-yr
1/19/96	3,760	Blizzard of '96	<10-yr
6/20/03	3,660	Unnamed	<10-yr
7/28/04	3,290	Unnamed	<10-yr

Figure 3-17 Mean Daily Peak Discharge at Red Clay Creek near Kennett Square, PA. (USGS 01479820)

Brandywine Creek Watershed

There are 11 USGS continuous stream gage stations in the Brandywine Creek watershed. The highest storms of record at the gage stations were Hurricane Floyd and Agnes. The Brandywine at Chadds Ford, PA station, based on 44 years of record, records Hurricane Floyd as the highest storm of record in September 1999 at 26,900 cfs. For the same period of record, 44 years, the Brandywine Creek at Wilmington, DE station records Hurricane Agnes (June 1972) as the highest peak discharge at 29,000 cfs. The following tables list the top 10 peak discharge events at two USGS gages in the lower Brandywine Creek watershed.

BRANDYWINE CREEK AT WILMINGTON, DE			
Date	Peak Discharge (cfs)	Named Storm	Flood Frequency
6/23/72	29,000	Agnes	>50-yr
9/17/99	28,700	Floyd	>50-yr
5/1/14	24,000	Unnamed	>25-yr
1/25/79	22,400	Unnamed	>25-yr
9/13/71	21,300	Unnamed	25-yr
9/29/04	20,800	Jeanne	25-yr
9/15/03	17,900	Henri	>10-yr
8/19/55	17,800	Unnamed	>10-yr
1/20/96	17,800	Blizzard of '96	>10-yr
1/26/78	17,200	Unnamed	>10-yr

Figure 3-17 Mean Daily Peak Discharge at Brandywine Creek at Wilmington, DE. (USGS 01481500)

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

Figure 3-19 Mean Daily Peak Discharge at Brandywine Creek at Chadds Ford, PA. (USGS 01481000)

The following tables list the top 10 peak discharge events at three USGS gages in the upper Brandywine Creek watershed.

WEST BRANCH BRANDYWINE CREEK NEAR HONEY BROOK, PA			
Date	**Peak Discharge (cfs)**	**Named Storm**	**Flood Frequency**
1/19/96	3,800	Blizzard of '96	>10-yr
6/22/72	3,660	Agnes	>10-yr
7/1/84	3,650	Unnamed	>10-yr
10/8/05	3,390	Rita	>10-yr
9/8/87	3,300	Unnamed	>10-yr
9/23/11	3,170	Unnamed	>10-yr
10/19/96	2,960	Josephine	<10-yr
9/16/99	2,950	Floyd	<10-yr
7/21/88	2,920	Unnamed	<10-yr
6/20/03	2,790	Unnamed	<10-yr

Figure 3-20 Mean Daily Peak Discharge at West Branch Brandywine Creek near Honey Brook, PA. (USGS 01480300)

WEST BRANCH BRANDYWINE CREEK AT MODENA, PA			
Date	**Peak Discharge (cfs)**	**Named Storm**	**Flood Frequency**
6/29/73	9,600	Unnamed	>10-yr
6/22/72	7,940	Agnes	>10-yr
4/30/14	6,500	Unnamed	>10-yr
1/19/96	6,120	Blizzard of '96	<10-yr
9/16/99	6,090	Floyd	<10-yr
10/8/05	6,090	Rita	<10-yr
9/6/79	5,090	David	<10-yr
9/9/87	4,960	Unnamed	<10-yr
1/26/78	4,890	Unnamed	<10-yr
10/19/96	4,840	Josephine	<10-yr

Figure 3-21 Mean Daily Peak Discharge at West Branch Brandywine Creek at Modena, PA. (USGS 01480617)

EAST BRANCH BRANDYWINE CREEK BELOW DOWNINGTOWN, PA			
Date	**Peak Discharge (cfs)**	**Named Storm**	**Flood Frequency**
6/22/72	8,160	Agnes	>10-yr
9/16/99	7,200	Floyd	>10-yr
6/28/06	6,870	Unnamed	>10-yr
10/19/96	6,700	Josephine	>10-yr
1/19/96	6,560	Blizzard of '96	>10-yr
8/28/11	6,360	Irene	>10-yr
9/15/03	6,230	Henri	>10-yr
4/30/14	6,180	Unnamed	<10-yr
7/7/84	5,980	Unnamed	<10-yr
1/24/79	5,670	Unnamed	<10-yr

Figure 3-22 Mean Daily Peak Discharge at East Branch Brandywine Creek below Downingtown, PA. (USGS 01480870)

Impaired Streams

As pollutants enter the streams from all sources (wastewater discharges, wildlife, stormwater runoff from various land cover types, etc.), its levels can become high enough to have negative impacts. When pollutant levels in streams become too high the streams can no longer support certain uses that they normally could support, such as aquatic species and habitat, recreation, or water supply. The states of Pennsylvania and Delaware, under the federal Clean Water Act, are required to assess, inventory and report all stream segments and waterbodies that do not meet their water quality standards for specific uses. This reporting serves as a basis for regulations aimed at restoring the water quality of the waterways and watershed health. TMDLs are one mechanism used by USEPA and the states to set target pollution loads to achieve healthy waters.

Every two years Pennsylvania and Delaware update and report their inventories of impacted water bodies to USEPA, identifying waters that, based on testing protocols, do not meet the minimum standards. The states must identify the cause of the impairment, such as nutrients, sediment, bacteria, PCBs, metals, etc. When pollution reduction efforts result in water bodies meeting their water quality standards, they may be removed from the impaired list.

The latest year for which data have been approved by USEPA for stream impairments in the Brandywine-Christina watershed is 2016. The maps in **FIGURE 3-23** indicate impaired streams for three pollutants, nutrients (nitrogen and phosphorous), pathogens (bacteria), and sediment (for Pennsylvania only).

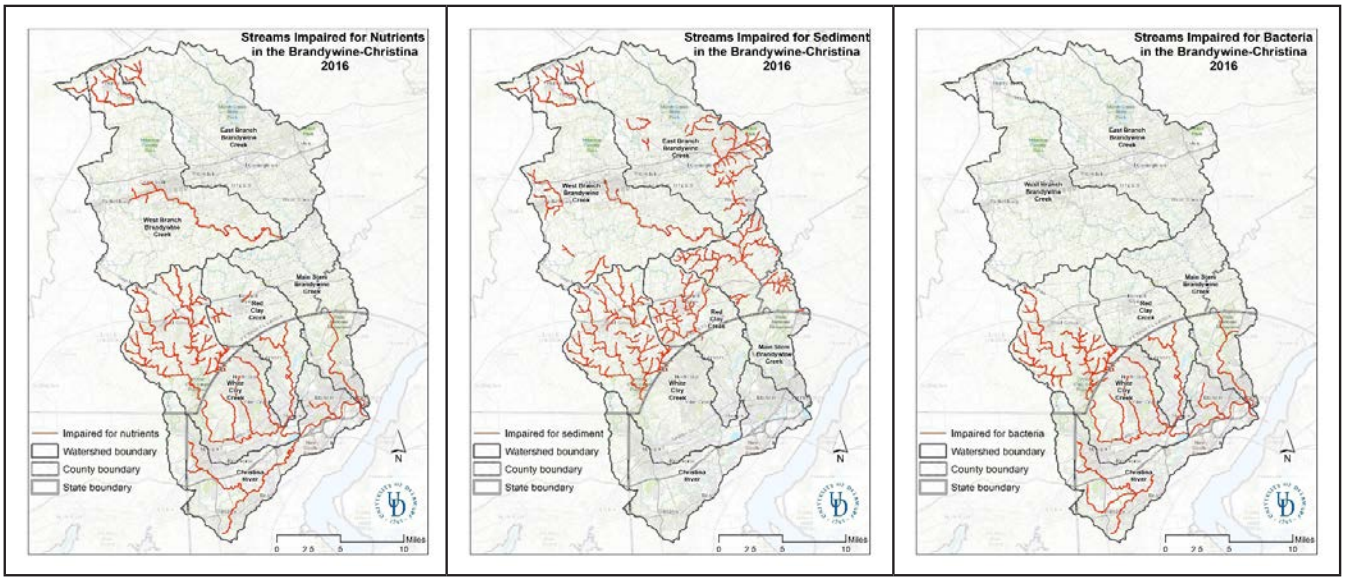


Figure 3-23 Impaired streams in the Brandywine-Christina watershed, from the USEPA 2016 list of impaired streams for Pennsylvania and Delaware, for (from left to right) nutrients, sediment, and bacteria. (DNREC and PADEP)

As of 2016, the Delaware portion of the watershed has 51.4 miles of stream impaired for nutrients and 116.5 miles impaired for bacteria, and the Pennsylvania portion has 135.5 miles impaired for nutrients, 68.7 miles impaired for bacteria and 308.1 miles impaired for sediment.

Special protection waters

Both the states of Pennsylvania and Delaware have designated certain waters that merit special protections due to their intrinsic importance based on water quality, habitat, ecological significance, sensitivity or recreational value. In Pennsylvania these waters have the designation of High Quality (HQ) or Exceptional Value (EV) waters, and receive special protections as specified in the Pennsylvania Code (§ 93.4b of the Pennsylvania Code: "Qualifying as High Quality or Exceptional Value Waters"). Watersheds whose waters are designated High Quality must meet certain criteria for water quality and support of aquatic biota. Exceptional Value waters meet the criteria for HQ streams, as well as additional characteristics such as supporting native trout populations or being within protected lands (e.g., parks or wildlife areas). The map in **FIGURE 3-25**, produced by the CCWRA (2015), shows designated HQ and EV catchments shaded green and blue, and HQ and EV stream segments depicted in green and dark blue, respectively. Watershed boundaries are indicated by thick gray lines. Pennsylvania has 142.6 miles of stream designated HQ; of those, 41 miles are also designated as EV waters.

In Delaware special protections are afforded waters designated as having Exceptional Recreational or Ecological Significance (ERES). According to the Delaware Code, ERES-designated waters shall be maintained or returned, to the "maximum extent practicable", to their natural condition (Delaware Administrative Code, Title 7: 7401 Surface Water Quality Standards, see chapter 5). Delaware has designated 98.5 miles of stream in the watershed, as of ERES. **FIGURE 3-26** shows designated ERES waters in the Brandywine-Christina watershed, in addition to other designations related to water quality, including primary surface drinking water sources, recreational waters, and waters supporting aquatic wildlife and cold water fish.

Trout streams

Pennsylvania is host to many streams with naturally reproducing trout. In the Brandywine-Christina watershed these fall mainly above the confluence of the East and West Branches of the Brandywine Creek. Trout is a species sensitive to water quality conditions in streams, and therefore the presence of naturally replicating populations is a potential indicator of a healthy watershed. In Pennsylvania there are 189 miles of designated cold-water fishery streams and 92 miles of naturally-reproducing trout streams. **FIGURE 3-27** shows the locations of those streams.

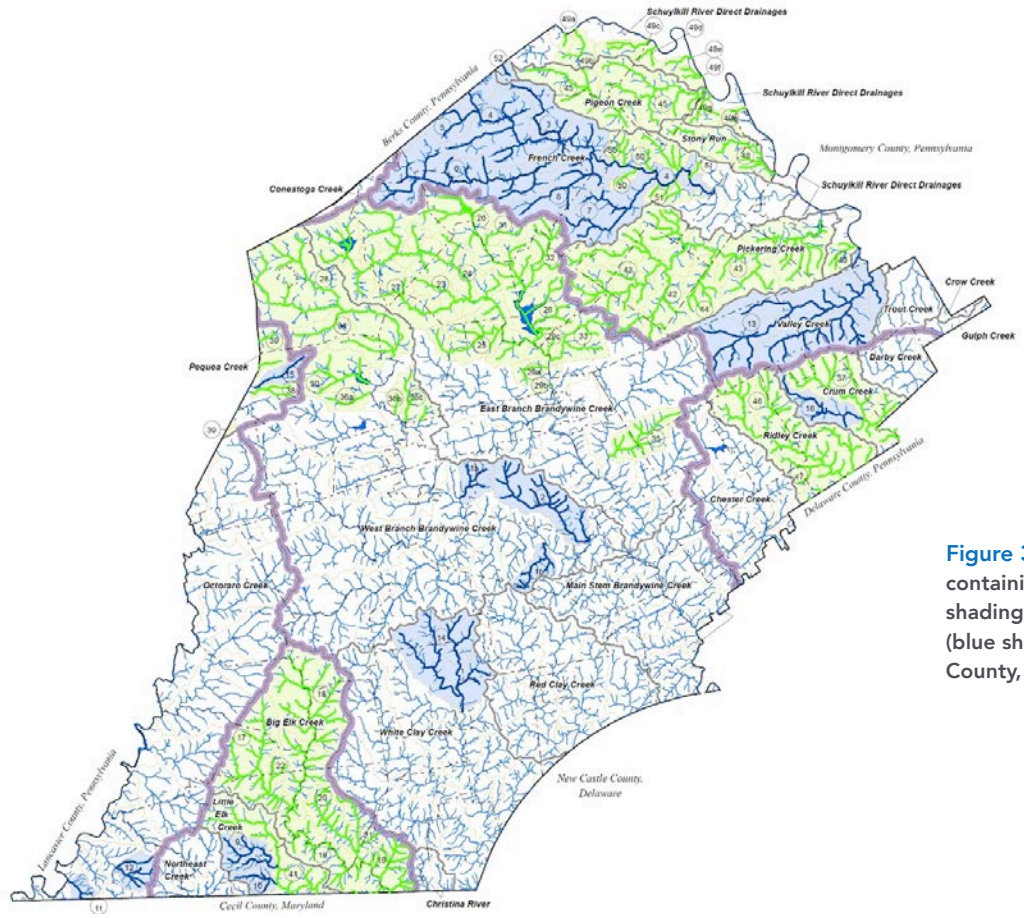


Figure 3-25 Watersheds containing High Quality (green shading) and Exceptional Value (blue shading) waters in Chester County, PA. (CCWRA, 2005)

STREAM	PUBLIC WATER SUPPLY SOURCE	PRIMARY CONTACT RECREATION	SECONDARY CONTACT RECREATION	FISH, AQUATIC LIFE & WILDLIFE	COLD WATER FISH (PUT-AND-TAKE)	ERES WATERS*
Brandywine Creek	(a)	x	x	x	(b)	(h)
Red Clay Creek	x	x	x	x	(e)	(q)
White Clay Creek	(a)	x	x	x	(f)	(g)

Figure 3-26 Special protection waters in the Delaware portion of the Brandywine-Christina watershed. Letters in parentheses indicate designation applies only to a portion of the stream, or during a specific time of year, see below. (DNREC)

(a) Designated use for freshwater segments only.
(b) Designated use from March 15 to June 30 on: 1. Beaver Run from PA/DE line to Brandywine, 2. Wilson Run Route 92 through Brandywine Creek State Park,
(c) Designated use from March 15 to June 30 on: 1. Christina River from MD/DE line through Rittenhouse Park.
(e) Designated use year round on: 1. Red Clay Creek from PA/DE line to the concrete bridge above Yorklyn
(f) Designated use year round on: 1. White Clay Creek from the PA/DE line to the dam at Curtis Paper. Designated use from March 15 to June 30 on: 2. Mill Creek from Brackenville Road to Route 7, 3. Pike Creek from Route 72 to Henderson Road.
(g) Designated use from PA/DE line to the dam at Curtis Paper.
(h) Designated use from PA/DE line to Wilmington city line.
(q) ERES designation is for Burrows Run from the Pennsylvania Line to the confluence with Red Clay Creek

Nonpoint source pollution modeling

In support of the Delaware River Watershed Initiative (DRWI), funded through a grant from the William Penn Foundation (WPF), the Academy of Natural Sciences of Drexel University, with Penn State University, developed a model of nonpoint source pollution loading by source at the stream-reach scale for the entire Delaware Basin. This model, called the Stream Reach Assessment Tool (SRAT), can highlight which areas of the watershed may be hotspots for certain pollutants. This effort has helped guide identification of "focus areas" for the Brandywine-Christina Watershed Partners (also funded through the DRWI). **FIGURE 3-28** shows the annual yields predicted for total nitrogen (TN), total phosphorus (TP), and total suspended sediment (TSS) in each stream reach catchment in the Brandywine-Christina watershed.

These maps indicate that nutrients (nitrogen and phosphorus) and sediments derive primarily from the agricultural regions of the western and northern portions of the Brandywine Creek, Red Clay Creek and White Clay Creek watersheds. Note that the sediment map does not reflect instream erosion, which can be a significant source of sediment in streams.

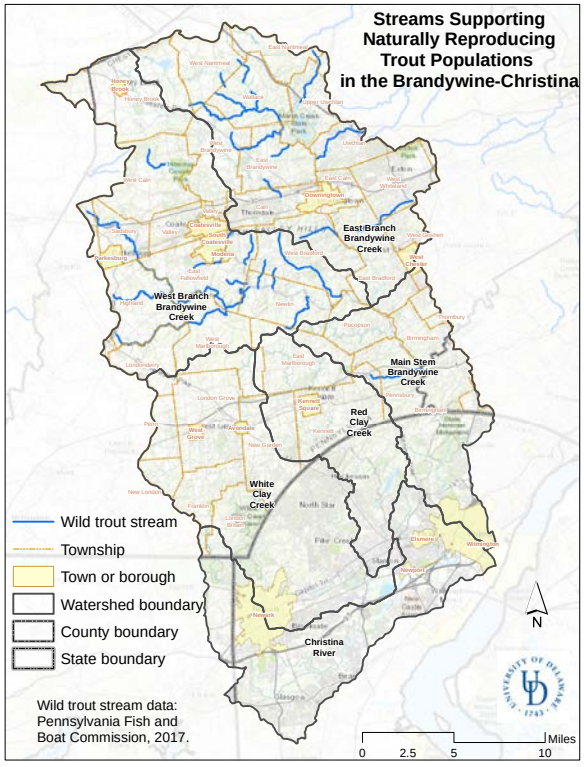


Figure 3-27 Naturally reproducing trout streams in the Brandywine-Christina watershed. (PA Fish and Boat Commission, 2017)

Sea-Level

Approximately 40 square miles or 7% of the Brandywine-Christina watershed is tidally influenced and therefore subject to sea level rise and increasing chloride levels at the White Clay Creek at Stanton water supply intake. Peak high tides recorded at the USGS Christina River at Wilmington and Newport tide gages began to increase in 2000 and peaked in 2012 and have declined over the 4 years since then (**FIGURE 3-29 & 3-30**).

Groundwater Levels

The Chester County Observation Well Network was established by the CCWRA and the USGS in 1973, and includes 25 wells across Chester County of which 12 wells are in the Chester County portion of the Brandywine-Christina Basin. Well CH-10 with a period of record spanning 62 years (1951–2013) exhibited a small statistically significant upward trend in annual mean water level of 0.22 ft per decade (**FIGURE 3-21**). In Delaware,

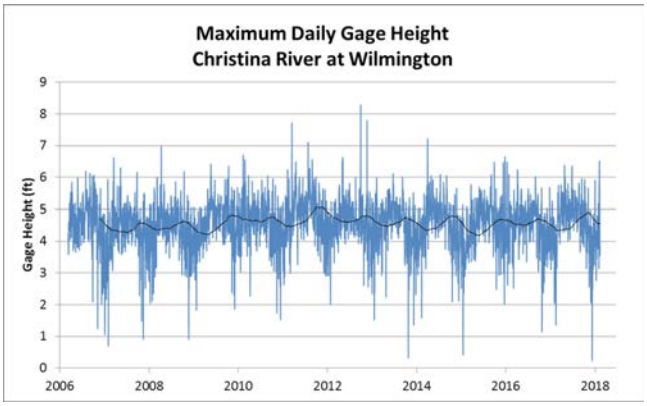


Figure 3-29 Maximum high tides recorded at the Christina River at Wilmington, DE tide gage. (USGS)

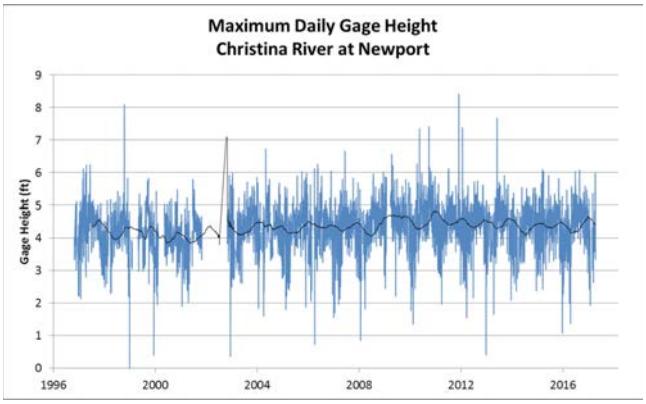


Figure 3-30 Maximum high tides recorded at the Christina River at Newport, DE tide gage. (USGS)

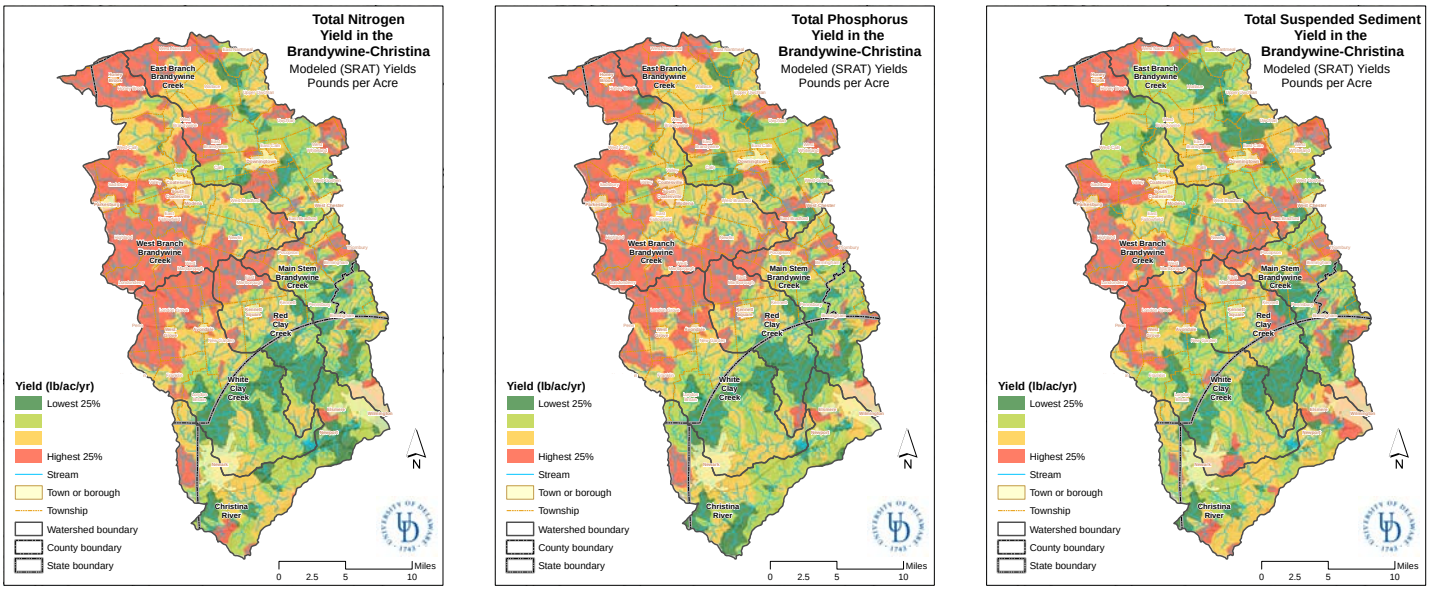


Figure 3-28 Relative annual yields, by stream reach catchment, for (from left to right) nitrogen, phosphorus, and sediment, based on SRAT model. (ANS, Stream Reach Assessment Tool)

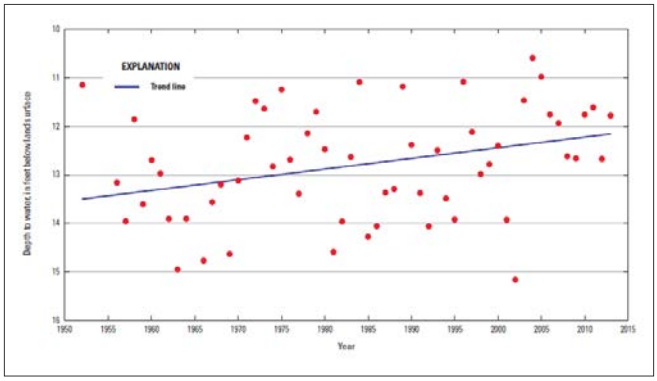


Figure 3-32 Annual mean water level in well CH-10, Chester County, Pennsylvania, 1952-2013. (Sloto and Reif 2017)

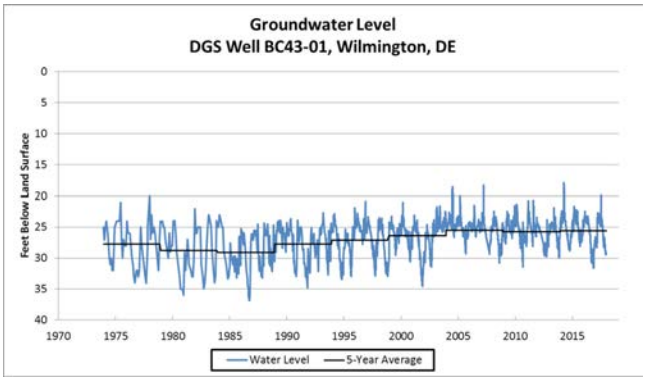


Figure 3-32 Groundwater level in DGS Well BC43-01 in Wilmington, Delaware. (DGS)

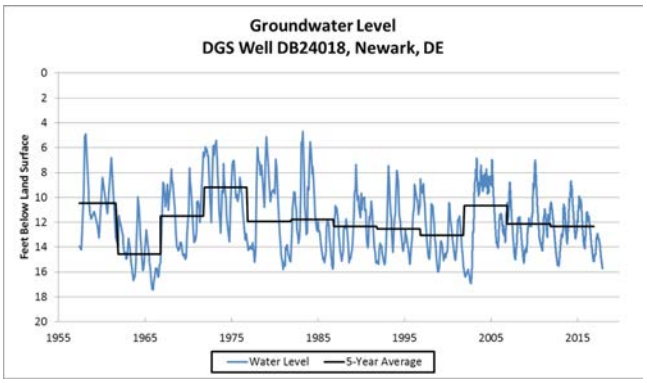


Figure 3-33 Groundwater level in DGS Well DB24-018 in Newark, Delaware. (DGS)

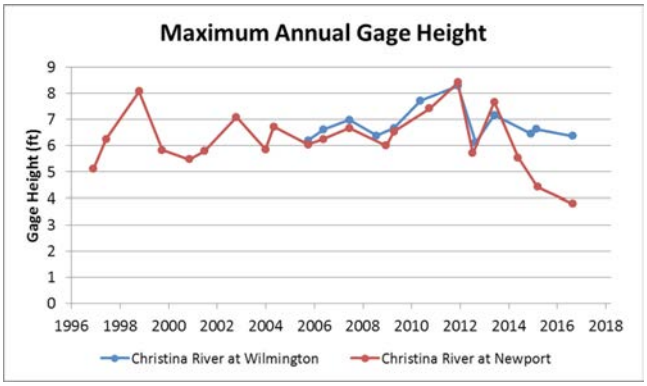


Figure 3-31 Maximum high tides recorded at the Christina River at Wilmington and Newport, DE tide gages. (USGS)

groundwater levels have increased by almost five feet since the 1980s in DGS Well BC43-01 in Wilmington, DE and levels have remain more or less constant since the 1970s in DGS Well DB24-018 in Newark, DE (**FIGURE 3-32**).

Fish and Wildlife Resources

Macroinvertebrates

Benthic macroinvertebrates are aquatic organisms that live on the stream bottom. These serve as a useful tool to assess stream health at a specific site because they are directly impacted by water quality and physical conditions. Macroinvertebrate data is available for the Pennsylvania portion of the watershed through the biological monitoring network, established by the USGS and CCWRA. Macroinvertebrate data in Delaware is provided by the Delaware Nature Society.

Since 1969, the USGS and CCWRA have an established biological monitoring network in Chester County. Samples are taken at 27-30 sites annually, with 18 fixed-location sites (long-term monitoring of trends) and 9 -12 flexible-location sites (spatial coverage-local determination of water quality conditions). The sampling measures baseflow conditions for water chemistry, instream habitat, and benthic macroinvertebrates (Reif, 2009). The network has nine fixed sampling sites located in the Brandywine-Christina watershed, which include:

1. Glenmoore (East Branch Brandywine)
2. Below Downingtown (East Branch Brandywine)
3. Honey Brook (West Branch Brandywine)
4. Modena (West Branch Brandywine)
5. Buck Run (West Branch Brandywine)
6. East Branch Red Clay
7. West Branch Red Clay
8. East Branch White Clay Creek at Avondale, PA
9. Middle Branch White Clay Creek near Avondale, PA

Samples are collected October-December. The Chester County Index of Biotic Integrity (IBI) uses six individual metrics to provide a single IBI score 0-100 scale. IBI score is scaled to local conditions found in Chester County and are based on the same IBI metrics used by PADEP. The following data was collected 1998-2016 (**FIGURE 3-34 & 3-35**) at the nine sites in the Brandywine-Christina watershed. In general, the higher the score the better the site and fluctuations are normal in invertebrate data. The scoring can be generally interpreted in three categories:

1. 80–100 (good water quality)
2. 60–79 (fair water quality)
3. below 60 (poor water quality)

The 2016 sampling provided the following results:

- Three sites in the Brandywine watershed, had an IBI score above 80:
    - Glenmoore (East Branch Brandywine)
    - Below Downingtown (East Branch Brandywine)
    - Buck Run (West Branch Brandywine)
- Three sites in the Brandywine Creek and White Clay creeks had a score between 52 and 79:
    - Modena (West Branch Brandywine)
    - Honey Brook (West Branch Brandywine)
    - Middle Branch White Clay
- Three sites in the Red Clay and White Clay creeks had a score below 51:
    - East Branch Red Clay
    - West Branch Red Clay
    - East Branch White Clay

The Chester County biological monitoring network consists of sampling 18 sites and nine flexible sites that are selected each year. Taylor Run, Bucktoe Creek and Pocopson Run in the Red Clay Creek watershed were part of the nine sites selected in 2016. CCWRA requested these be sampled to assist the Brandywine Red Clay Alliance in establishing a baseline of water quality conditions for future restoration

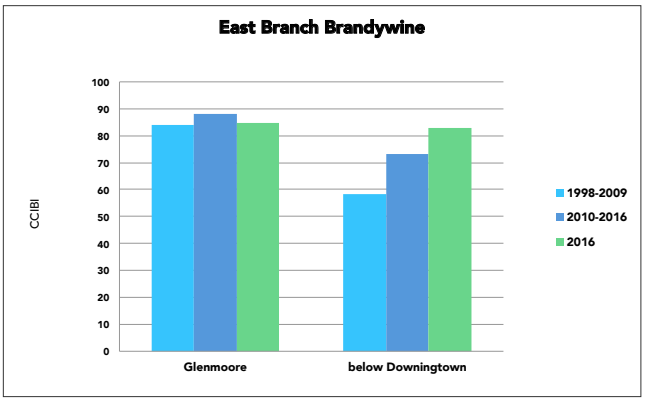


Figure 3-34 East Branch Brandywine macroinvertebrate sampling data, 1998-2016. (USGS, Reif, 2017)

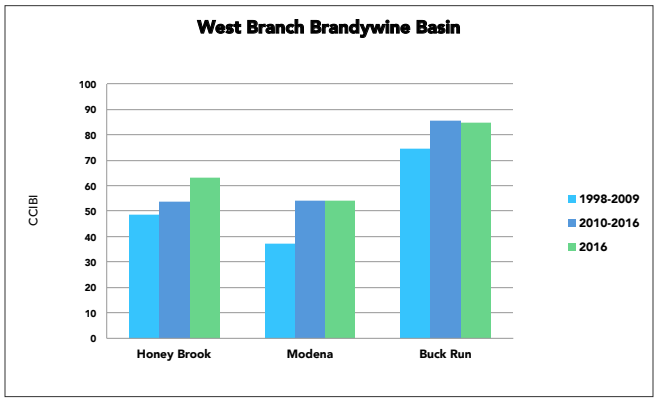


Figure 3-35 West Branch Brandywine macroinvertebrate sampling data, 1998-2016. (USGS, Reif, 2017)

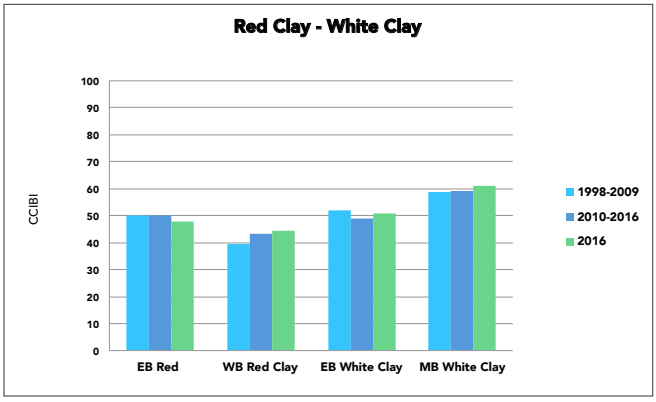


Figure 3-36 Red Clay and White Clay macroinvertebrate sampling data, 1998-2016. (USGS, Reif, 2017)

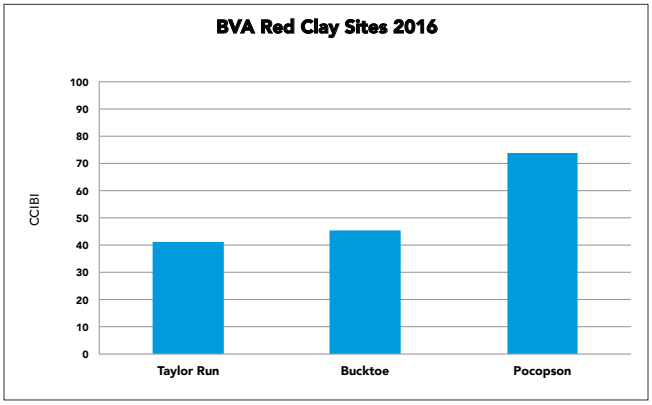


Figure 3-37 2016 sampling results at Taylor Run, Bucktoe and Pocopson Creeks. (USGS, Reif, 2017)

work that will be conducted at these sites. The results of the sampling work in 2016 provide a snapshot of the three creeks showing that Taylor and Bucktoe generally demonstrate poor water quality and Bucktoe shows fair water quality (**FIGURES 3-34, 3-35, 3-36 & 3-37**).

Additional macroinvertebrate surveys were conducted in the Delaware portion of the Brandywine-Christina watershed from 2011-2015. This work was supported by the Delaware Nature Society with additional support provided by The Christina Conservancy and Noramco. The surveys were conducted by Delaware Nature Society Stream Watch Interns and volunteers. The interns and volunteers conducted rapid macroinvertebrates surveys at approximately 21 sites in the watershed. The rapid macroinvertebrate surveys were coupled with habitat, chemistry and bacteria data at some sites. Most sites were sampled using kick-nets (500um) in riffle habitats. During the sampling period, sites were sampled annually during the summer. Each site was sampled one to six times. An averaged stream rating of Good, Fair or Poor was assigned based on a simple, weighted diversity rating per *Volunteer Stream Monitoring: A Methods Manual (EPA 1987).*

Results from this sampling provided a Fair rating for 13 of the 21 sites and a Good rating for the remaining eight sites. Of the 21 sites, not one was rated poor. The Brandywine, Red Clay and White Clay creeks all received both Good and Fair ratings at the various sampling sites located throughout each watershed. The Christina River had only one sampling location and this was rated as Fair.

Birds

The Brandywine-Christina watershed is an Important Bird Area in the mid-Atlantic region (National Audubon Society, 2018). The area are host to over 200 species of birds, including many year-round residents as well as migrants. The watershed contains several Important Bird Areas as designated by the National Audubon Society, including Great Marsh, the Laurels and Stroud Preserves, the Red Clay Valley, White Clay Creek State Park, and a portion of the globally significant Delaware Coastal Zone. In the spring, stream corridors such as the White Clay valley serve as important pathways for migratory songbirds. Many of the large, contiguous pastures and meadows in the central portion of the watershed provide critical nesting habitat for grassland species.

Birds serve as an important indicator of watershed health (USEPA 2018). Roger Tory Peterson called them "ecological litmus paper" due to their sensitivity to environmental conditions. The population trend in certain key species can potentially indicate the trajectory of the watersheds in which they live and breed.

Since 1966, the USGS Patuxent Wildlife Research Center has conducted their annual North American Breeding Bird Survey, a scientifically rigorous count of birds across the country, based on thousands of 24.5 mile routes distributed geographically and by habitat type (Sauer, et al., 2017). The results are analyzed and tabulated to determine, abundance and trends, by various geographic scales, down to blocks approximately 13 miles on a side (Breeding Bird Atlas Species Maps, 2018).

Trends for several key migratory species that nest in the watershed were examined to determine whether the populations were increasing or decreasing over the period from 1996 to 2015. Many factors can affect breeding populations, including habitat alterations, climatic factors, environmental toxicity, conditions in the wintering grounds, among others. The trends, therefore are not diagnostic of changing watershed conditions, but can indicate the degree to which natural conditions in the watershed meet the needs of sensitive breeding species.

Six breeding migratory bird species were considered, whose nesting habitats represent several ecological niches, including pasture and meadow, woody or forested riparian corridor, and streamside locations. The condition of these key habitats reflect overall watershed health.

Two grassland species, Eastern Meadowlark (*Sturnella magna*) and American Kestrel (*Falco sparverius*), require large areas of pasture or meadow for nesting and feeding. The Eastern Meadowlark is a ground-nesting songbird in the blackbird

Figure 3-38 National Audubon Society Important Bird Areas (IBAs) in the Brandywine-Christina watershed region. Green represents areas important at the state level and red represents global significance. (National Audubon Society, 2018)

family that feeds on the ground on insects. The American Kestrel is North America's smallest falcon, hunting rodents in open fields, often from a perch or while hovering, and nesting in cavities, often in trees near their hunting grounds. **FIGURES 3-39 AND 3-40** show a strong negative trend in both populations, reflecting the regional trend for these species.

The Common Yellowthroat *(Geothlypis trichas)* and Kentucky Warbler *(Geothlypis formosa)* are species in the wood warbler family that require woody or shrubby habitat near water. They are both nest in thick undergrowth and have a skulking habit. Common Yellowthroat is often seen and heard near the edge of thickets surrounding wetlands and waterbodies, while Kentucky Warbler nests in deeper woods usually near streams, where it is often difficult to see, though it can be easily heard while on territory. **FIGURES 3-41 AND 3-42** illustrate the negative trend in both of these species' breeding populations.

Two other species in the wood warbler family, Louisiana Waterthrush (*Parkesia motacilla*) and Northern Parula (*Setophaga americana*), are breeding migrants that typically nest very close to flowing stream water, and do best where there is a sizable riparian buffer. Both species are dependent on streamside habitats. The Louisiana Waterthrush feeds and nests on or near the bank of streams, vocally defending its territory. The

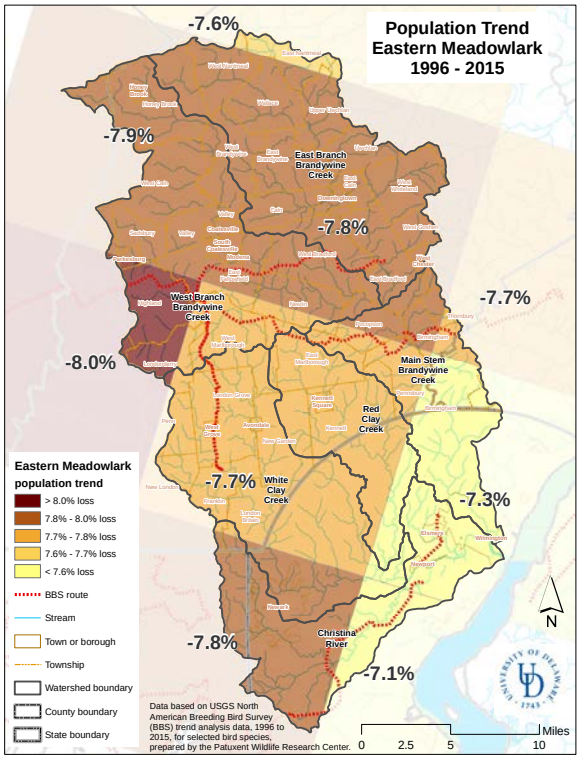


Figure 3-39 Eastern Meadowlark, % change in population by Breeding Bird Survey block in the Brandywine-Christina watershed, 1996–2015. (Breeding Bird Atlas Species Maps, 2018)

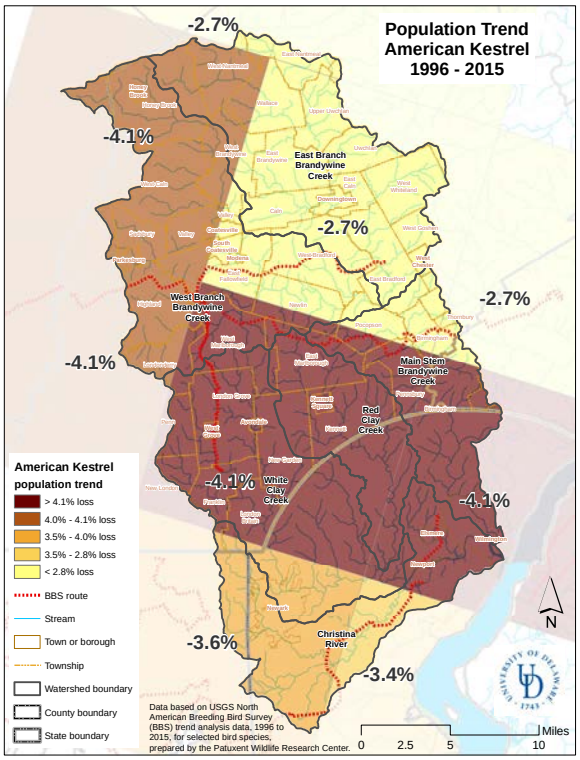


Figure 3-40 American Kestrel, % change in population by Breeding Bird Survey block in the Brandywine-Christina watershed, 1996–2015. (Breeding Bird Atlas Species Maps, 2018)

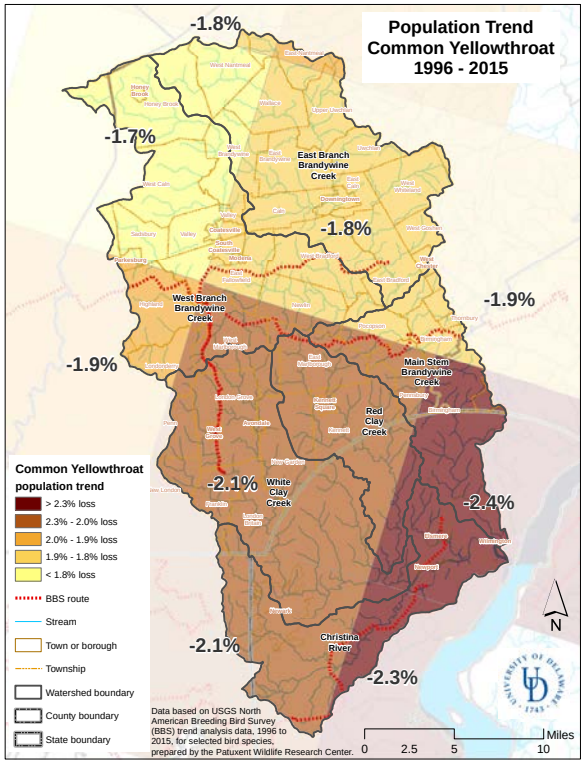


Figure 3-41 Common Yellowthroat, % change in population by Breeding Bird Survey block in the Brandywine-Christina watershed, 1996–2015. (Breeding Bird Atlas Species Maps, 2018)

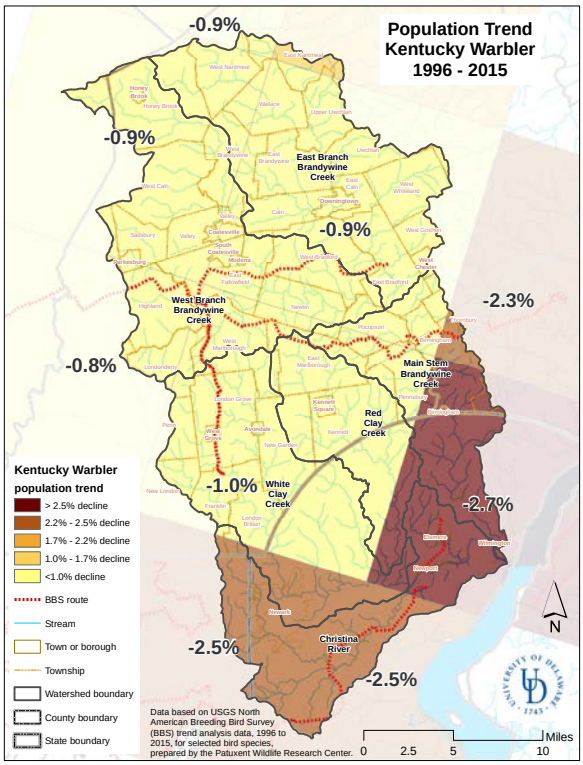


Figure 3-42 Kentucky Warbler, % change in population by Breeding Bird Survey block in the Brandywine-Christina watershed, 1996–2015. (Breeding Bird Atlas Species Maps, 2018)

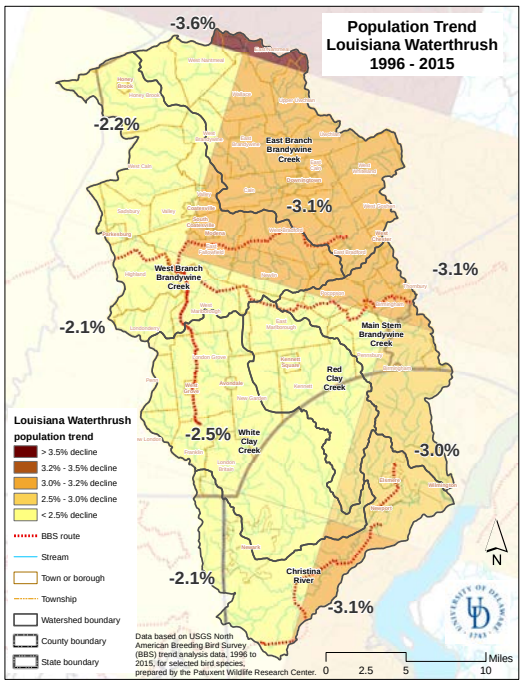


Figure 3-43 Louisiana Waterthrush, % change in population by Breeding Bird Survey block in the Brandywine-Christina watershed, 1996–2015. (Breeding Bird Atlas Species Maps, 2018)

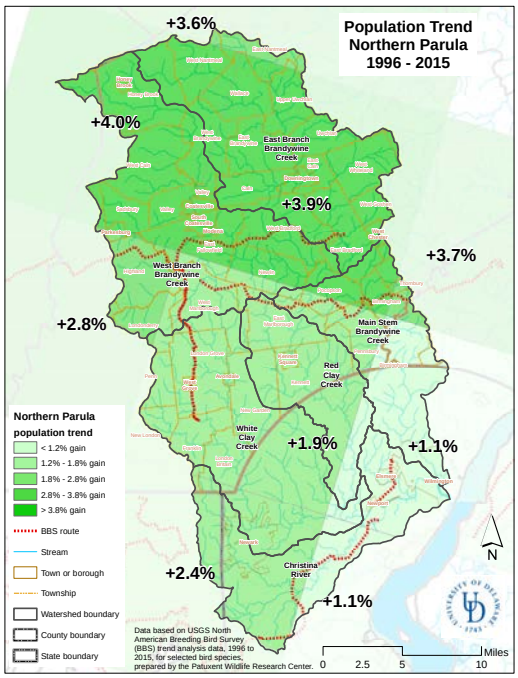


Figure 3-44 Northern Parula, % change in population by Breeding Bird Survey block in the Brandywine-Christina watershed, 1996–2015. (Breeding Bird Atlas Species Maps, 2018)

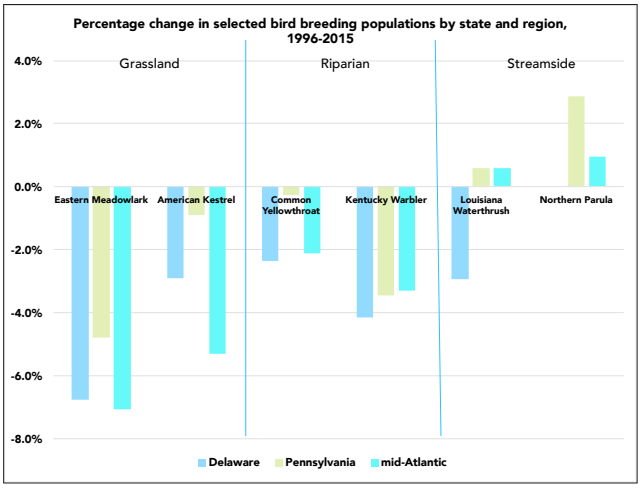


Figure 3-45 State and regional trends for selected breeding bird species found in the Brandywine-Christina watershed, 1996-2015. (Breeding Bird Atlas Species Maps, 2018)

Northern Parula generally feeds by glean insects from high tree branches and builds hanging nests in trees adjacent to water bodies or streams. Louisiana Waterthrush has seen significant declines in recent years as its riparian habitat is threatened (FIGURE 3-43), while the Northern Parula has seen population gains over the same period (FIGURE 3-44).

The trends for these species in the Brandywine-Christina watershed is similar to those seen state-wide and regionally. FIGURE 3-45 illustrates the trends in the breeding populations of these species for the states of Delaware and Pennsylvania, and for the mid-Atlantic portion of the east coast. The habitat associated with each species is noted on the graph.

Freshwater Mussels

Freshwater mussels are bivalve mollusks that have the capacity to provide significant water quality benefits. They are extremely important to natural aquatic ecosystems, as they suck water in and filter it—by trapping solids such as dirt, algae and other pollutants—and then release the clean water back into the stream or river system. Mussels also provide one of the best possible bioindicators of stream health; water quality influences aquatic organisms and is especially important for animals like freshwater mussels.

Freshwater mussels are among the most imperiled flora and fauna in the Delaware River Basin and the nation as a whole. The mussel population's decline (and in some cases, disappearance) from the local waterways and their role in water quality improvements (through their filtering capabilities) prompted

the Partnership for the Delaware Estuary (PDE) to launch the Freshwater Mussel Recovery Program (FMRP) in 2007 with the first introduction of mussels in 2011. According to the PDE, in the Delaware River Basin, and specifically northern Delaware, approximately 12 species of freshwater mussels are considered native, yet only one of these species has been found in the last 10 years in any numbers above the head of tide in the Christina Basin (Brandywine-Christina watershed) (PDE, 2014). Although historical data is limited, there is ample evidence that suggests that major streams in northern Delaware once harbored diverse and robust mussel assemblages (PDE, 2014). There are numerous factors that may account for the current-day absence of these assemblages including, but not limited to, impaired water or habitat quality and anthropogenic causes (spills, predation and dams).

PDE conducted an extensive survey of the lower Brandywine Creek in Pennsylvania in 2000 and a follow-up survey in Delaware in 2012 near Thompson's Bridge (above and below the bridge). According to PDE, one species of native mussel, *Elliptio complananta,* was found to be abundant within at least some area of the lower Brandywine Creek in Delaware (PDE, 2014). Based on their survey, "it is reasonable to extrapolate that >100,000 mussels exist within the 1-mile reach above/below the bridge" and this finding is consistent with earlier survey work upstream in the Pennsylvania portion of the Brandywine (PDE, 2014).

In this same study, survey work on the Red and White Clay Creeks found no presence of freshwater mussels in the surveyed areas yet preliminary research indicated that food, habitat and water conditions in the Red and White Clay Creeks were capable of supporting mussels. In an effort to learn more about where and in what conditions these mussels can survive, PDE transplanted mussels from the nearby Brandywine Creek to select locations within the Delaware portion of the White Clay and Red Clay Creeks and monitored for survivorship in 2013-2014.

Measuring and recording mussel abundance and growth during survey work in the Red and White Clay Creek watersheds. Photo credit: Partnership for the Delaware Estuary

The survey results and growth data indicate the freshwater mussels released into the White and Red Clay Creeks are surviving, the average overall bed retention for Red Clay and White Clay Creeks was similar, about 70% (PDE, 2014). This demonstrates that mussels have the potential to survive non-ideal conditions in these post-developed streams. On the contrary, due to the harsh winter and freezing conditions, relocated mussels in the Newark reservoir did not show such success rates and experienced 100% mortality. In this study, using literature values and derivations, the reintroduced and surviving mussels in the Red and White Clay Creeks are estimated to remove 2.9 and 3.3 kilograms of dry Total Suspended Sediment (TSS) per year, respectively (PDE, 2014).

FMRP efforts are ongoing in other parts of the Brandywine-Christina watershed. PDE conducted freshwater mussel surveys in nine streams in Northern Delaware to identify the status of the mussel population and the potential for mussel reintroduction. The mussel survey in the Christina River revealed no evidence of freshwater mussel presence. Some reaches of the river revealed favorable mussel habitat and were selected as reintroduction sites in June 2014 (PDE, 2015). The reintroduction efforts in the Christina River demonstrated potential stable trends and further research should target the areas within the Christina River that fared best in this study (PDE, 2015).

PDE conducted research in the northern portion of the Brandywine-Christina watershed in five freshwater ponds and streams on or adjacent to the property of Longwood Gardens in southeast Pennsylvania. Longwood Gardens is situated partly in the Brandywine Creek watershed and partly in the Red Clay Creek watershed and historical data suggests that these streams once held robust populations of freshwater mussels. Of the five ponds selected, two of the ponds are hydrologically connected to the Brandywine and Red Clay creeks. Qualitative surveys did not yield evidence of or historical mussel presence within any of the study ponds (PDE, 2015). Three of the five ponds were determined to have suitable freshwater mussel habitat. Based on the suitability for freshwater mussels, PDE has identified several potential tactics

that can be used in the future to restore freshwater mussels in the identified ponds at the study site.

In partnership with SUEZ (an investor-owned water purveyor), PDE is also working on mussel restoration in northern Delaware at Bellevue Lake. In August 2017, PDE released 1,200 juvenile mussels into Bellevue Lake. The mussels will grow in the lake until they are relocated to the Red and White Clay creeks, a source water supply for SUEZ. Once relocated, the mussels will serve to filter and clean the waterways with the intent that less treatment will be necessary in the long-term ultimately lowering treatment costs.

The mussels' role in reducing TSS loads in the stream can help to improve impaired streams throughout the watershed. The FMRP also conducts education and outreach related to the mussel research. The mussel survey work, reintroduction, education and outreach play a beneficial role in improving the water quality in the Brandywine-Christina watershed.

Fish

Brandywine Creek

In April, May and June 2016, the Delaware Division of Fish and Wildlife sampled the Brandywine Creek and counted three American shad, two Hickory shad, and 28 striped bass below Dam No. 1 on Market Street in Wilmington and six American shad, zero hickory shad, and zero striped bass above Dam No. 1 up to Dam No. 2 (FIGURE 3-43). The Market Street Dam No. 1 is slated to be removed by the City of Wilmington in fall 2018.

FISH SPECIES	FISH COUNT	
	Below Dam No. 1 (Apr-May 2016)	Above Dam No. 1 (Jun 1, 2016)
Alewife	1	0
American Eel	4	15
American Shad	3	6
Blueback Herring	5	0
Bluegill	9	8
Channel Catfish	10	2
Common Carp	36	5
Gizzard Shad	76	0
Hickory Shad	2	0
Largemouth Bass	1	0
Menhaden	1	0
Needlefish	1	0
Smallmouth Bass	6	2
Striped Bass	28	0
Tiger Muskie	6	2
Rock Bass	0	5
White Perch	18	0
White Sucker	18	17
Yellow Perch	18	0

Figure 3-43 Fish abundance along Brandywine Creek above/below Dam No. 1 at Market Street. (Delaware Division of Fish and Wildlife)

Family	Scientific Name	Common Name
Achiridae	*Trinectes maculatus*	Hogchocker
Anguillidae	*Anguilla rostrata*	American Eel
Atherinopsidae	*Menidia beryllina*	Inland Silverside
Centrarchidae	*Lepomis cyanellus*	Green Sunfish
	Lepomis gibbosus	Pumpkinseed
	Lepomis machrochirus	Bluegill
	Micropterus salmoides	Largemouth Bass
	Pomoxis nigromaculatus	Black Crappie
Clupeidae	*Alosa aestivalis*	Blueback Herring
	Alosa pseudoharengus	Alewife
	Alosa sapidissima	American Shad
	Brevoortia tyrannus	Atlantic Menhaden
	Dorosoma cepedianum	Gizzard Shad
Cyprinidae	*Cyprinella analostana*	Satinfin Shiner
	Cyprinus carpio	Common Carp
	Hybognathus regius	Eastern Silvery Minnow
	Notropis hudsonius	Spottail Shiner
Engraulidae	*Anchoa mitchilli*	Bay Anchovy
Fundulidae	*Fundulus diaphanus*	Banded Killifish
	Fundulus heteroclitus	Mummichog
Ictaluridae	*Ameiurus nebulosus*	Brown Bullhead
	Ictalurus punctatus	Channel Catfish
Moronidae	*Morone americana*	White Perch
	Morone saxatilis	Striped Bass
Percidae	*Etheostoma olmstedi*	Tessellated Darter
	Perca flavescens	Yellow Perch
Portunidae	*Callinectes sapidus*	Blue Crab

Figure 3-44 Fish abundance along tidal Christina River between Wilmington–Newport, DE. (Delaware Division of Fish and Wildlife)

Christina River

In July through November 2016, the Delaware Division of Fish and Wildlife sampled the tidal Christina River in Delaware and counted 23 American shad, 66 blueback herring, and 23 striped bass between Wilmington and the mouth of the White Clay Creek at Newport (FIGURE 3-44).

White Clay Creek

In 2009 and 2010, the Delaware Division of Fish and Wildlife with assistance by the University of Delaware Water Resources Center conducted fish abundance surveys along the lower White Clay Creek and counted over 1,500 hickory shad and up to 20 striped bass in the tidal reach downstream of the since removed Dam No. 1 at River Mile (RM) 4.6 (FIGURES 3-44, 3-45 & 3-46). ■

FISH SPECIES	FISH COUNT		
	4/22/10	5/13/10	4/19/09-5/29/09
Hickory Shad	1520	340	12
Alewives	480	0	
American Shad	1	0	1
Blueback Herring	0	0	
Sea Lamprey	1	8	
Striped Bass	0	20	1
White Perch	0	1	
Eels	Present	Present	

Figure 3-44 Fish abundance along White Clay Creek below Dam No. 1 (RM 4.6). (DNREC)

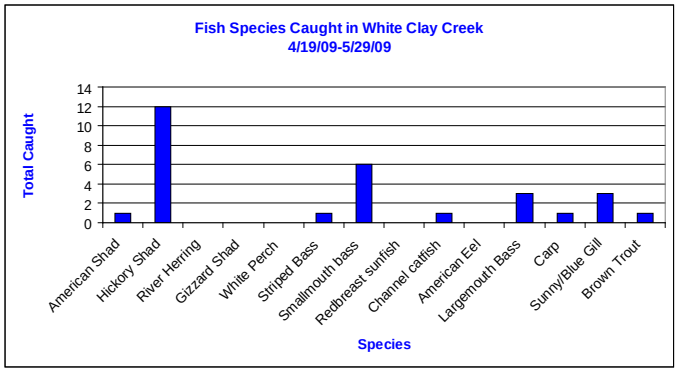
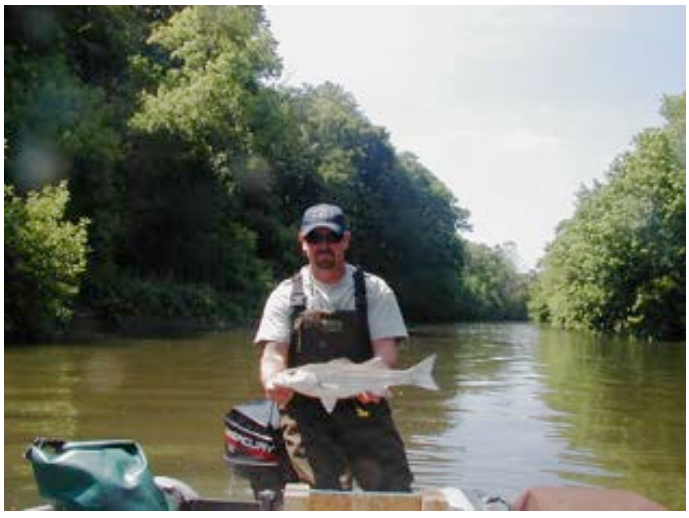


Figure 3-45 Fish species caught during angler survey in White Clay Creek, Apr 19-May 29, 2009. (DNREC and UDWRC)



American shad (left) on April 22, 2010 and striped bass (right) on May 13, 2010 in White Clay Creek. Photo credit: DNREC.

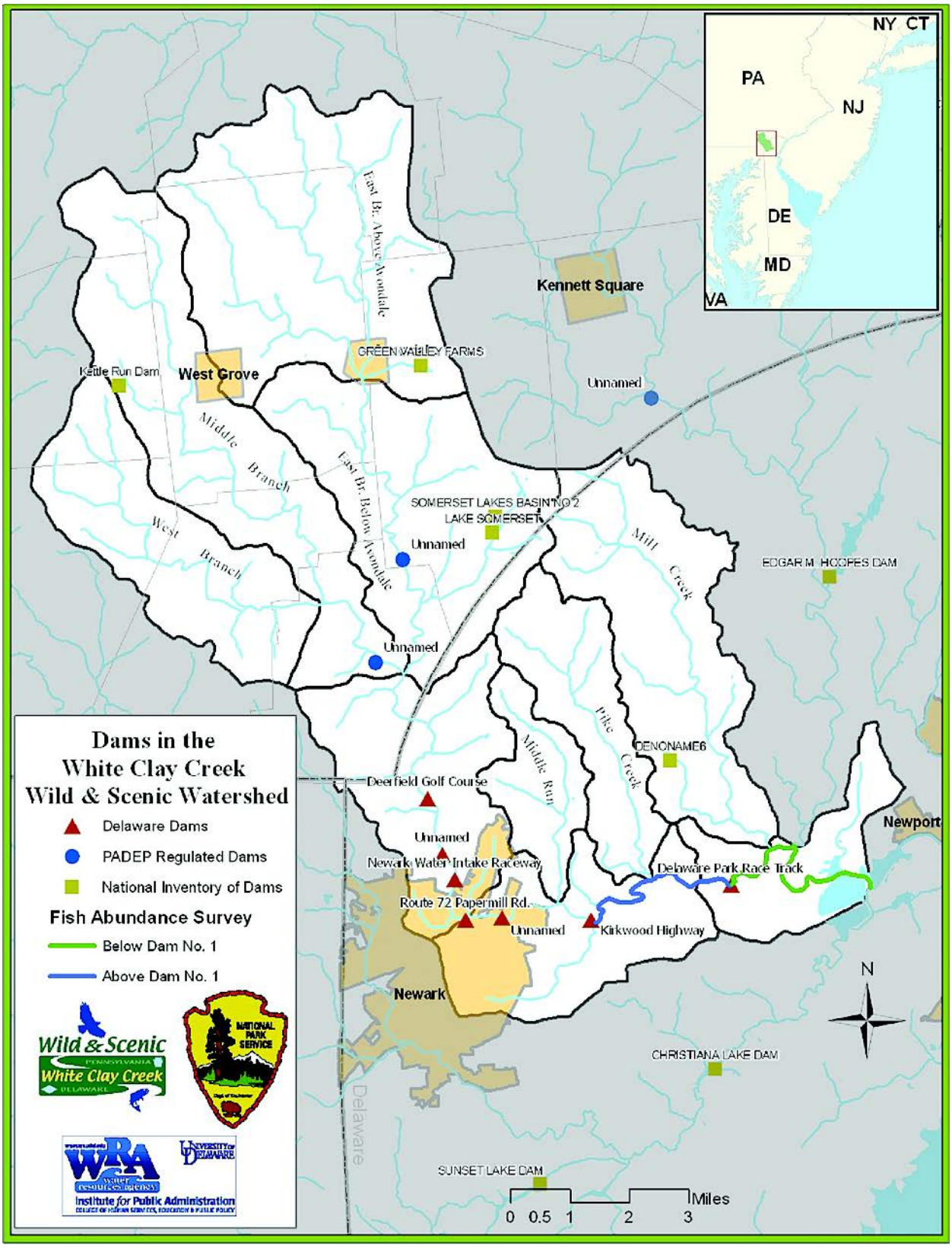


Figure 3-46 Delaware DNREC fish abundance surveys along the White Clay Creek, April/May 2010. (UDWRC)

Chapter 4

Water Quality

Dissolved Oxygen

As part of the USGS/Chester County/CCWRA cooperative program, USGS has monitoring dissolved oxygen (DO) at three stations in the Chester County portion of the Brandywine Creek watershed since 1974 (Modena, Below Downingtown and Chadds Ford) and water-quality monitors are operated continuously in non-winter months (March through November). According to the USGS report, the number of days per year since 1974 when the minimum daily DO concentration was less than 6 mg/L was evaluated. Low DO concentrations have a detrimental effect on aquatic life. Prior to 1988, it was common in the summer months for minimum daily DO concentrations at East Branch Brandywine Creek below Downingtown, PA (01480870) and West Branch Brandywine Creek at Modena, PA (01480617) to be less than 6 mg/L. Since 1988, the percent of days the minimum DO concentration was greater than 6 mg/L has increased at East Branch Brandywine Creek below Downingtown, PA and West Branch Brandywine Creek at Modena, PA **(FIGURE 4-1)**. (Sloto and Reif, 2017). There was a statistically significant increase in DO concentration at West Branch Brandywine Creek at Modena (Sloto and Reif 2017). **(FIGURE 4-2)**.

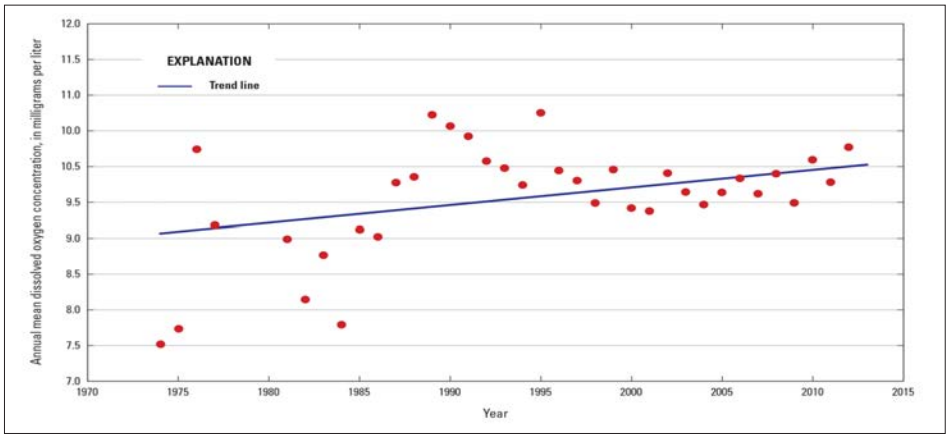


FIGURE 4-2 Annual mean Dissolved Oxygen at West Branch Brandywine Creek at Modena, PA. (Sloto and Reif, 2017)

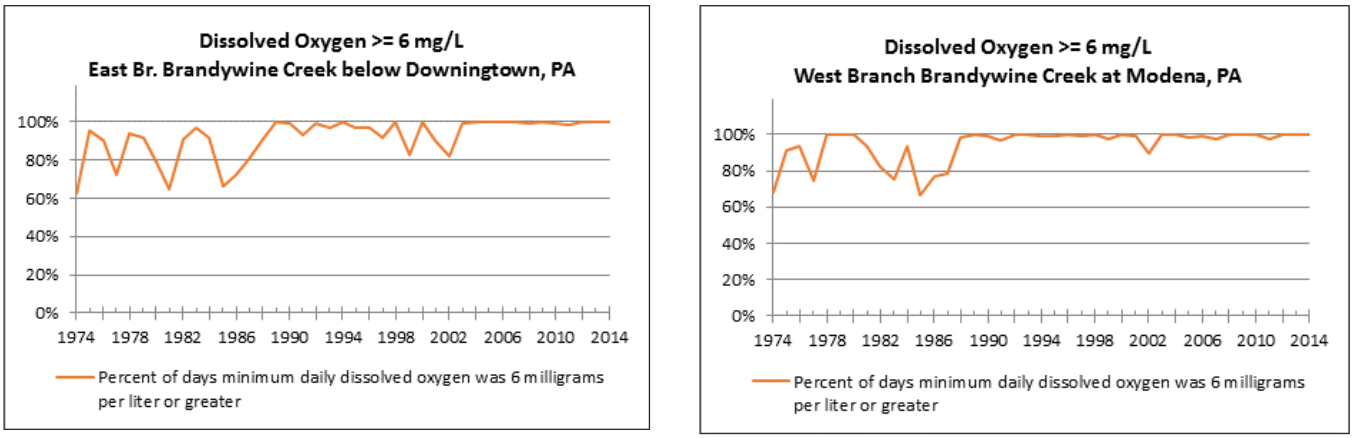
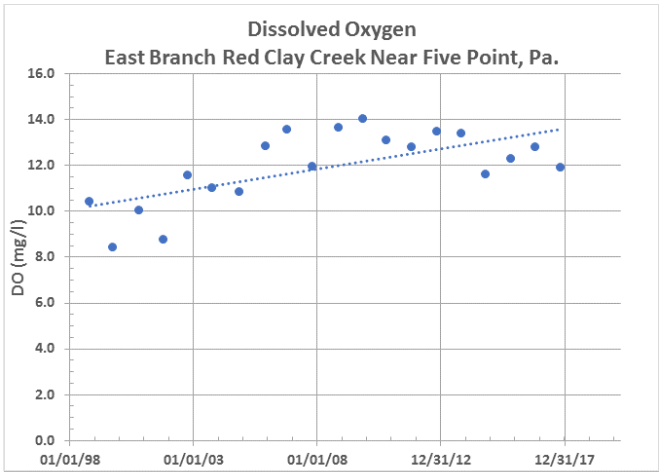
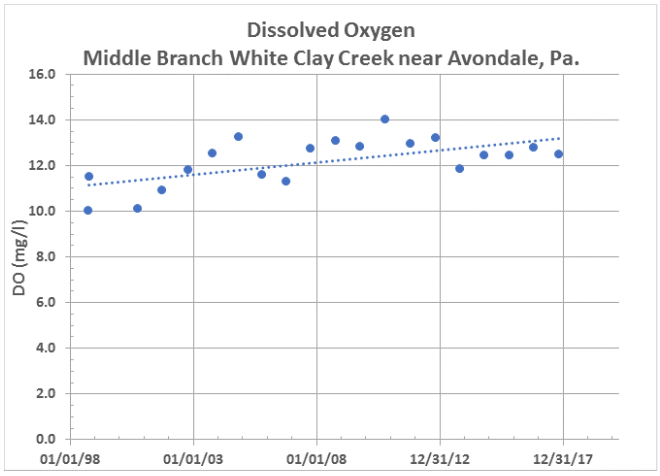
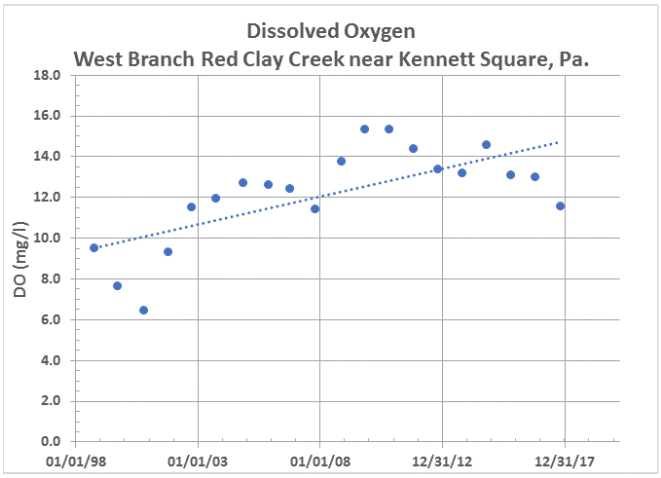
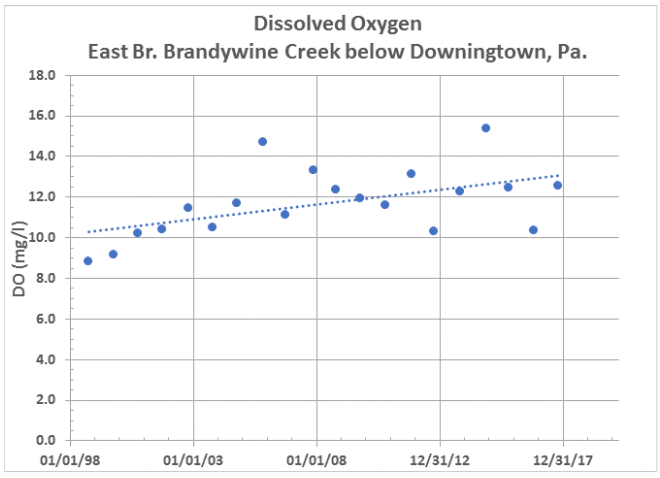


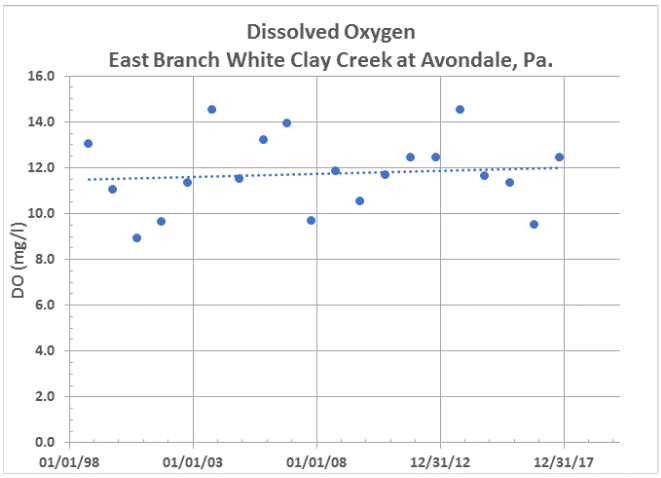
FIGURE 4-1 Dissolved oxygen at East Branch and West Branch Brandywine Creek. (Sloto and Reif 2017)











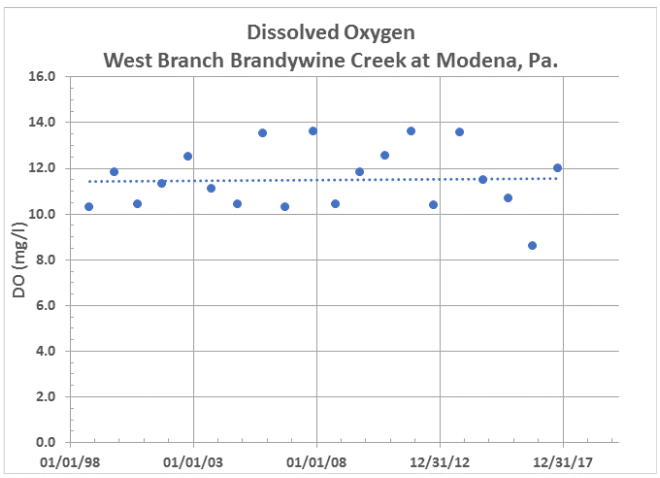


FIGURE 4-3 Dissolved oxygen measured along Brandywine, Red Clay, and White Clay creeks, PA. (USGS)

DO levels have increased since 1996 at all six water quality monitoring stations operated by the USGS and CCWRA along the Brandywine, Red Clay, and White Clay creeks in Chester County, Pennsylvania (FIGURE 4-3).

At water quality monitoring stations operated by the Delaware DNREC, DO levels have increased since 2000 along the Brandywine, Red Clay, White Clay Creeks and Christina River in Delaware (FIGURE 4-4).

Phosphorus

Orthophosphate levels have decreased since 1998 at 3 water quality monitoring stations operated by the USGS and CCWRA along the Brandywine, Red Clay and White Clay creeks in Chester County, PA (FIGURE 4-5). Orthophosphate levels remain low and constant along the East Branch Red Clay Creek and East Branch White Clay Creek. Orthophosphate levels have increased along the East Branch Brandywine Creek below Downingtown.

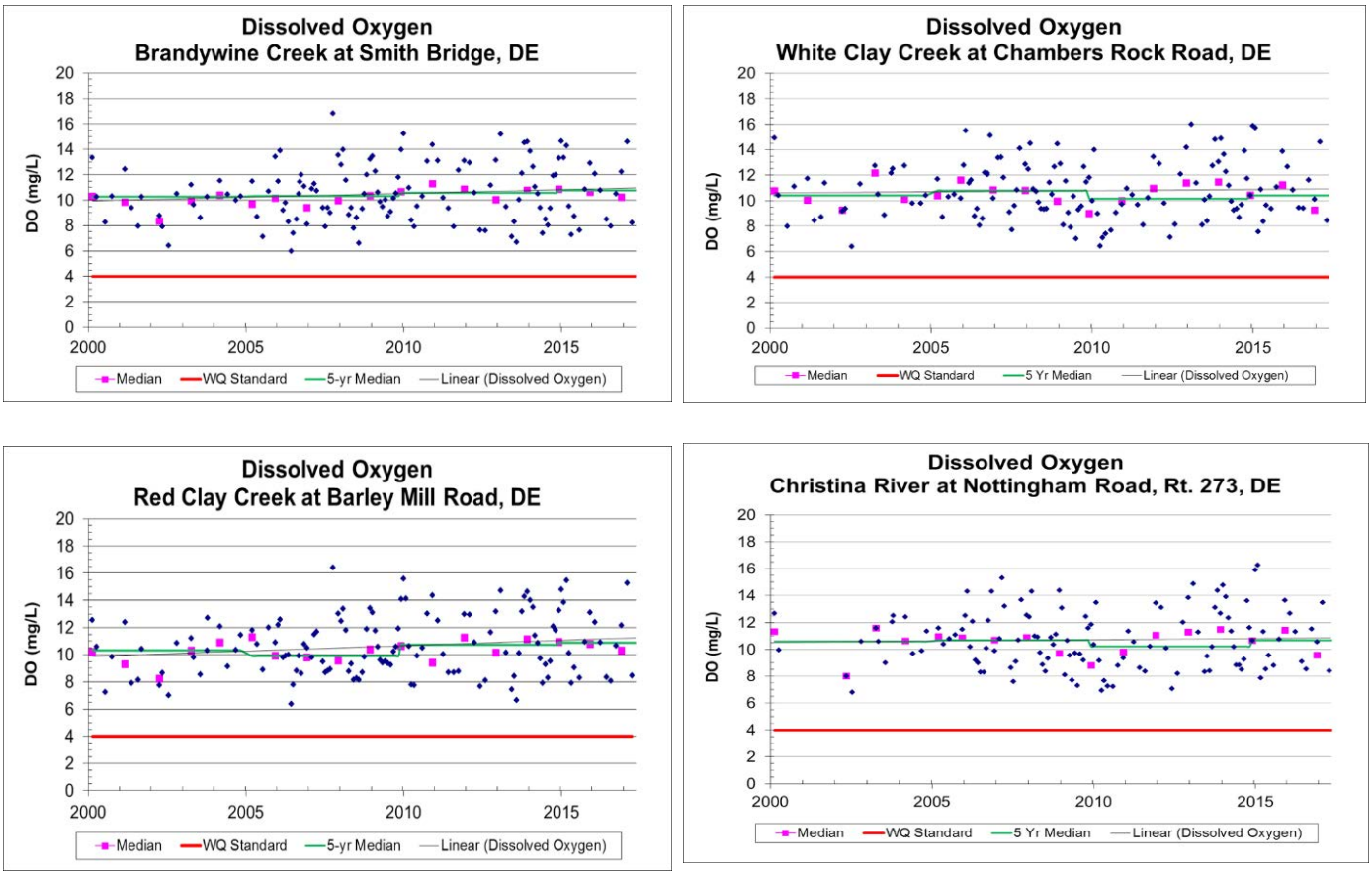
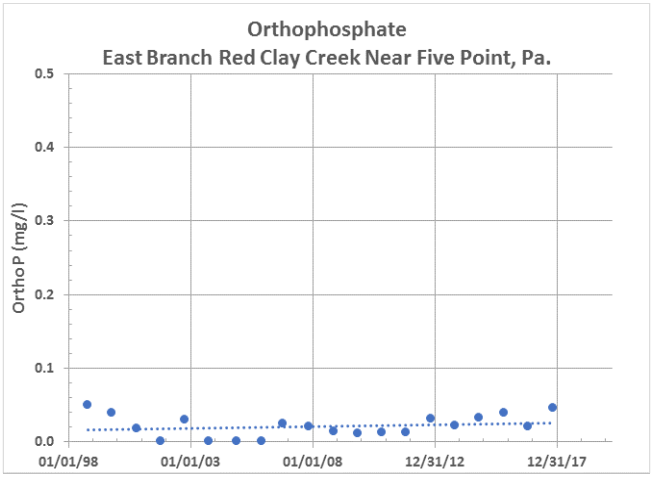
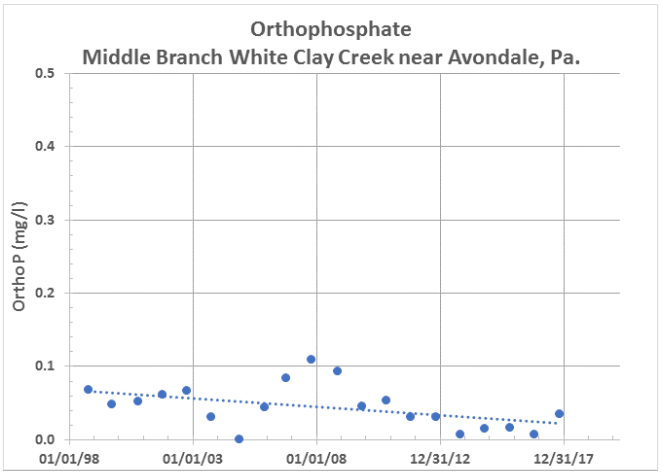
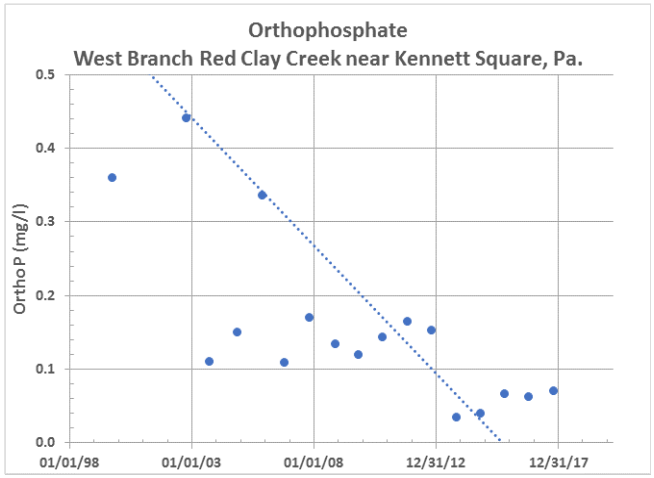
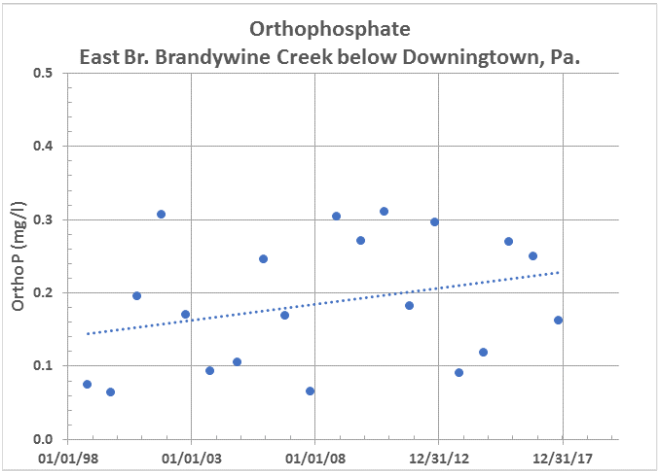


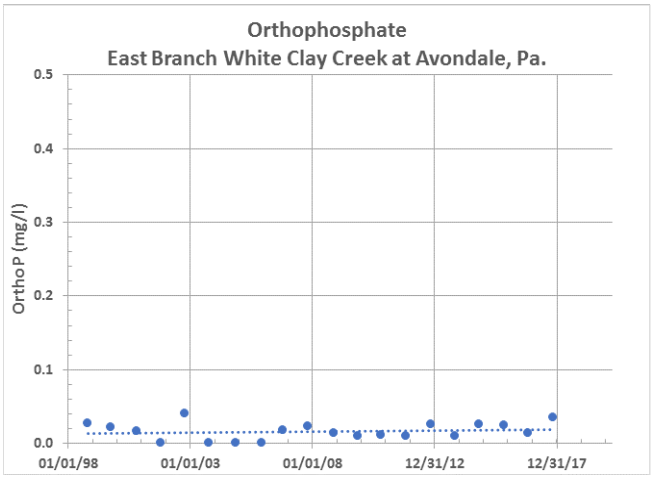
FIGURE 4-4 Dissolved oxygen levels along the Brandywine Creek, Red Clay Creek, White Clay Creek, Christina River, DE. (DNREC)











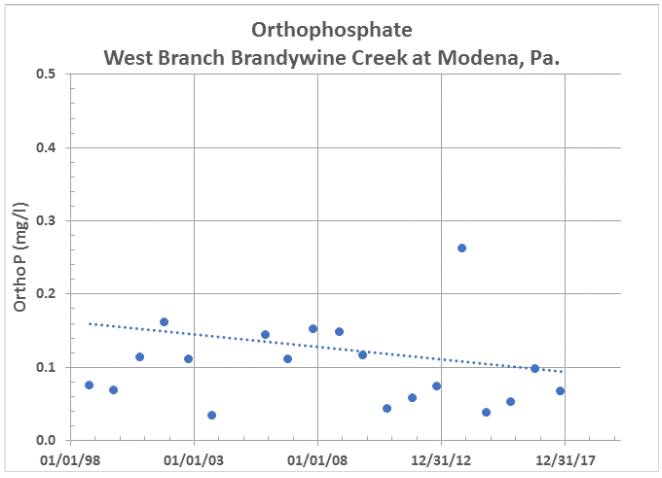
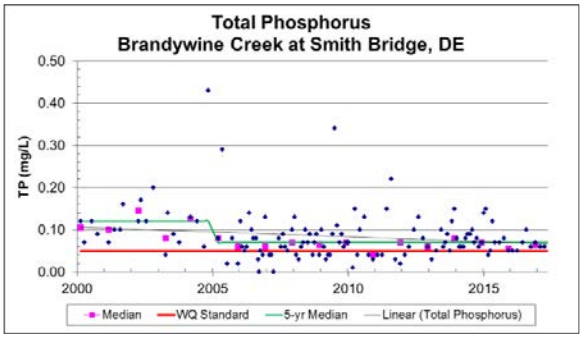


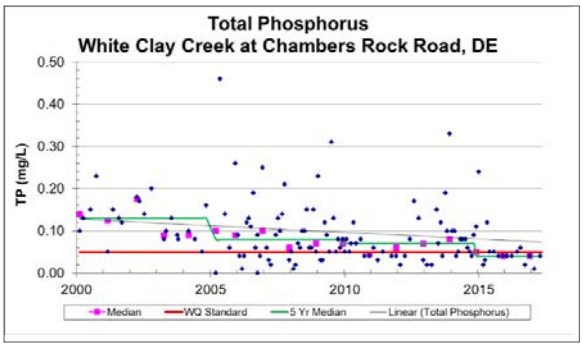
FIGURE 4-5 Orthophosphate levels measured along the Brandywine, Red Clay and White Clay creeks, PA. (USGS)

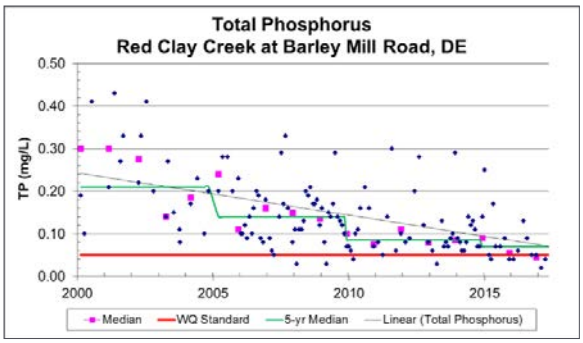
At water quality monitoring stations operated by DNREC, total phosphorus levels have decreased since 2000 along the Brandywine, Red Clay, White Clay Creeks and Christina River in Delaware **(FIGURE 4-6)**.

Nitrogen

Nitrate nitrogen levels have increased since 1998 at water quality monitoring stations operated by the USGS and CCWRA along the West Branch Red Clay Creek and East Branch and West Brach of the Brandywine Creek. Nitrate levels have decreased along the East Branch Red Clay Creek and Middle







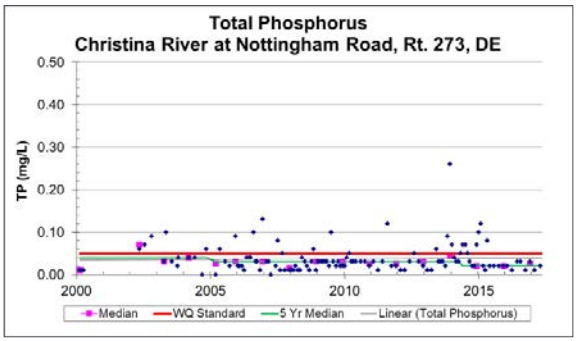
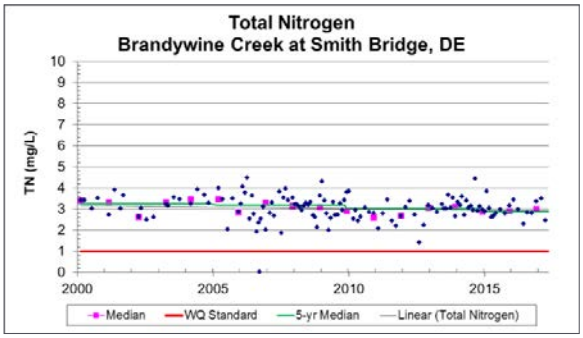
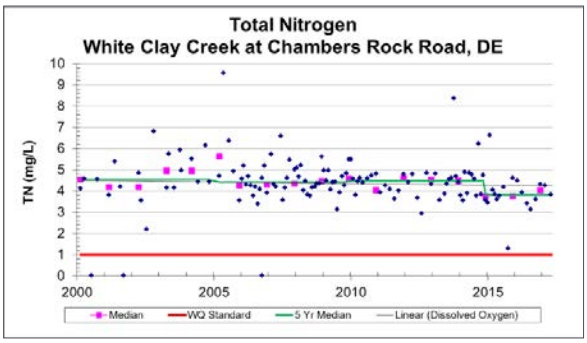
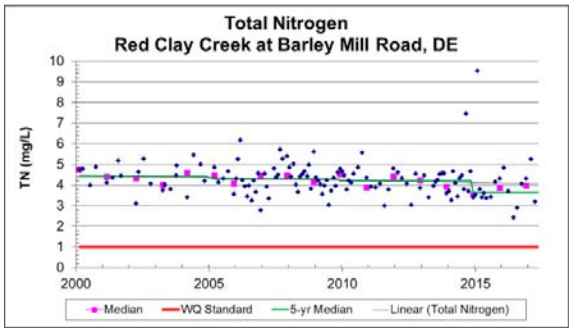


FIGURE 4-6 Total phosphorus levels along the Brandywine Creek, Red Clay Creek, White Clay Creek, Christina River, DE. (DNREC)







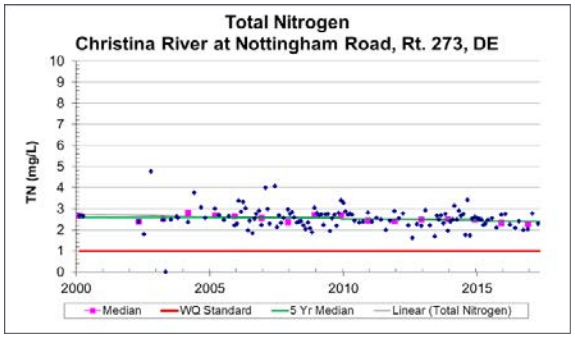
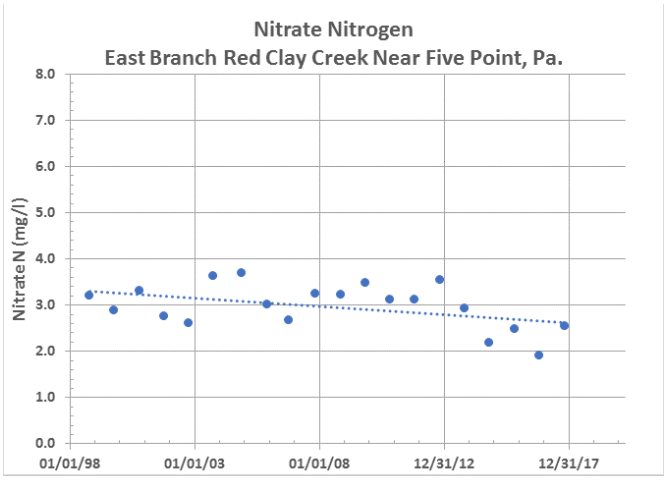
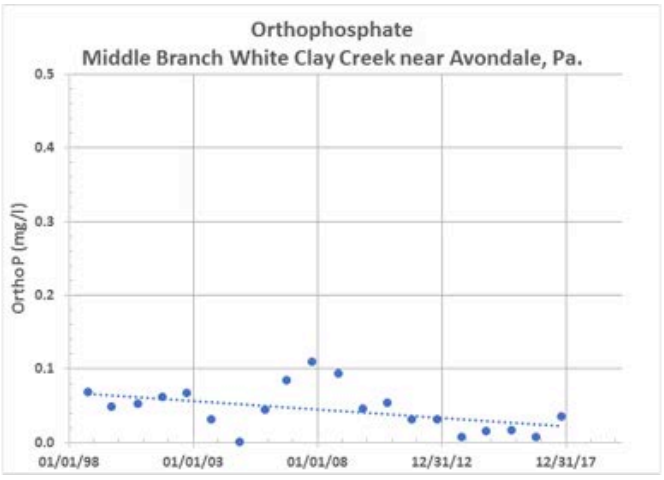
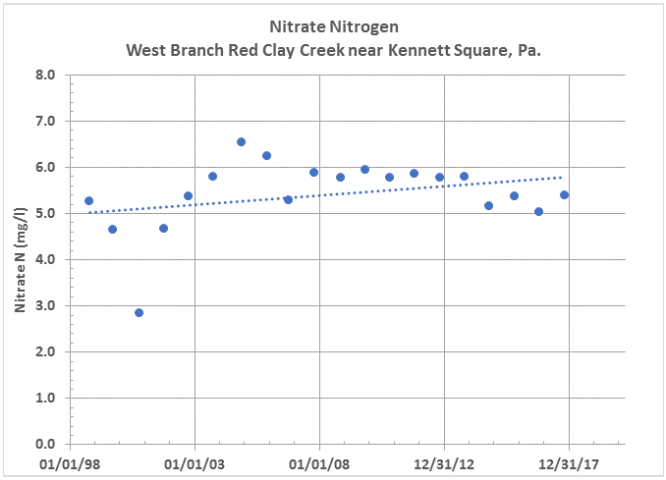
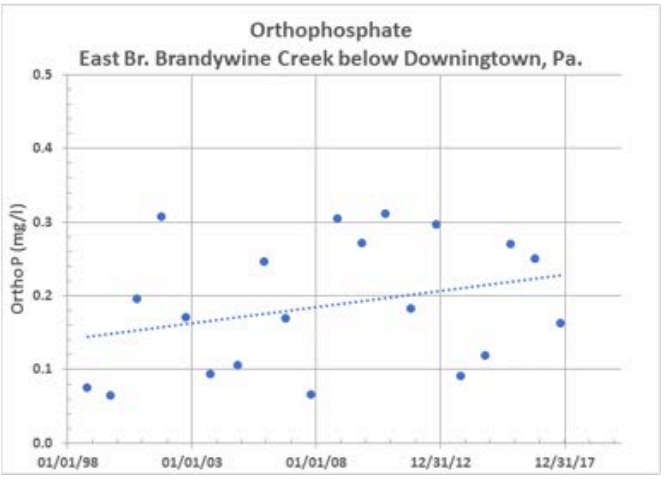


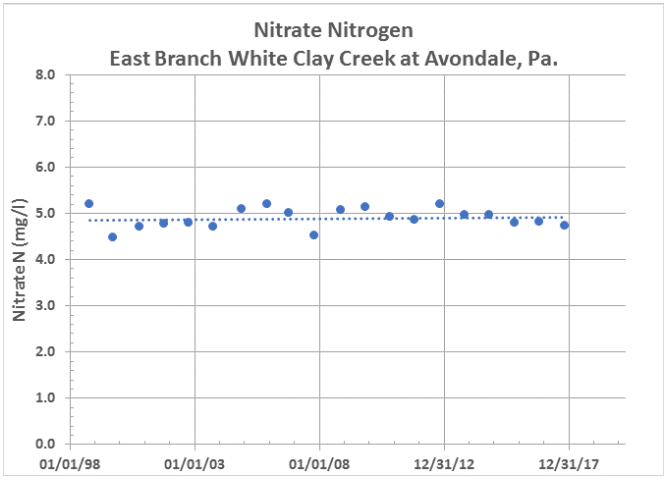
FIGURE 4-7 Total nitrogen levels along the Brandywine Creek, Red Clay Creek, White Clay Creek, Christina River, DE. (DNREC)











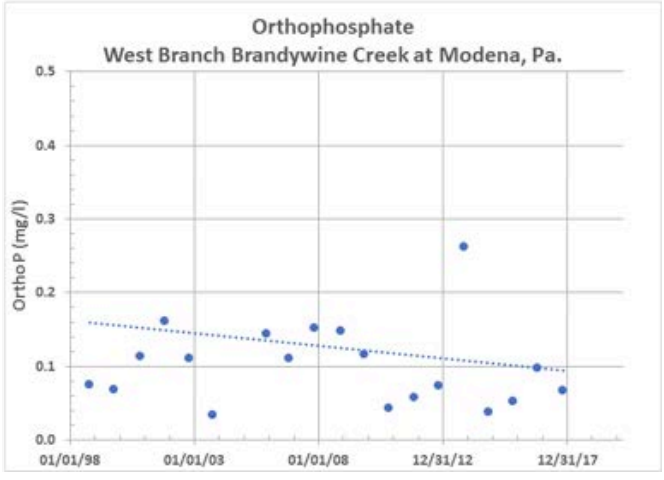


FIGURE 4-8 Nitrate nitrogen levels measured along Brandywine, Red Clay and White Clay creeks, PA. (USGS)

Branch White Clay Creek, and remained constant along the East Branch White Clay Creek (FIGURE 4-6).

At water quality monitoring stations operated by the Delaware DNREC, total nitrogen levels have decreased since 2000 along the Brandywine, Red Clay, White Clay Creeks and Christina River in Delaware (FIGURE 4-7).

Total Suspended Sediment

As part of the USGS/Chester County/CCWRA cooperative programs, the USGS has deployed turbidity sensors and conducted sediment sampling along the White Clay Creek near Strickersville, PA and along the Brandywine Creek at Honey Brook, Modena and below Downingtown stations (FIGURE 4-8).

- Annual suspended sediment yields (tons/mi²/yr) are generally highest at Honey Brook and lowest at below Downingtown, among the Brandywine Creek stations.
- Annual suspended sediment yields are significantly higher at the White Clay gage than at any of the Brandywine Creek gages, generally at least two times larger than Brandywine annual yields.
- The maximum daily TSS load occurred on February 25, 2016 at all stations along the Brandywine Creek and on February 24, 2016 at the White Clay Creek gage. The daily suspended sediment yields are three to five times higher at the White Clay Creek gage than at any of the three Brandywine Creek gages.

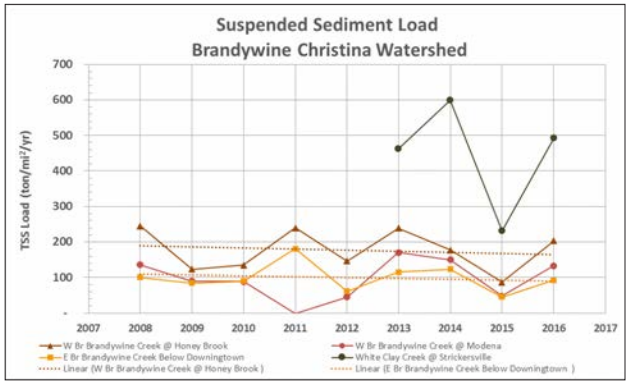
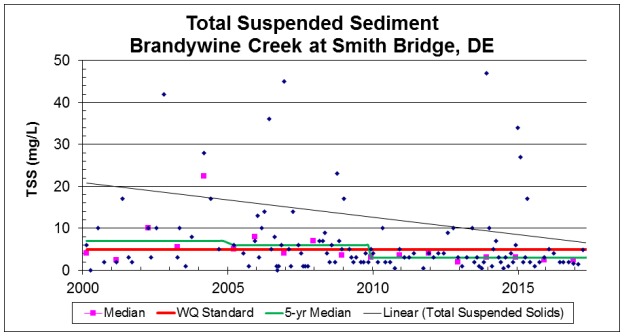
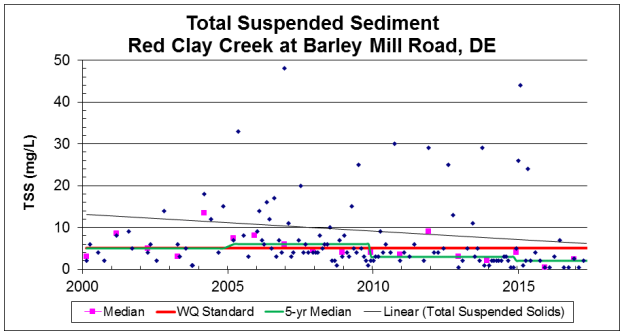
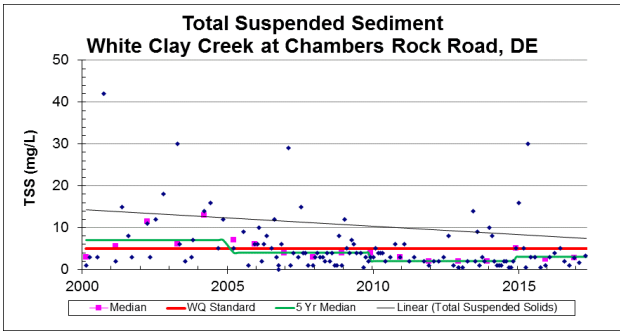


FIGURE 4-8 Annual suspended sediment load along the Brandywine Creek and White Clay Creek in Pennsylvania. (Sloto and Reif 2017)







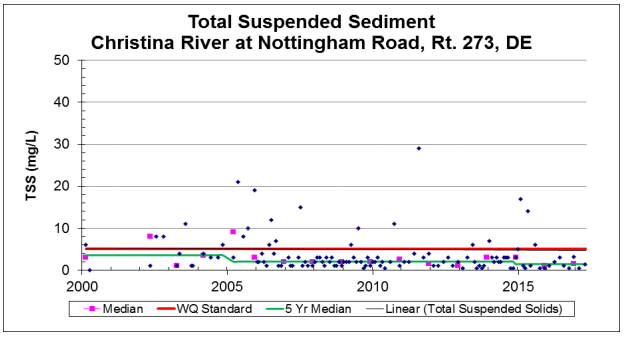


FIGURE 4-9 Total suspended sediment on the Brandywine, Red Clay, White Clay Creeks and Christina River, DE. (DNREC)

At water quality monitoring stations operated by DNREC, TSS levels have decreased since 2000 and have approached the 40 mg/l target level along the Brandywine, Red Clay, White Clay Creeks and Christina River in Delaware (FIGURE 4-9).

Water purveyors in the Brandywine-Christina watershed operate water supply intakes that curtail withdrawals when stream turbidity exceeds 20 NTU. Between 2012 and 2016, water purveyors would have curtailed withdrawals when

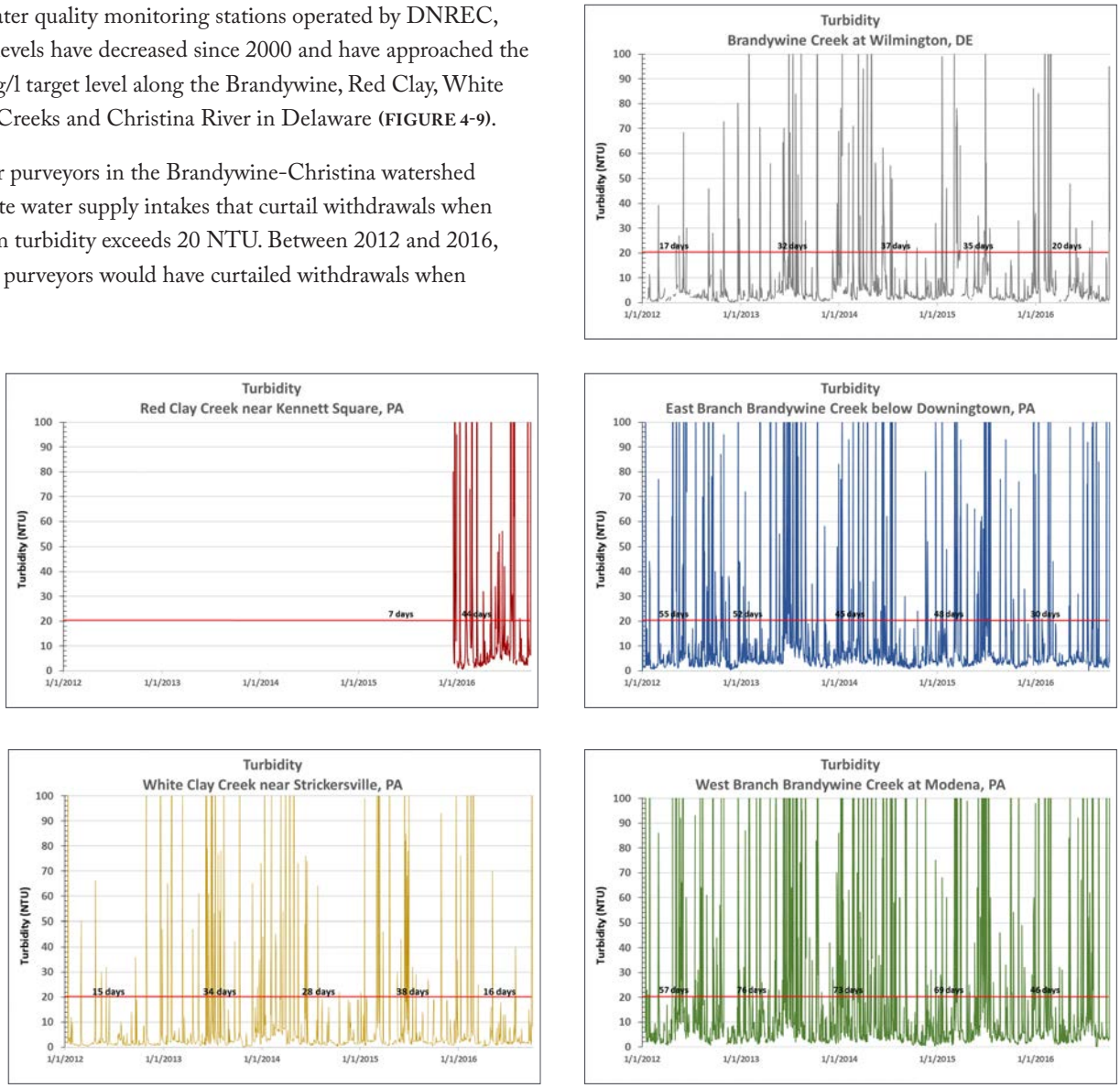


FIGURE 4-10 Turbidity along the Brandywine, Red Clay and White Clay creeks (USGS)

		DAYS > 20 NTU:					
STREAM	WATER PURVEYOR	2012	2013	2014	2015	2016	MEAN
Brandywine Creek at Wilmington, DE	City of Wilmington	17	32	37	35	20	28
EB Brandywine Creek Downingtown, PA	AQUA PA, Downingtown	55	52	45	48	30	46
WB Brandywine Creek at Modena, PA	PA American Water Co.	57	76	73	69	46	64
White Clay Creek near Strickersville, PA	City of Newark	15	34	28	38	16	26
Red Clay Creek near Kennett Square, PA	SUEZ DE					44	44

FIGURE 4-11 Days with high turbidity on the Brandywine, Red Clay, White Clay Creeks and Christina River, DE. (USGS)

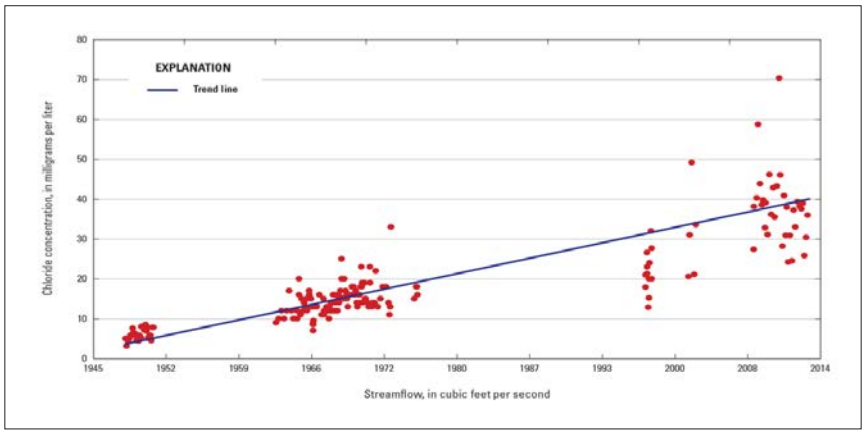


FIGURE 4-12 Chloride concentration in relation to streamflow at the Brandywine Creek at Chadds Ford, PA. (Sloto and Reif 2017)

turbidity exceeded 20 NTU for 26 days along White Clay Creek, 28 days along the Brandywine Creek in Wilmington, 44 days along the Red Clay Creek, 46 days along the East Branch Brandywine Creek, and 64 days along the West Branch Brandywine Creek **(FIGURES 4-10 & 4-11)**.

Chloride/Salinity

Chloride and salinity levels in the Brandywine-Christina watershed are rising due to road salt. The EPA, PADEP and DNREC have set secondary chloride drinking water standard at 200 mg/l. An upward trend in chloride concentrations was determined for Brandywine Creek at Chadds Ford, PA (01481000) for 1948–2013 where chloride levels have doubled over the past 20 years **(FIGURE 4-12)**. Annual mean specific conductance (SC) , which may be used to estimate chloride levels by the equation Cl = (SC-310)(0.28), has increased since the

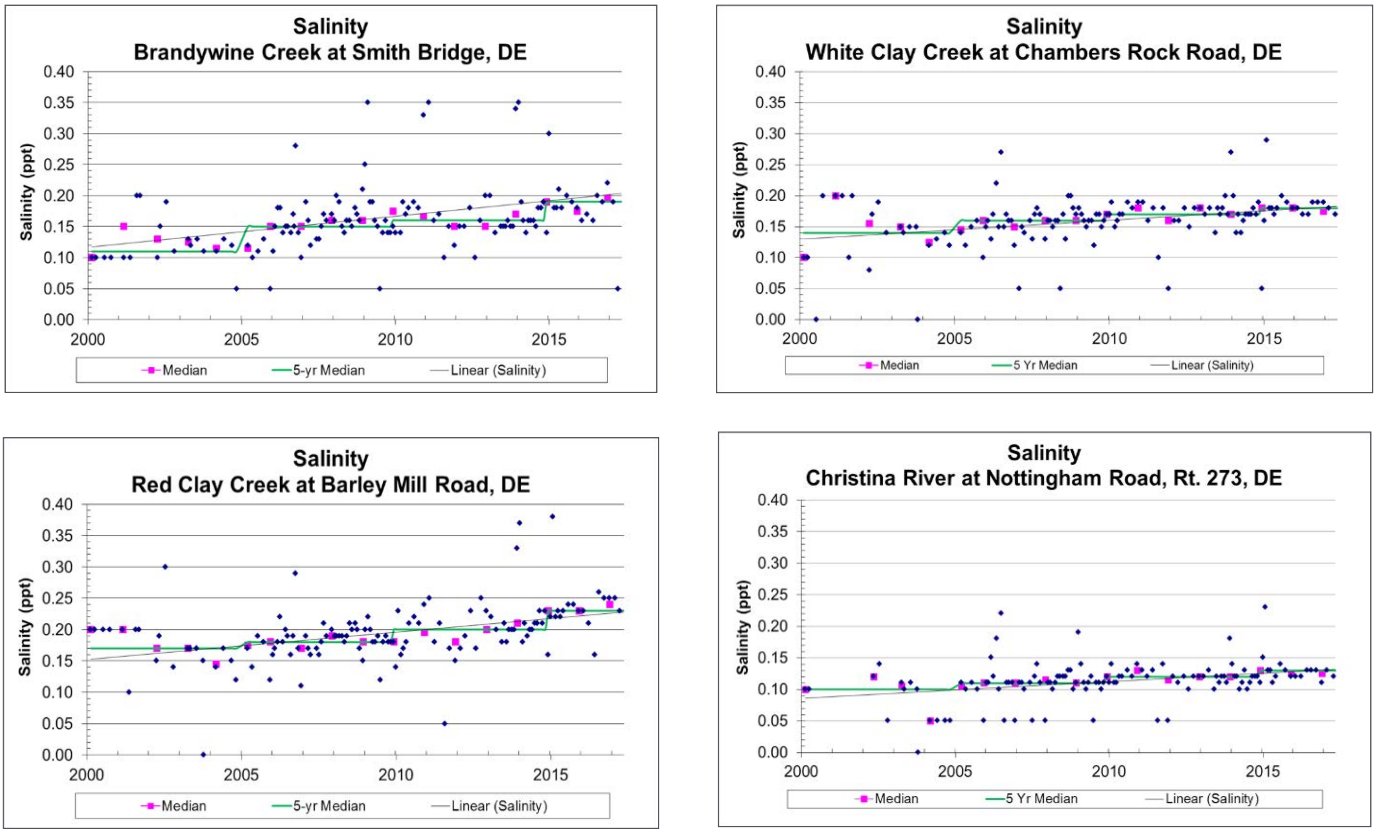


FIGURE 4-14 Salinity along the Brandywine, Red Clay, White Clay Creeks and Christina River, DE. (DNREC)

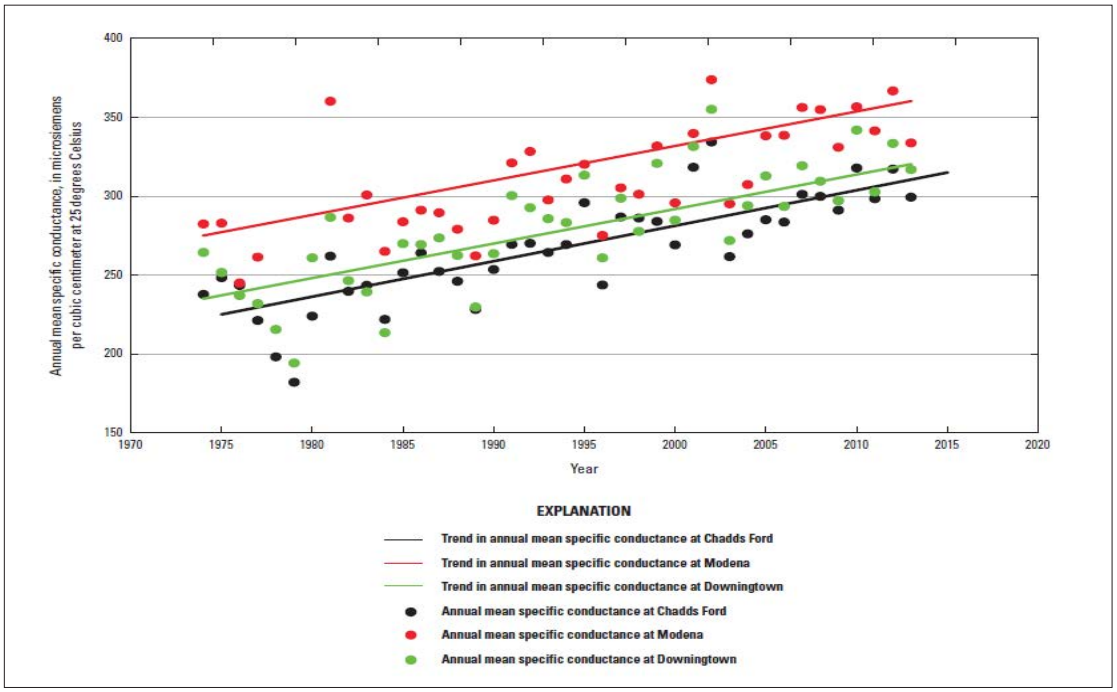


FIGURE 4-13
Annual mean specific conductance along Brandywine Creek in Chester County, PA. (Sloto and Reif 2017)

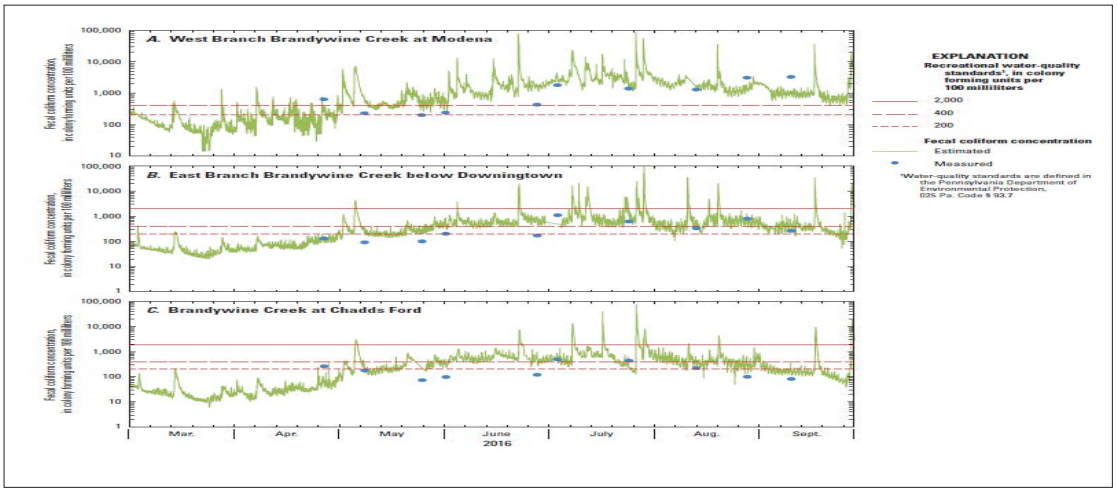


FIGURE 4-15
Estimated fecal coliform for Brandywine Creek at Chadds Ford, PA. (Senior 2017)

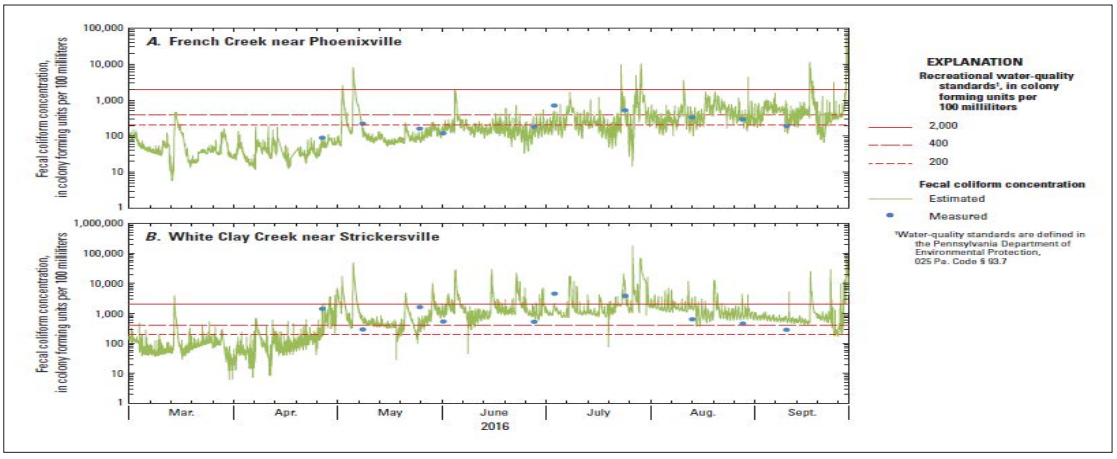


FIGURE 4-16
Estimated fecal coliform for White Clay Creek near Strickersville, PA. (Senior 2017)

1970s along the Brandywine Creek at Chadds Ford, Modena and Downingtown, PA **(FIGURE 4-13)**.

DNREC defines fresh water as water which contains natural levels of salinity at or below five parts per thousand (ppt). At water quality monitoring stations operated by DNREC, salinity levels have increased since 2000 along the Brandywine, Red Clay, White Clay Creeks and Christina River in Delaware **(FIGURE 4-14)**.

Bacteria

The USGS estimated from streamflow and turbidity measurements that fecal coliform levels typically decline below the 200 coliform forming units (CFU)/100 ml swimming recreation standard set by PADEP from September through April and then exceed the standard during the warmer months of June through September **(FIGURES 4-15 & 4-16)**. Bacteria levels along the Brandywine Creek are typically lower than along the White Clay Creek.

Delaware uses *Enterococcus* bacteria levels as the indicator to determine impacts of pathogens in streams. Bacteria in streams can come from a wide variety of sources, including human and livestock waste and wildlife. Delaware's geometric mean bacteria standard for swimming is at 100 colony forming units per 100 mL (cfu/100mL). Due to the nature of growth of bacteria colonies, there is a large range of values in the data from 2000 to 2017 for all four stations in Delaware operated by DNREC **(FIGURE 4-17)**. The five-year median values in the Brandywine Creek have decreased, while the Red Clay Creek values have remained relatively constant and the White Clay Creek and Christina River values do not have clearly discernable trends. Every station—with the exception of Christina River—has exhibited yearly geometric means of less than the Delaware standard. All of the stations contain bacteria levels much greater than 100 cfu/100mL.

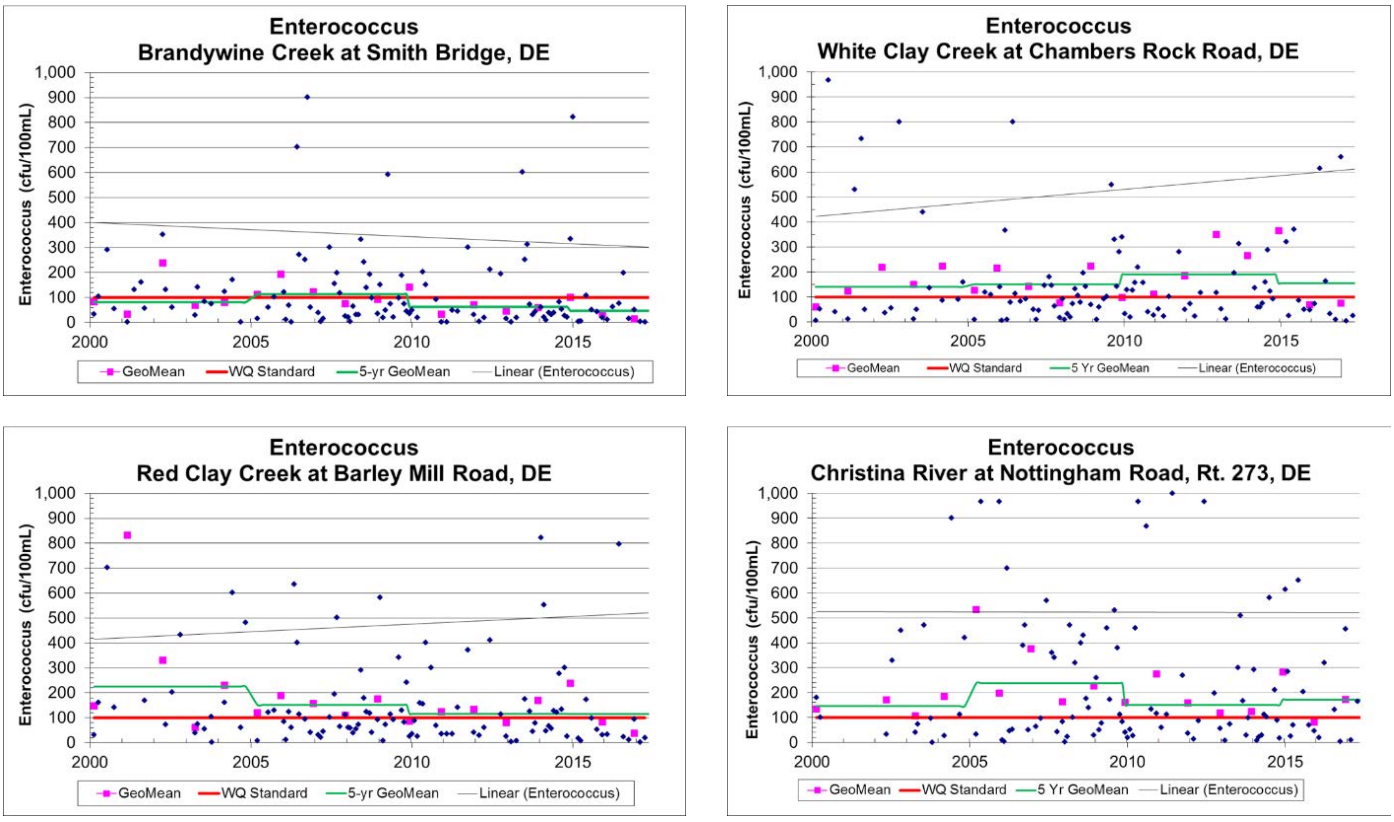


FIGURE 4-17 Enterococcus bacteria along the Brandywine, Red Clay, White Clay Creeks and Christina River, DE. (DNREC)

Water Temperature

Statistically significant upward trends in stream temperature were observed at the Brandywine Creek at Chadds Ford and White Clay Creek near Strickersville, PA **(FIGURE 4-18 & 4-19)**. The increase in stream temperature 0.6°C (1°F) per decade at Brandywine Creek at Chadds Ford, PA (01481000). The warming may be caused by climatic changes, warming of the earth's surface caused by urbanization, and (or) increasing quantities of warm effluent discharged to Brandywine Creek. (Sloto and Reif, 2017)

At water quality monitoring stations operated by the Delaware DNREC, there does not seem to be a noticeable rise or fall in stream water temperature since 2000 along the Brandywine, Red Clay, White Clay Creeks and Christina River in Delaware **(FIGURE 4-20)**. ■

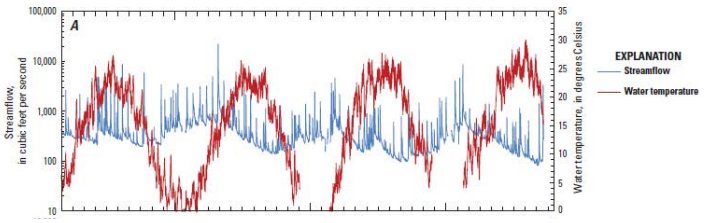


FIGURE 4-18 Stream temperature and streamflow for Brandywine Creek at Chadds Ford, PA. (Senior 2017)

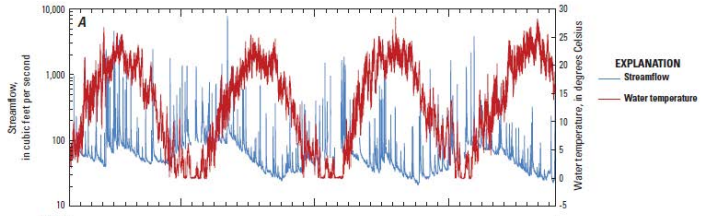


FIGURE 4-19 Stream temperature and streamflow for White Clay Creek near Strickersville, PA. (Senior 2017)

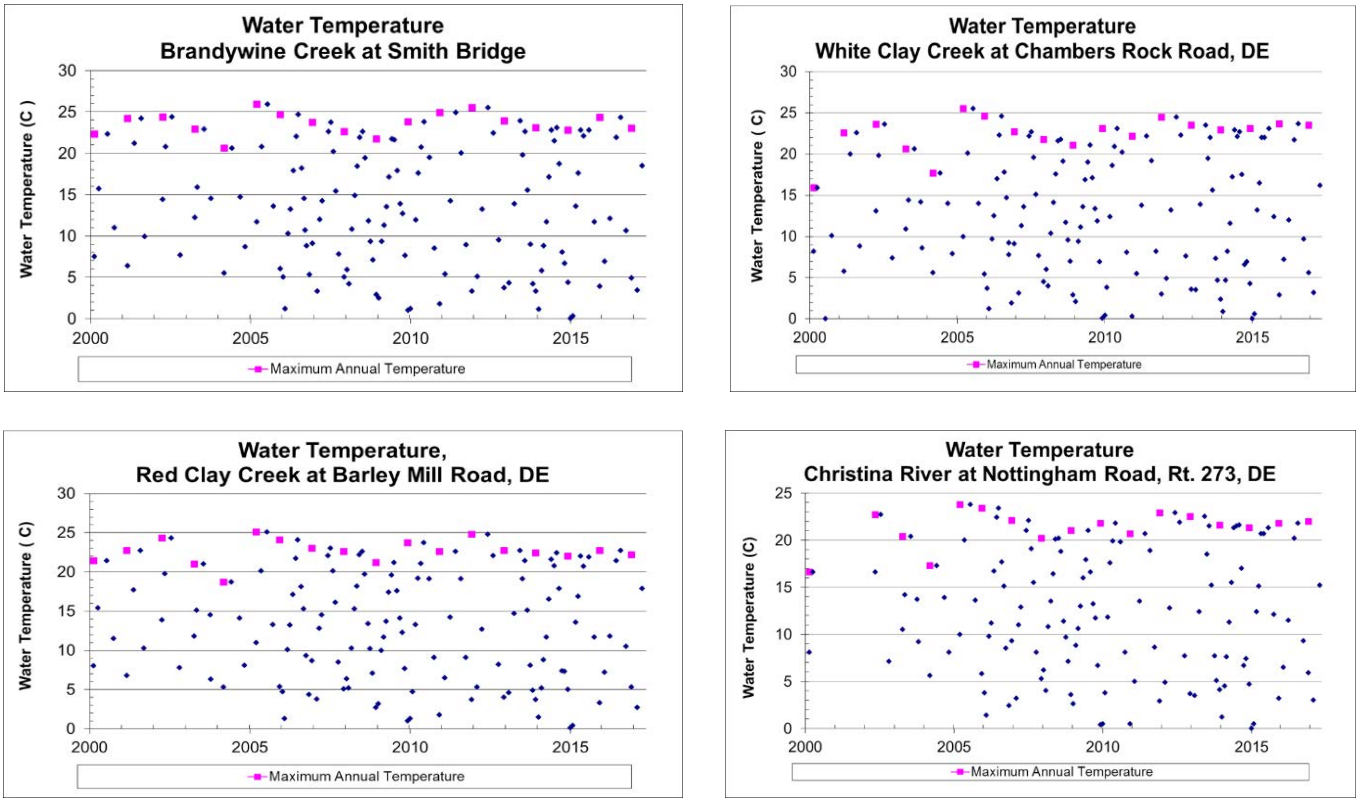


FIGURE 4-19 Water temperature along the Brandywine, Red Clay, White Clay Creeks and Christina River, DE. (DNREC)

Chapter 5

Land Use and Conservation

The Brandywine-Christina watershed falls principally within two states, Pennsylvania to the north and Delaware to the south. The Pennsylvania portion is characterized by more open space, including agricultural land and forests, while the more urban, southerly portion in Delaware tends to have more built-up land.

Land Use

Current land cover

The Brandywine-Christina watershed is characterized by a diverse mix of land uses and cover types. The Brandywine watershed extends from the City of Wilmington in the south to the agricultural region in northern Chester County. Streams in the watershed pass through a wide mix of agricultural lands, industrialized, and urban and suburbanized areas, until they meet the Christina River near the Delaware River. Both the White Clay Creek and Red Clay Creek watersheds extend into rural and suburbanized areas of Chester County. These areas are experiencing increased growth. They also include areas of livestock and dairy farming, cultivated land and many mushroom farms. The Christina River watershed lies almost entirely in Delaware, at the edge of the Piedmont province, in a mainly urbanized corridor characterized by high population density, high levels of pavement and impervious land cover. Except for the upper reaches west of the City of Newark, DE, the Christina is fairly wide and meandering with relatively little topographic fall.

The National Oceanic and Atmospheric Administration (NOAA) Office for Coastal Management (previously the Coastal Services Center, CSC and the Office of Ocean and Coastal Resource Management which merged in 2014) in their Coastal Change Analysis Program (C-CAP) has created a series of land cover datasets approximately every five years from 1996 to 2010 (1996, 2001, 2006, 2010) for all coastal watersheds. These layers are based on satellite imagery, and are consistent across time periods and state boundaries. As such they provide a source of consistent data across jurisdictions in the Basin for determining both existing land cover and trends over time.

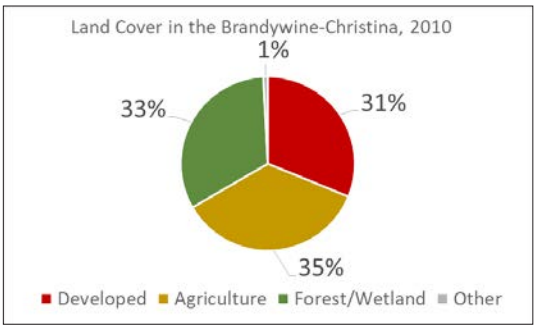


FIGURE 5-2 Proportion of major land cover types in the Brandywine-Christina watershed, 2010. (NOAA C-CAP)

FIGURE 5-1 presents land cover in the Brandywine-Christina watershed in 2010, categorized into seven generalized classes.

FIGURE 5-2 presents the proportion of major land cover types: developed (or urbanized), agricultural (livestock farms, cultivated land and pasture) and natural (forest and wetlands) lands.

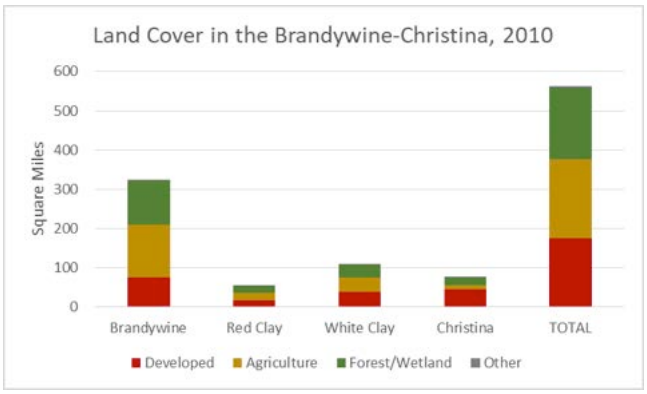


FIGURE 5-3 Proportion of major land cover types in the Brandywine-Christina watershed, 2010. (NOAA C-CAP)

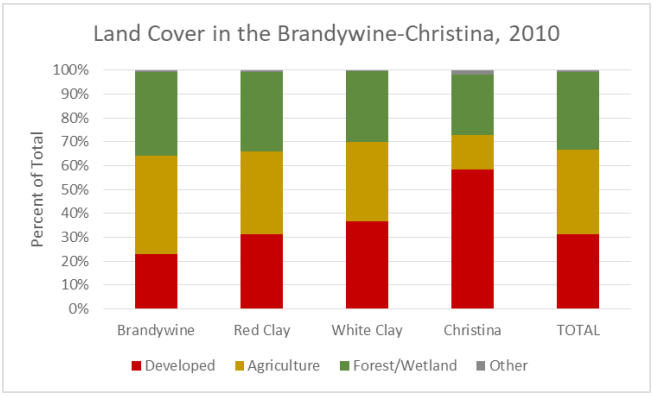


FIGURE 5-4 Land cover in the Brandywine-Christina watershed by watershed and overall, as a percentage of the total, 2010. (NOAA C-CAP)

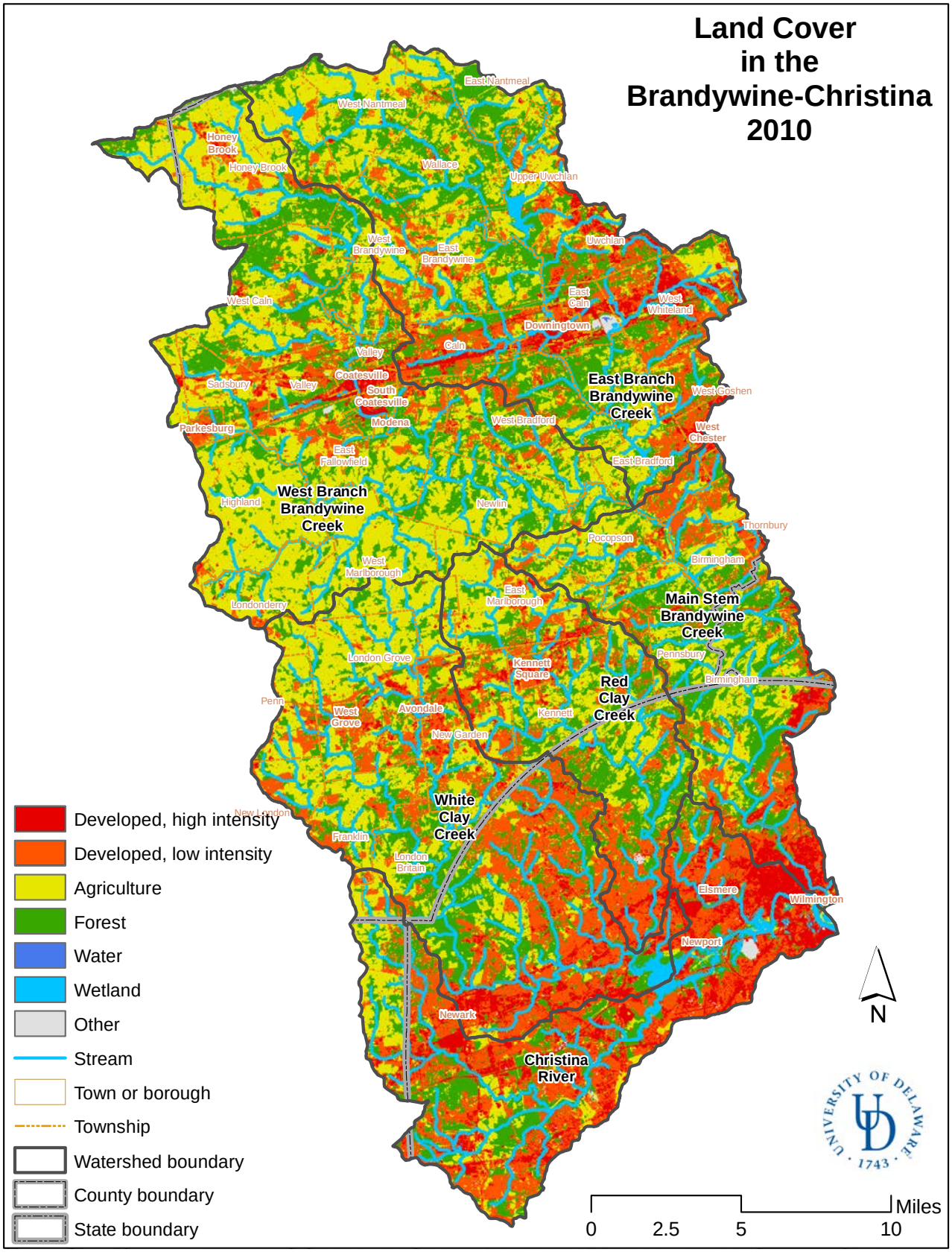


FIGURE 5-1 Land cover in the Brandywine-Christina watershed, based on 2010 NOAA CSC C-CAP.

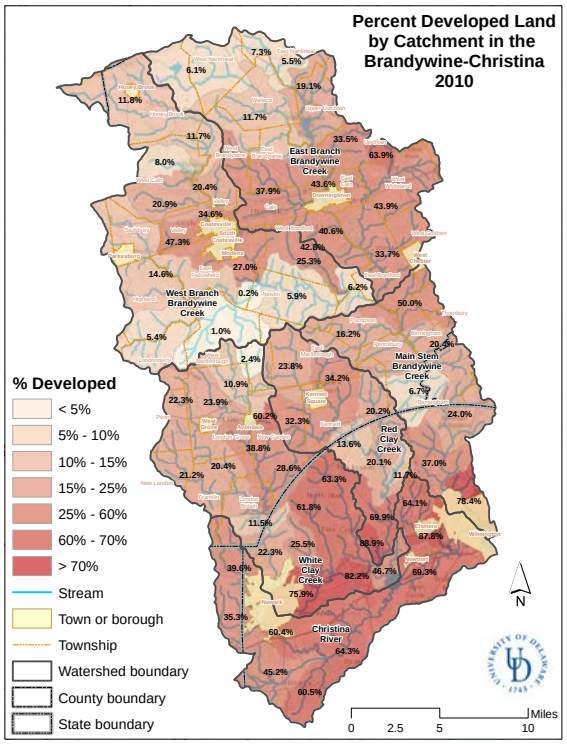


FIGURE 5-5 Percentage of developed land in the sub-watersheds of the Brandywine-Christina watershed, 2010. (NOAA C-CAP)

Each of the major classes constitute approximately a third of the basin's area. FIGURE 5-3 shows the proportions, by watershed, in the Brandywine-Christina watershed of land cover types.

The maps in FIGURES 5-5 TO 5-7 show the percentage of developed, agricultural and natural land, respectively, by the sub-watersheds of the Brandywine-Christina watershed. The watersheds in Delaware near Wilmington and along the I-95 corridor are the most heavily developed, along with those in the Great Valley (also called the Chester Valley). Agriculture predominates in the upper West and East Branches of the Brandywine, while natural areas occur most prominently in the northern watersheds in Delaware and in the upper East Branch of the Brandywine in Pennsylvania.

Land cover trends

Overall, the Brandywine-Christina watershed, as well as each watershed within, between 1996 and 2010 have seen an increase in developed land, and over the same period a corresponding decrease in agriculture and natural areas (SEE FIGURE 5-8).

The maps in FIGURES 5-9 TO 5-11 show the change, by watershed, of the three major land cover types between 1996 and 2010 (to-

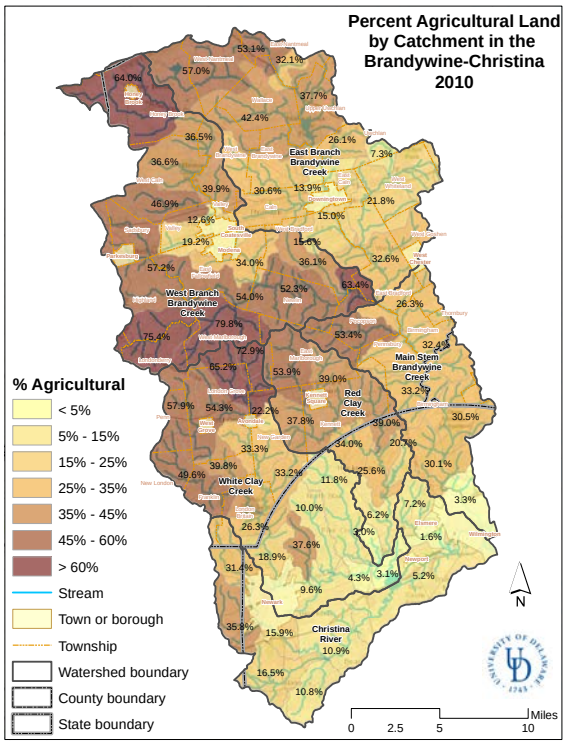


FIGURE 5-6 Percentage of agricultural land in the sub-watersheds of the Brandywine-Christina watershed, 2010. (NOAA C-CAP)

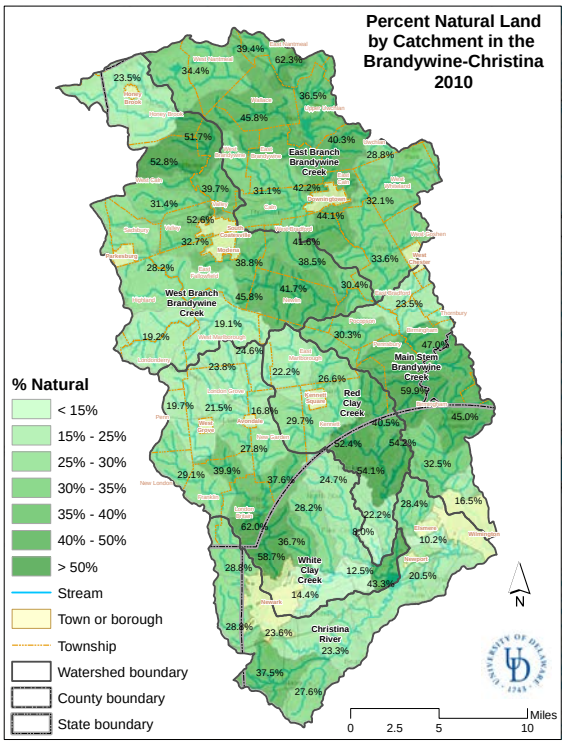


FIGURE 5-7 Percentage of natural land in the sub-watersheds of the Brandywine-Christina watershed, 2010. (NOAA C-CAP)

tal change normalized by watershed area). Areas of the greatest increase in development and concurrent loss of agricultural land include the East Branch of the Brandywine near West Chester, the lower sub-watersheds in the Red and White Clay Creek watersheds, and the area south of Newark, DE. Natural land (i.e., forests and wetlands) decreased more uniformly across the Brandywine-Christina watershed with somewhat higher losses in the Great Valley portion of the Brandywine Creek watershed.

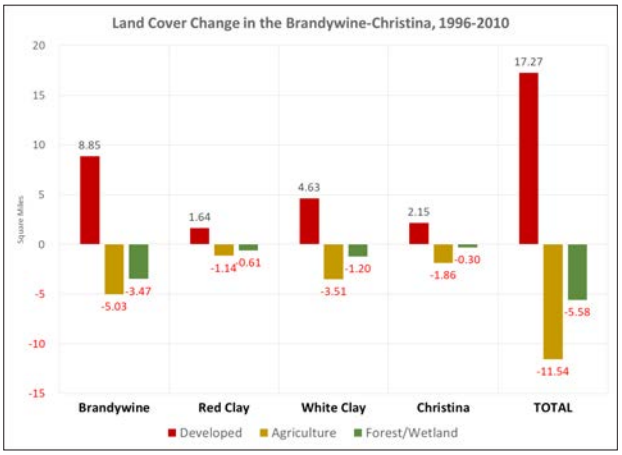


FIGURE 5-8 Change in major land cover types in the Brandywine-Christina watershed, by watershed, 1996 to 2010. (NOAA C-CAP)

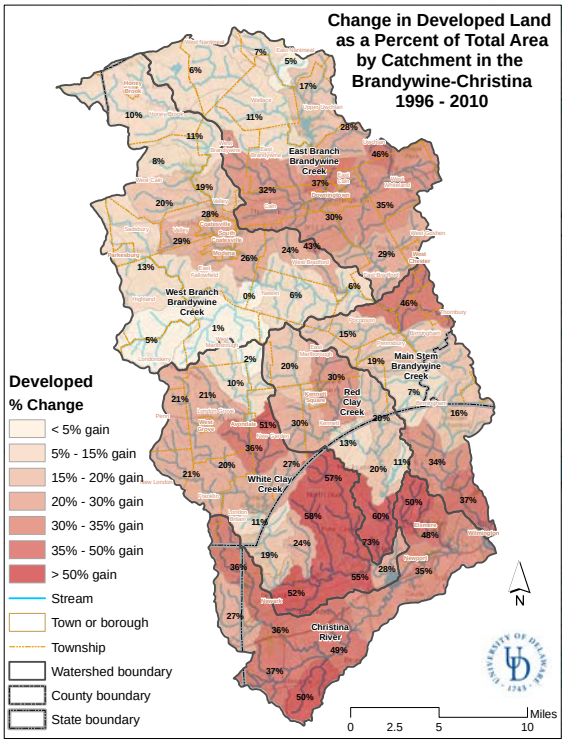


FIGURE 5-9 Change in developed land, by sub-watershed, between 1996 and 2010. (NOAA C-CAP)

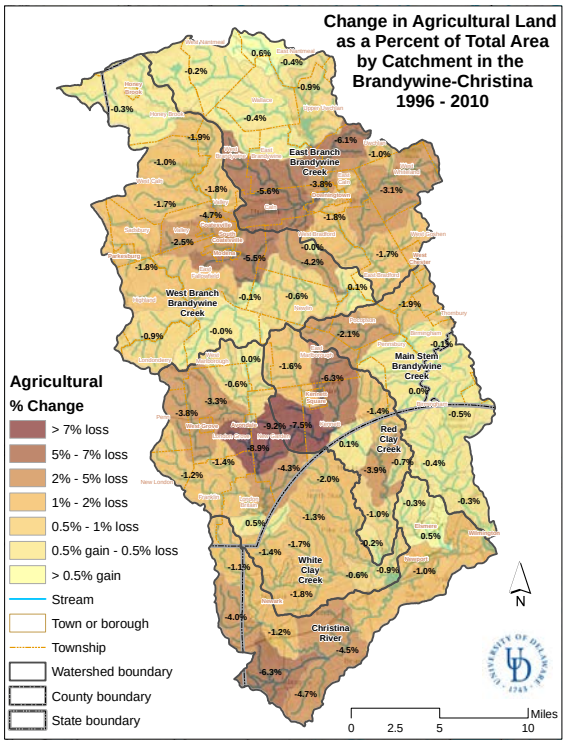


FIGURE 5-10 Change in agricultural land, by sub-watershed, between 1996 and 2010. (NOAA C-CAP)

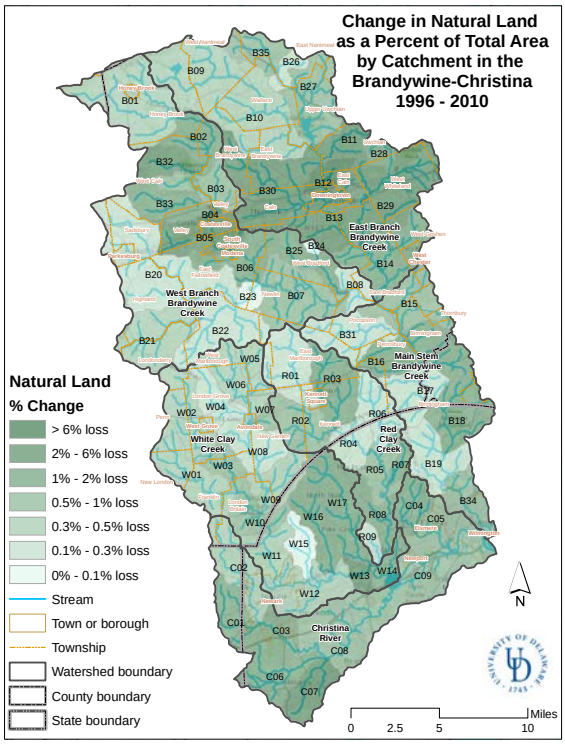


FIGURE 5-11 Change in natural land, by sub-watershed, between 1996 and 2010. (NOAA C-CAP)

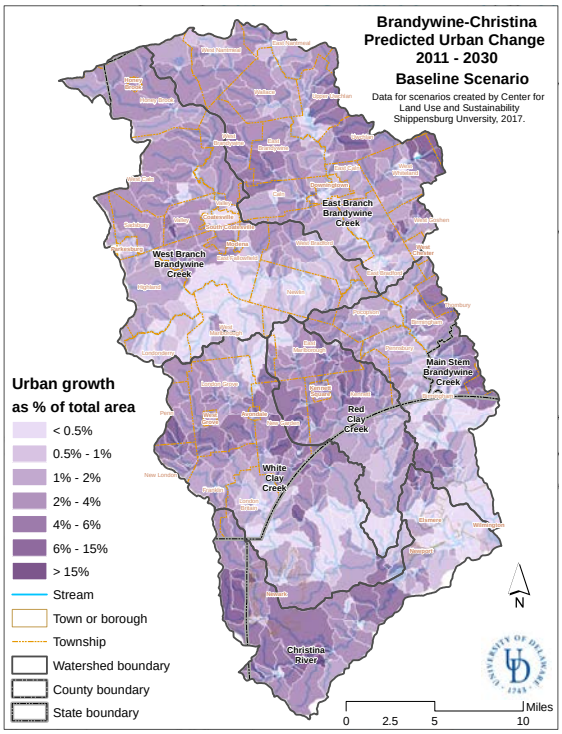


FIGURE 5-12 Projected change in developed land, by catchment, under the Baseline scenario, 2011 to 2030. (CLUS)

Future scenarios

To support planning for growth in the Delaware River Basin, Shippensburg University Center for Land Use and Sustainability (CLUS), in collaboration with the University of Vermont Spatial Analysis Lab, the USGS and Northern Arizona University, has developed a model to predict long-term growth. Models were developed at the catchment scale based on projections under three potential planning scenarios:

- **Baseline**—if future growth follows current trends, and land use policies remain constant ("business as usual").
- **Corridors**—if natural resource protections are weak and development sprawls along existing transportation corridors.
- **Centers**—if future growth is directed toward existing town centers and natural resource protections are enhanced.

The following FIGURES 5-12 TO 5-14 show the change predicted by the CLUS model between 2011 (the baseline year) and 2030 under each of the three growth scenarios, Baseline, Corridors and Centers, respectively.

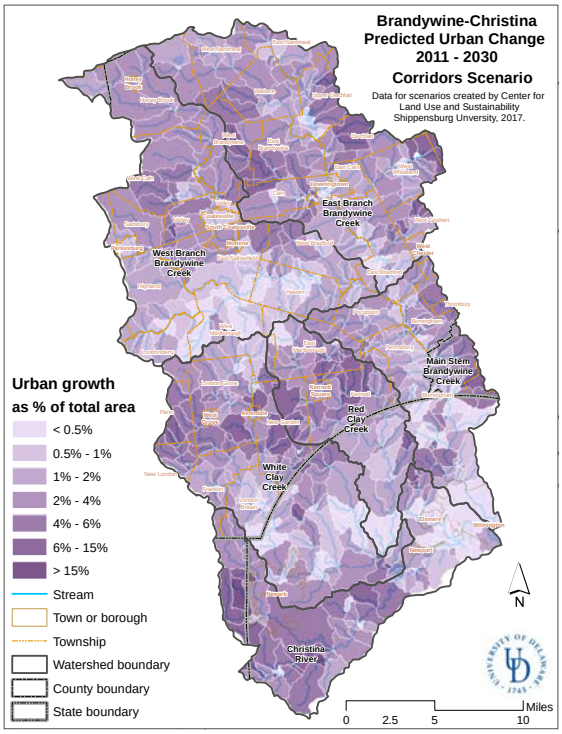


FIGURE 5-13 Projected change in developed land, by catchment, under the Corridors scenario, 2011 to 2030. (CLUS)

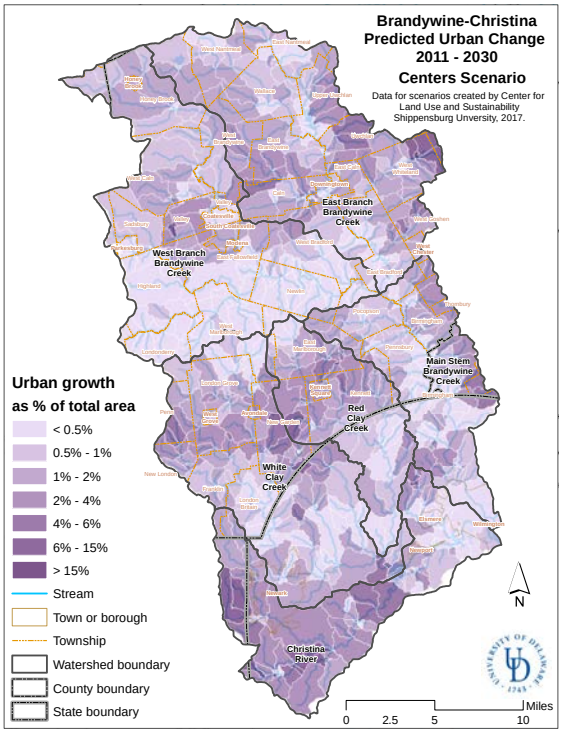


FIGURE 5-14 Projected change in developed land, by catchment, under the Centers scenario, 2011 to 2030. (CLUS)

Impervious Cover

Impervious cover is any land cover type that prevents rain water from percolating into the ground, such as roads, parking lots, sidewalks and rooftops. Water that is not permitted to infiltrate runs off the landscape, often finding its way into streams and other water bodies, either by direct overland flow or through artificial stormwater conduits.

The amount of imperviousness in a watershed has a direct impact on the health of the watershed and the waters that drain it. As water runs off hard surfaces it can pick up contaminants such as dirt, gravel and other solid debris, substances such as motor oil, nutrients, pesticides and other pollutants.

Since there is little attenuation of the amount of water flowing overland, the sheer volume of water can also present problems for streams, as they become "flashier" during times of heavy rains. The loss of groundwater recharge potential from impervious cover also leads to lower flows in dry weather. Increased flows can lead to increased flooding of low-lying areas, erosion problems and exceedance of stormwater system capacity.

If the percentage of imperviousness in a watershed is too high, the habitat and ecology of a stream becomes impaired. The Center for Watershed Protection has determined that percentages of imperviousness above 10% can cause degradation in stream health, and percentages over 25% result in streams not being able to support most aquatic species, see **FIGURE 5-15**.

Imperviousness correlates closely with areas of development. More highly urbanized areas have a higher degree of hard, impermeable surfaces, and a lower amount of natural land surface and open areas that can help ameliorate water runoff through percolation into the soil, attenuation and temporary detention by natural depressions and wetlands, or uptake by vegetation.

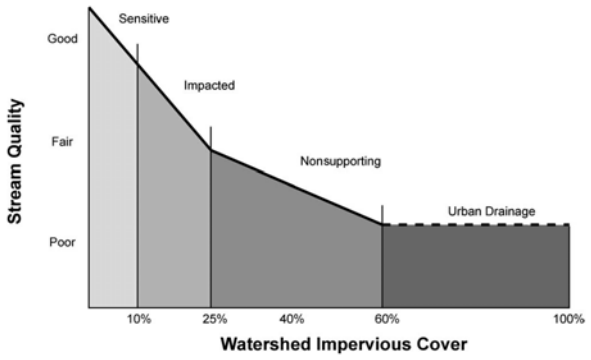


FIGURE 5-15 Relationship between impervious cover and stream quality. (Center for Watershed Protection, 1998)

The negative effects of imperviousness in a watershed can be lessened through the use of updated design of stormwater management systems to include infiltration, water quality treatment, reduced volume of discharges to streams, energy dissipation at outfalls, implementation of low impact, or "green" infrastructure stormwater measures, disconnection of impervious cover from direct flow into waterways, or conversion of hard surfaces to more permeable materials.

The USGS Multi-Resolution Land Characteristics Consortium (MRLC) has developed a National Land Cover Database (NLCD) of land cover and related characteristics, including impervious cover, every five years for the past several decades. Impervious cover information at the national level is available for 2001, 2006 and 2011. While these data are relatively coarse, compiled at a resolution of 30 meters square, they provide a consistency across state boundaries and across time that many other data sets do not. They are, therefore useful to estimate imperviousness at the catchment and watershed scales, and to assess trends.

FIGURE 5-16 presents the location and degree of imperviousness across the Brandywine-Christina watershed based on 2011 NLCD data.

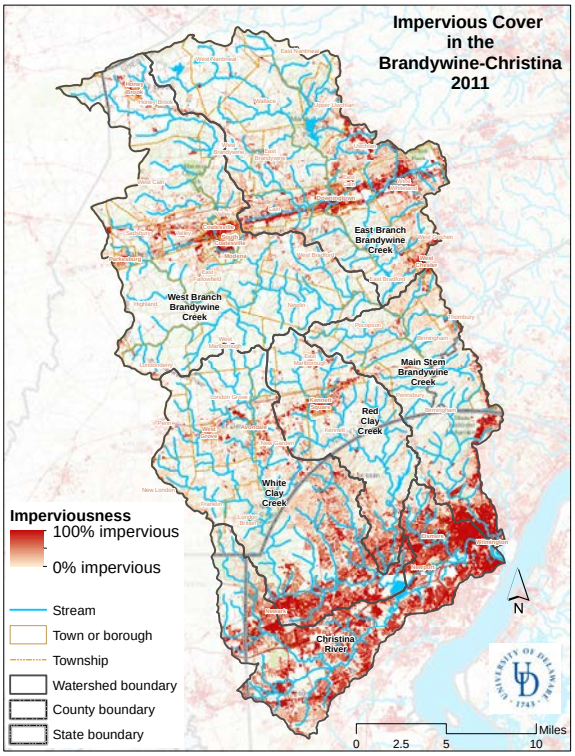


FIGURE 5-16 Developed imperviousness in the Brandywine-Christina watershed, 2011. (USGS NLCD)

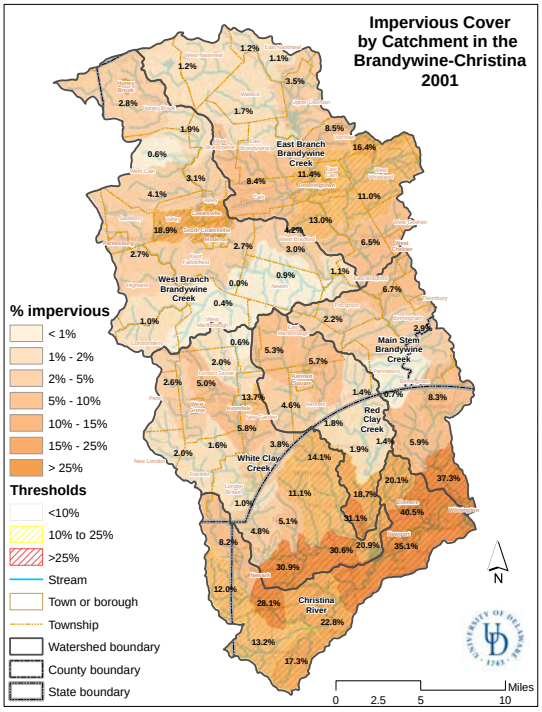


FIGURE 5-17 Imperviousness by watershedss, 2001. (USGS NLCD)

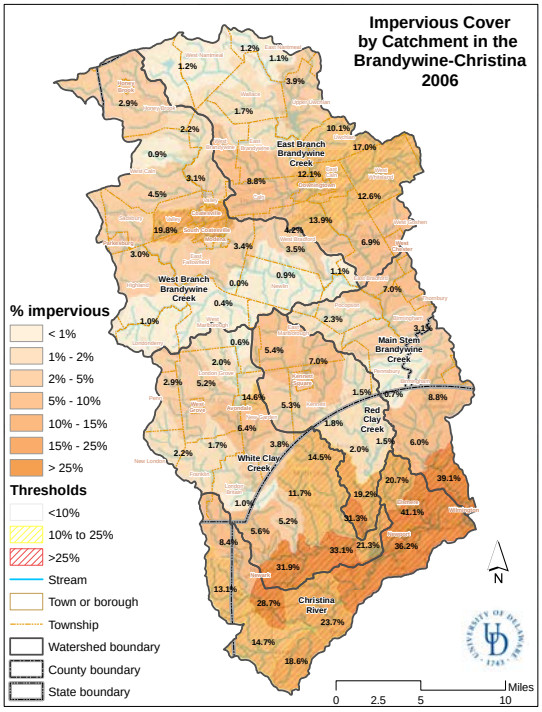


FIGURE 5-19 Imperviousness by watersheds, 2006. (USGS NLCD)

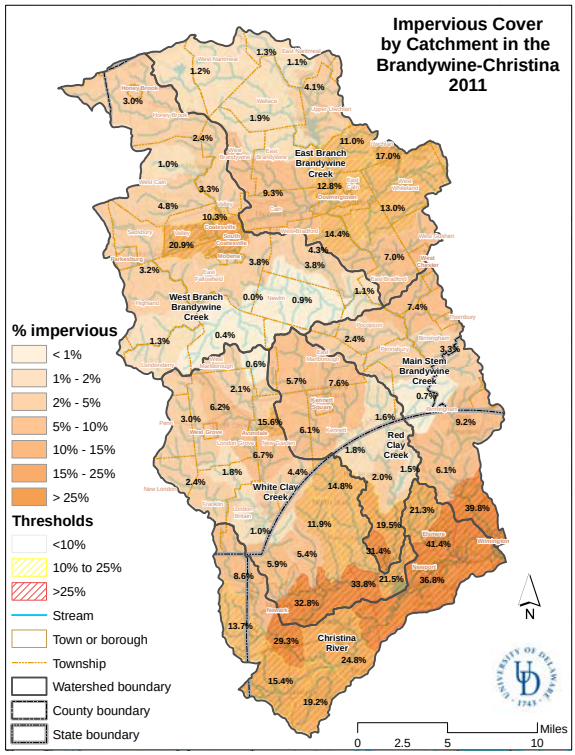


FIGURE 5-18 Imperviousness by watersheds, 2011. (USGS NLCD)

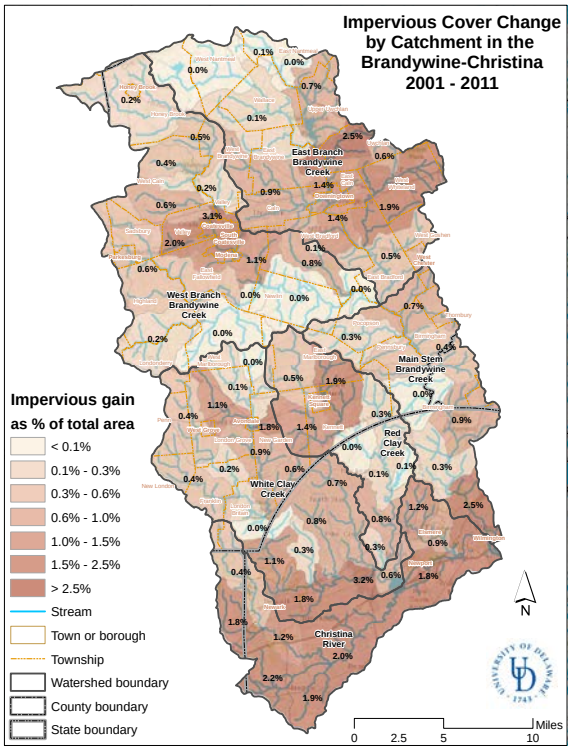


FIGURE 5-20 Change in imperviousness, 2001 to 2011. (USGS NLCD)

The percentage of imperviousness by sub-watershed in the Brandywine-Christina watershed for the years 2001, 2006 and 2011 is presented in **FIGURES 5-17 TO 5-19**. Sub-watersheds whose imperviousness levels are above the 10% threshold indicating "impacted" health, and the 25% threshold indicating "non-supporting" health are highlighted in orange and red crosshatching, respectively. The change in imperviousness over the same period (normalized by sub-watershed area) is presented in **FIGURE 5-20.**

The graph in **FIGURE 5-21** shows how the level of imperviousness has changed between 2001 and 2011 in the watersheds of the Brandywine-Christina watershed, and in total (Xian, et al, 2011).

Of the four major watersheds in the Brandywine-Christina watershed, only the Christina River watershed is highly impacted (approaching "non-supporting"), based on the CWP threshold of 10% imperviousness (this number is 25% for "non-supporting" watersheds). Levels of imperviousness in the White Clay Creek watershed and the basin as a whole are approaching that level, however, as of 2011.

Many individual sub-watersheds are above the 10% threshold, especially in the Delaware portion of the watershed, as well as the urbanized Route 30 corridor in Pennsylvania. Many of the sub-watersheds in the I95 corridor in Delaware exceed the 25% imperviousness threshold over which watershed health is considered "non-supporting."

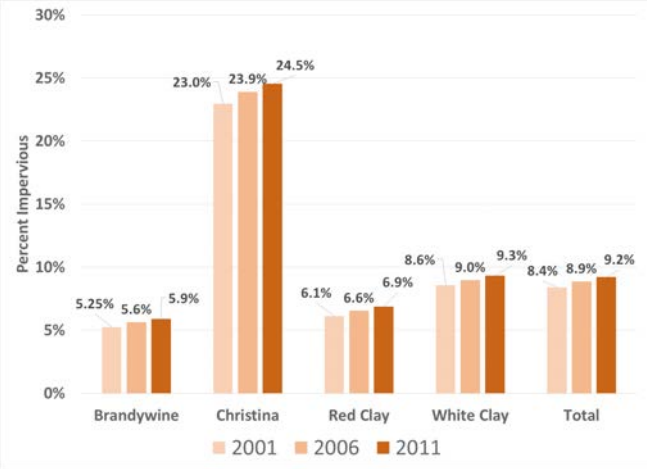


FIGURE 5-21 Imperviousness by year and watershed, 2001, 2006, and 2011. (USGS NLCD)

Natural Resources Ordinances

Chester County municipalities in the watershed boast the most progressive land use regulations in Pennsylvania, attributed to the County's first *Landscapes* County Comprehensive Plan (1996) and an implementation program, called the Vision Partnership Program (VPP). The Chester County Board of Commissioners first established the VPP grants in 1996 to promote cooperation between local governments and the County to implement *Landscapes*, the County's Comprehensive Policy Plan. The resulting ordinances, often funded under the VPP, added standards for natural resource protection, conservation subdivision, village/infill development and other "smart growth" approaches.

In December 2017, Chester County Planning Commission updated their inventory of natural resources standards for all municipalities in Chester County. Of the 45 municipalities in the Chester County portion of the watershed, 24 of 45, or over half, have riparian buffer ordinances and most are described as rigorous. Data analysis shows that of the 21 municipalities that do not have riparian buffer ordinances seven are boroughs. This is important because the boroughs are typically dense and have little opportunity to protect riparian buffers, so may be of less priority or concern. In addition, the boroughs are very small compared to the townships. As a result, the inventory concludes that the majority of the Chester County Brandywine-Christina watershed has riparian buffer ordinances and about 1/3 of the basin land area is still in need of continued efforts to add riparian buffer protections.

The availability of William Penn Foundation DRWI funding and the presence of two local nonprofits with professional planning and design staff, the Brandywine Conservancy and Natural Lands, provided an opportunity to advance water quality through riparian buffer standards, thereby complementing streamside buffer restoration occurring in the landscape. Specifically, the DRWI funding provided for riparian buffer restoration, an element not typically found in zoning regulations.

In 2014, the Brandywine Conservancy, in partnership with the Pennsylvania Land Trust Association, developed a model riparian buffer ordinance. The ordinance based regulatory standards on the science of buffers, most notably a literature review by the Stroud Water Research Center (Sweeney, B.W., and J.D. Newbold. 2014. Journal of the American Water Resources Association) that addressed how wide a streamside forest buffer needs to be to protect water quality habitat and

biota for small streams. The review found that a minimum 100-foot buffer, on each side of a waterway, was necessary to manage the most common sources of stream impairment in the Brandywine-Christina watershed – nitrogen, phosphorus and sediment. The review also demonstrated that streamside buffers could have a restorative effect on water quality. The resulting riparian buffer standards differ from typical buffer regulations in that they require the *restoration* of the 100-foot buffer, versus solely a building setback from the stream.

Funding from the William Penn Foundation, for Phase 1 of the DRWI Brandywine-Christina Watershed Partners, included technical assistance to municipalities to adapt the model riparian buffer ordinance to local situations. The Brandywine Conservancy and Natural Lands partnered on this cluster effort and engaged a land use attorney to review the model ordinance, thereby ensuring the legality of the approach under state enabling legislation. Funding provided time to talk with municipal officials, the outcome resulting in 11 municipalities requesting a review of their local land use regulations, called an Assessment (several additional municipalities signed on outside the scope of this grant). The Phase I goal included adoption of the model ordinance by five municipalities. At the end of Phase 1, seven municipal ordinances had been prepared. The Townships of East Bradford, East Brandywine, Pennsbury and Pocopson adopted the ordinance; New London and West Bradford Townships were undergoing the adoption process at the conclusion of Phase 1; and London Grove Township was considering, but placed their ordinance on hold. **FIGURE 5-22** shows the Brandywine-Christina watershed municipal participation in the DRWI Riparian Buffer Ordinance Assessments. The green shading specifies 10 of the 11 townships that signed on for the DRWI Riparian Ordinance Assessments. Honey Brook Township, the eleventh township, is not shaded on the map. The participating communities learned more about the benefits of planting trees along watercourses and the ability to incorporate such requirements into zoning regulations.

In addition to the riparian buffer ordinance, the DRWI funding provided for water quality modeling conducted for New London and London Grove Townships. Such modeling demonstrated the impact on water quality of implementing the land use ordinance and subsequent 100-foot riparian buffer restoration. A riparian buffer planting guide can serve as a complement to the ordinance, or as a standalone guide for volunteer planting.

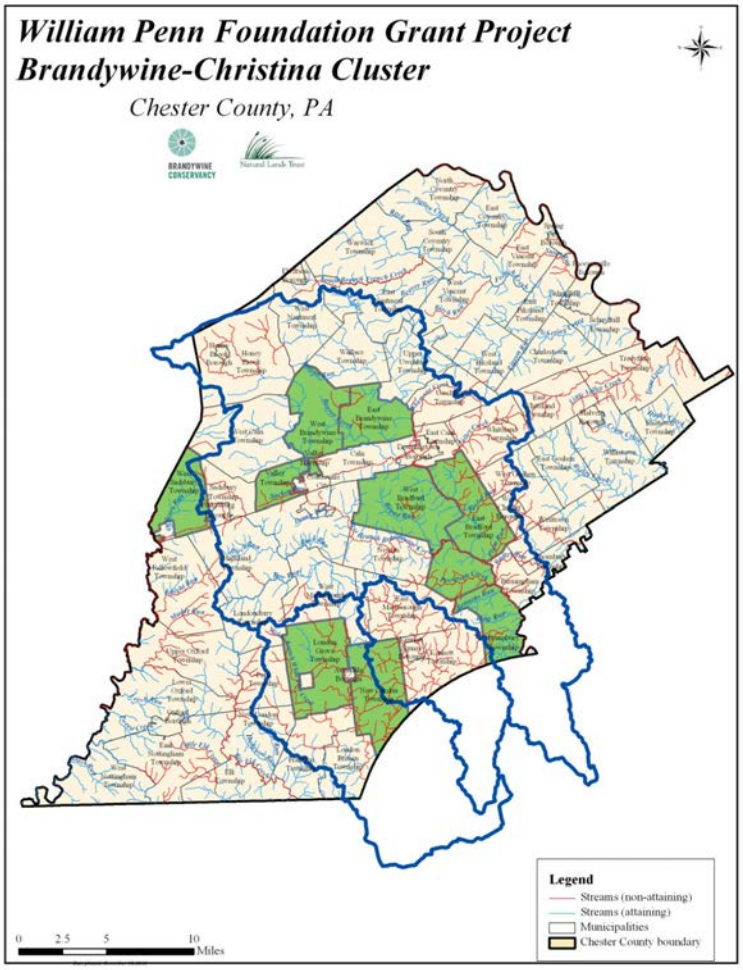


FIGURE 5-22 Brandywine-Christina watershed municipal participation in the DRWI Riparian Buffer Ordinance Assessments. (Chester County Planning Commission, Brandywine Conservancy, Natural Lands)

In addition to the ongoing ordinance work being conducted in Chester County, in 2014, the University of Delaware Water Resources Center conducted a comparative analysis of direct and indirect source water protection ordinances put in place by local governments in the Brandywine-Christina watershed (Miller, 2014). For this research, source water protection ordinances included direct source water protection, natural resource protection, stormwater management and education and accessibility. Miller examined and compared the direct and indirect source water protection ordinances among the municipalities in the watershed in Delaware and Pennsylvania. The research found that in general both states scored similarly as it relates to source water protection. This fairly high level of consistency across the basin lends itself to the protection of this entire area as a single watershed unit, which research has shown

is the most efficient level at which to manage water resources (Miller, 2014). This research also concluded that a state source water law is not the only means to encourage the regulatory protection of drinking water sources. Voluntary efforts at the local level appear to have a positive impact on the health and quality of source waters in the region. This is especially important in states like Pennsylvania, whose large size and diverse demographics might make it more difficult to garner the support for a statewide law than in a smaller state like Delaware (Miller, 2014). The research recommends that the natural resources most vulnerable to degradation or contamination due to a lack of ordinance protections are un-buffered streams and woodlands. Both of these resources have the potential to substantially impact the water quality (both surface and groundwater), and so working with municipalities to improve protections for these resources is critical. The work being conducted by Chester County, the Brandywine Conservancy and Natural Lands and the additional funding provided through the William Penn Foundation's DRWI to strengthen the natural resource ordinances in Chester County is a critical piece to protecting water quality through local environmental ordinances in the Brandywine-Christina watershed.

Protected Lands

Aside from federal, state, county and municipal expenditures acquiring public park land, until the 1990s most of the lands protected in the watershed were done so through voluntary charitable donations. But as development pressure increasingly consumed more open space, citizens in Chester County clamored for funds to preserve land. In 1989, the county raised $50 million through the issuance of a bond to fund the preservation of farmland and natural areas and help municipalities acquire parks. Chester County has ever since continued its financial commitment to protecting open space. Since that initial bond, the county has spent over $202,089,390 to preserve open space (Source: Chester County Open Space Preservation). By the early 2000s, local townships felt the need to create and fund their own open space preservation programs, albeit on a more modest scale than the county. Today, 17 municipalities within the watershed have adopted and are funding open space preservation programs, spending millions of dollars toward the effort. Many of the nonprofits are using additional funds from their organizations and other funding sources (including grants from the state and private foundations) to leverage county and municipal funding, or for independent non-county funded preservation projects. Preservation projects require significant additional funding for transaction costs such as surveys, appraisals, legal fees and title insurance, plus endowments to ensure the land is preserved in perpetuity.

The Brandywine-Christina watershed is blessed with extensive amounts of protected open spaces. These protected lands include:

- Lands owned by land trusts and other nonprofit organizations
- Lands subject to agricultural or conservation easements held by land trusts
- Lands subject to agricultural easements held by the county and/or state
- Public lands
- Other protected lands (including Homeowner Association (HOAs) properties and known deed restricted lands)

The Brandywine Conservancy collected data on protected lands in the Brandywine-Christina watershed. The data is from the following sources:

- Cecil County (MD) GIS Department (Dec. 2017)
- Chester County (PA) Planning Commission (Dec. 2016)
- Delaware County (PA) GIS Department (Nov. 2017)
- Lancaster County (PA) GIS Department (July 2017)
- New Castle County (DE) Land Use Department (Nov. 2017)

The Brandywine Creek watershed has the largest percentage of land protected (31%), followed by the White Clay Creek (28%), Red Clay Creek (27%) and Christina River (15%) watersheds **(FIGURE 5-23)**.

The Brandywine Creek, White Clay Creek and Red Clay Creek watersheds have the largest portion of lands in the eased/fee-owned to land trusts category. In the Christina River watershed, the public lands are the largest category of protected lands. The Christina River watershed is the area with the least amount of protected land, but it is also the most urbanized of the four watersheds within the Brandywine-Christina watershed.

The open space landowners and easement holders in the Brandywine-Christina watershed include the following entities:

- Federal: U.S. National Park Service
- States: DE, MD, PA
- Counties:
  - Chester County
  - Lancaster County
  - Delaware County

- Cecil County
- New Castle County

- Municipalities:
  - City of Newark (DE)
  - City of Wilmington (DE)
  - PA – various city, borough and township open space **(FIGURE 5-24)**

CITY

Coatesville

BOROUGHS

Avondale
Downingtown
Honey Brook
Kennett Square
Modena
Parkesburg
South Coatesville
West Chester
West Grove

TOWNSHIPS

Birmingham
Calm
Charlestown
East Bradford
East Brandywine
East Caln
East Fallowfield
East Marlborough
East Nantmeal
East Whiteland
Franklin
Highland
Honey Brook
Kennett
London Britain
London Grove
Londonderry
New Garden
New London
Newlin
Penn
Pennsbury
Pocopson
Sadsbury
Salisbury
Thornbury
Upper Uwchlan
Uwchlan
Valley
Wallace
West Bradford
West Brandywine
West Clan
West Fallowfield
West Goshen
West Marlborough
West Nantmeal
West Sadsbury
West Vincent
West Whiteland
Westtown

FIGURE 5-24 **Pennsylvania municipalities within the Brandywine-Christina watershed.**

The nonprofit easement holders and landowners in the Brandywine-Christina watershed include:

- Brandywine Conservancy
- Brandywine Red Clay Alliance
- Delaware Nature Society
- French & Pickering Creeks Conservation Trust
- Lancaster Farmland Trust
- London Britain Township Land Trust
- Natural Lands
- North American Land Trust
- Pennsbury Land Trust
- The Land Conservancy for Southern Chester County
- The Nature Conservancy in Pennsylvania
- The Wallace Trust

The colored municipalities shown on **FIGURE 5-25** represent 22 townships wholly or partly within the Brandywine-Christina watershed, that have dedicated funding for preserving open space within their jurisdiction.

Protected Type	Brandywine (acres)	Percentage of Watershed	White Clay (acres)	Percentage of Watershed	Red Clay (acres)	Percentage of Watershed	Christina (acres)	Percentage of Watershed
Eased/fee-owned to land trusts	32,322	16%	4,802	7%	4,980	14%	349	1%
County/state ag. Easements	11,879	6%	3,261	5%	1,036	3%	9	0%
Public lands	12,303	6%	9,154	13%	1,521	4%	4,292	9%
Other protected (HOA, etc.)	7,882	4%	2,241	3%	1,775	5%	2,595	5%
Total Protected Lands	64,386	31%	19,458	28%	9,312	27%	7,245	15%

FIGURE 5-23 **Protected lands by type and watershed in the Brandywine-Christina watershed. (BRC, Brandywine Conservancy)**

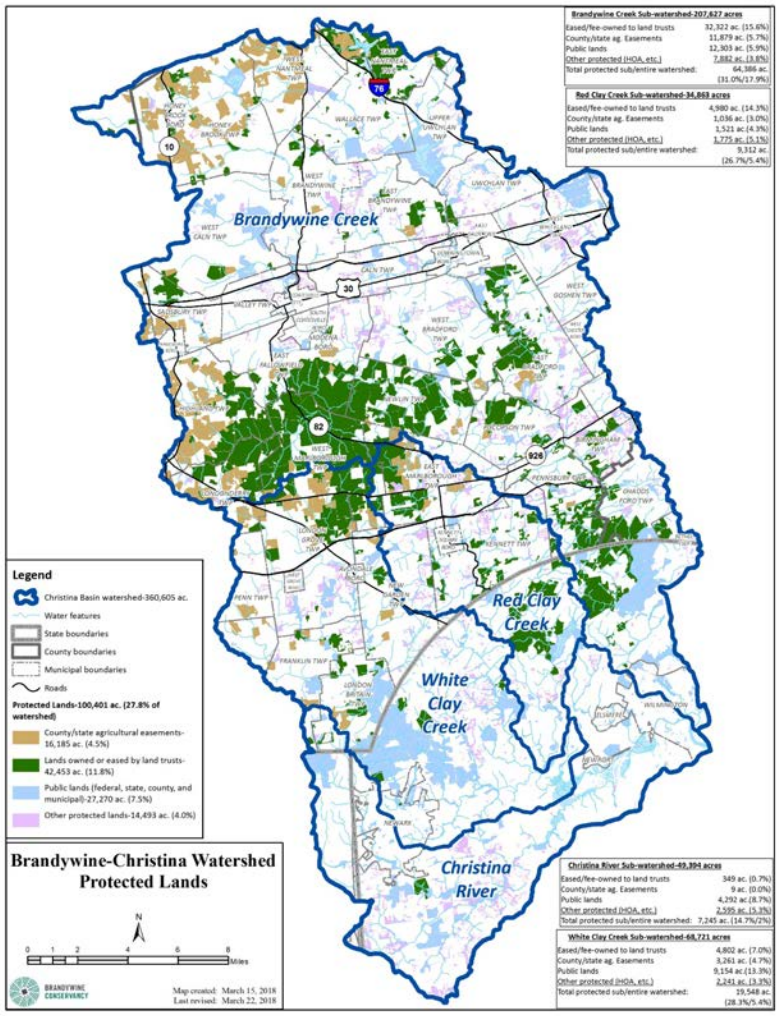


FIGURE 5-25 Protected lands in the Brandywine-Christina watershed. (Brandywine Conservancy)

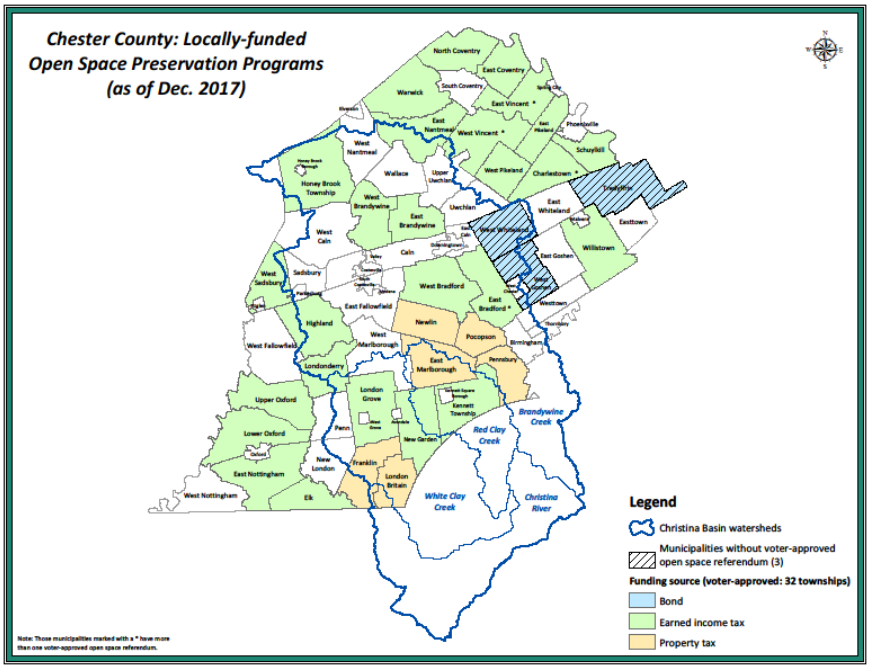


FIGURE 5-26 Locally-funded Open Space Preservation Programs in the Brandywine-Christina watershed. (Chester County Planning Commission)

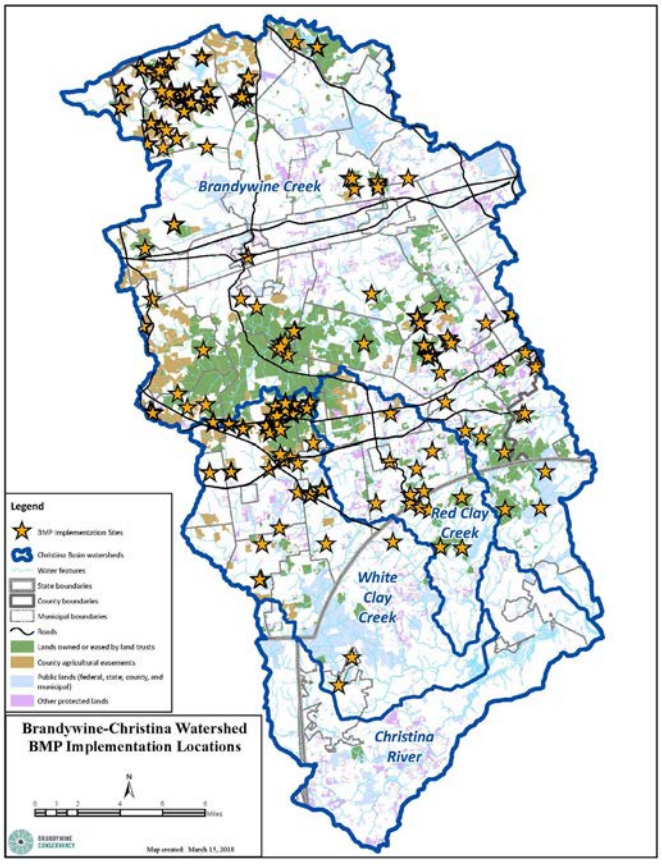


FIGURE 5-27 Ag BMP Implementation Locations in the Brandywine-Christina watershed. (Brandywine Conservancy)

Ag Restoration and Riparian Buffers

The Brandywine-Christina watershed's agricultural land uses pose the potential for water quality impairments. Agricultural land use regulations in Delaware and Pennsylvania require agricultural landowners and managers to meet standards for erosion, sedimentation and nutrient management. Fortunately, many of the management activities required to meet regulations and prevent water quality impairment is undertaken solely by those landowners and managers themselves; however there are numerous programs that offer both technical and financial assistance to develop conservation plans to manage their lands and implement the BMPs prescribed within their conservation plans.

The US Department of Agriculture's Farm Service Agency (FSA) and Natural Resources Conservation Service (NRCS) provide crucial voluntary technical assistance and financial assistance for landowners and agricultural producers to make and maintain conservation improvements on their land. The primary USDA programs for cost-share assistance in the watershed include: Agricultural Management Assistance, Conservation Innovation Grants, Conservation Stewardship Program (CSP), Environmental Quality Incentives Program (EQIP), Regional Conservation Partnership Program (RCPP) and the Conservation Reserve Program (CRP) and Conservation Reserve Enhancement Program (CREP). These programs together provide significant financial and technical resources to help local agricultural producers meet water quality regulations while producing the commodities our economy and food supply rely upon.

Replanting riparian forest buffers are a primary function of the restoration and conservation goals within the watershed. Forested streams in northern Delaware and southeastern Pennsylvania are crucial to improving and maintaining water quality; streamside forests filter potential pollutants before they enter the stream, provide carbon inputs through plant material falling into the stream that feed the instream biota, and provide shading which helps to regulate instream water temperatures. The streams in the watershed evolved primarily as cold water streams, so the temperature of the water is important for the organisms in the stream which also provide potential pollutant processing. Studies have shown that the wider the buffer the better for stream health with at least 100 feet as a primary goal (Sweeney and Newbold, 2014), however competing land uses and needs prevent this from always being achievable. Buffer restoration organizations strive for a 35-foot minimum in most funded programs. Ultimately restoring forests to all streams within the watershed, at any width, is an important component for improving water quality.

The collaboration and partnerships amongst government, nonprofits and other partners has resulted in the implementation of significant agricultural and riparian buffer BMPs in recent years **(FIGURE 5-27). FIGURES 5-28 & 5-29** provide sample data on some of the important work.

The data in the tables was provided by, and much of the work was undertaken by:

- Brandywine Conservancy
- Brandywine Red Clay Alliance
- Chester County Conservation District
- Natural Lands
- New Castle Conservation District
- Stroud Water Research Center
- The Land Conservancy for Southern Chester County
- White Clay Wild & Scenic River Program
- USDA Farm Service Agency
- USDA Natural Resources Conservation Service

DELAWARE AG BMP DATA*	NUMBER
Riparian Forest Buffer	10.0 acres
Tree/Shrub Establishment Total	376.5 acres
Wetland Restoration	4.5 acres
Waste storage facility improvements	3
Fence	1,652 ft
Nutrient Management	4,358.3 acres

**Delaware data from Brandywine-Christina watersheds not included on Figure 5-27 and not shown on Figure 5-28.*

FIGURE 5-28
Delaware Ag BMP Data. (New Castle Conservation District)

BRANDYWINE-CHRISTINA BMP DATA		NUMBER	
Riparian Forest Buffer	68,137 trees	250.3 acres	25.6 miles
Buffer Protection Fencing	10.3 miles		
Ag BMP Highlights:	Practice Type	# of Projects	
	Waste storage facility improvements	19	
	Animal Heavy Use Area Protection	13	
	Grassed Waterway	8	
	Ag Stormwater Management	24	
	Stream Crossings	19	
	Conservation Planning–Including Grazing and Nutrient Management	81	7,130 acres
WHITE CLAY CREEK BMP DATA			
Riparian Forest Buffer	20,468 trees	110.9 acres	8.3 miles
Buffer Protection Fencing	4.8 miles		
Ag BMP Highlights:	Practice Type	Metrics	
	Waste storage facility improvements	3	
	Level Lip Spreader	2.6 miles	
	Cropland Terrace	3.2 miles	
	Constructed wetlands	1.5 acres	
	Conservation Planning–Including Grazing and Nutrient Mgmt	10	750 acres
RED CLAY CREEK BMP DATA			
Riparian Forest Buffer	2,175 trees	20.4 acres	7.9 miles
Buffer Protection Fencing	1.6 miles		
Ag BMP highlights:	Practice Type	Metrics	
	Stream Crossings	2	
	Misc BMPs–Animal Trail, Grassed Waterway	18	
	Conservation Planning–Including Grazing and Nutrient Mgmt	1	77.9

FIGURE 5-29 **Brandywine-Christina Ag BMP Data. (CCCD)**

Stream Restoration

In 2010, Brandywine Red Clay Alliance (BRC) began stream restoration with the first project on upper Doe Run in the Brandywine watershed. Since then 17 projects have been completed **(FIGURE 5-30)** totaling over five miles in length. The sites chosen for restoration are on impaired streams as designated by PADEP. Within the Brandywine and Red Clay watersheds eight sub-watersheds have been identified for restoration plans. These plans then indicate those stretches of stream which, when restored, can have the largest impact on water quality.

Stream restoration has the goal of stabilizing streams so that bank erosion is minimized, habitat improved and aquatic life enhanced. To accomplish this goal the steep, eroding banks are graded to a lower slope and planted with native grasses and wildflowers. Instream structures such as cross vanes, J-hooks and root wads are used to maintain the stream channel, further protect the banks and to improve water quality and fish habitat. The streams are being monitored by Stroud Water Research Center and the Academy of Natural Sciences of Drexel University to note changes in water quality. ■

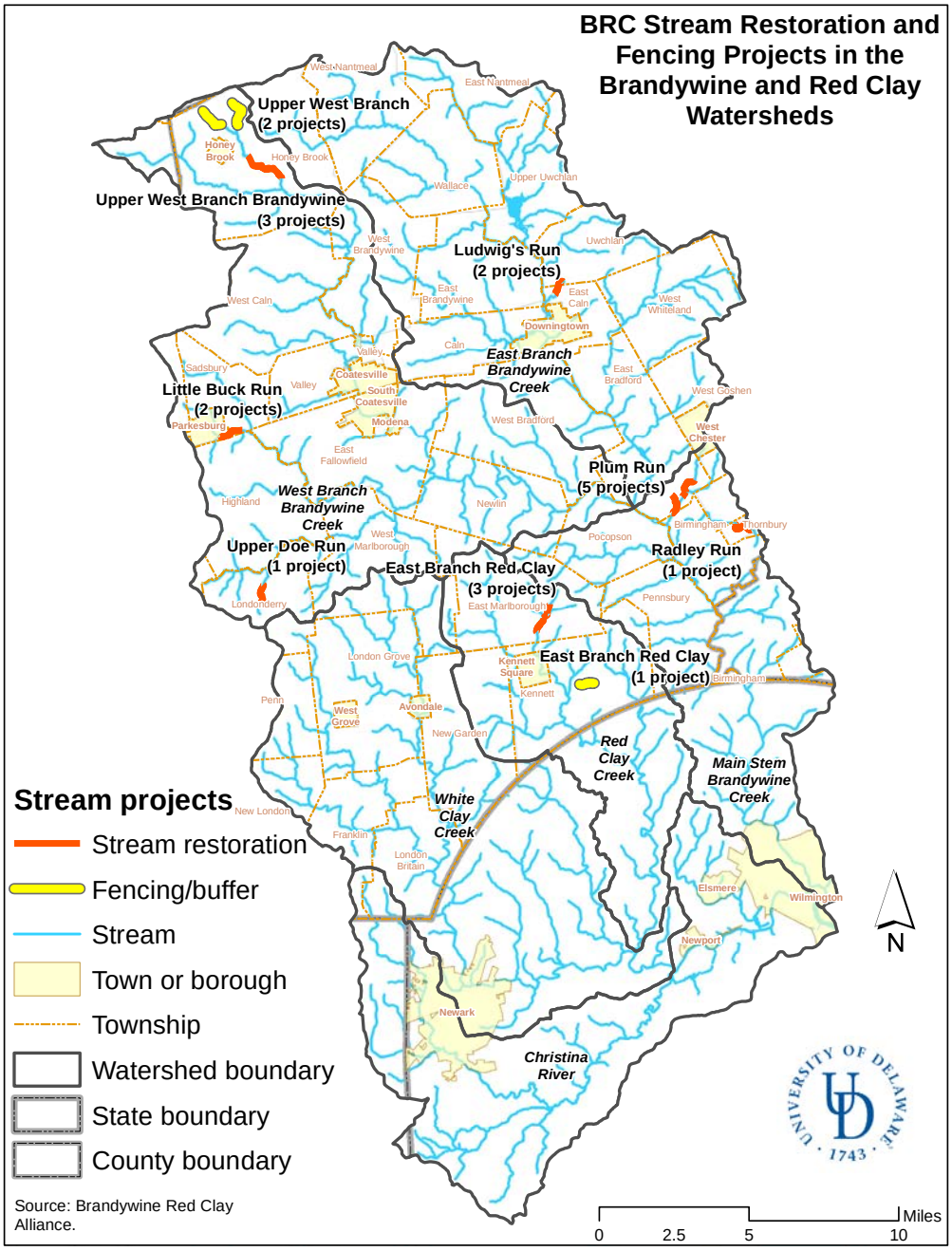


FIGURE 5-30 BRC Stream restoration and fencing/buffer projects (201-2018). (BRC)

Chapter 6

Watershed Modifications

Fish Passage

Fish passage research, focused on the Delaware portion of the Brandywine and White Clay creeks, with an effort to restore American shad migration, has been undertaken by the Brandywine Conservancy and the University of Delaware Water Resources Center. These groups, in partnership with numerous stakeholders, have compiled key information on the dam landscape in the Delaware portion of the Brandywine and White Clay creeks.

In 2005 the Brandywine Conservancy, funded through a grant by the National Fish and Wildlife Foundation (NFWF), undertook an analysis of the feasibility of restoring American shad to the Brandywine River, *The Restoration of American Shad to the Brandywine River: A Feasibility Study (2005)*. The initial focus of this work was on the 11 dams located in Delaware **(FIGURE 6-1)**. This feasibility report identified partner organizations for the restoration efforts, identified dam owners and key stakeholders, dam function and fish passage options and identified technical and legal requirements including costs and sources of funding for fish passage. This report indicated there are technically feasible options for providing fish passage at all of the dams (Brandywine Conservancy, 2009).

Using the shad restoration efforts on the Brandywine as a model, the University of Delaware Water Resources Center undertook a similar effort on the White Clay Creek. *The Restoration of Shad and Anadromous Fish to the White Clay Creek National Wild and Scenic River: A Feasibility Report (2010)* describes key information about each dam and identified partner organizations, dam owners, dam function, fish passage options and technical and legal requirements including costs and sources of funding for fish passage. This research found seven known dams on the Delaware portion of the White Clay Creek **(SEE FIGURE 3-46 ON PAGE 45)**. This research also included sampling events in the White Clay Creek conducted by DNREC, angler surveys and public education and outreach efforts through the *Shad in Schools Program*.

Much progress in the Brandywine and White Clay Creek watersheds have been made since these feasibility reports have been compiled. In December 2014, the Byrnes Mill Dam, also knowns as Dam #1 and located on the White Clay Creek Country Club golf course at Delaware Park was removed to restore fish passage. The removal connects 3.5 miles of the White Clay Creek National Wild and Scenic River to the tidal Christina and Delaware Rivers opening up close to four miles of the National Wild and Scenic River for domestic and anadromous fish passage. This is the first recorded dam removal in the state of Delaware. The University of Delaware Water Resources Center led the project with grant funding from the American Rivers and the National Oceanic and Atmospheric Administration (NOAA) Community-based Restoration Program, the National Fish and Wildlife Foundation, the FishAmerica Foundation and the National Park Service. On the Brandywine River, efforts and partnerships have been ongoing and more recently reenergized with the upcoming removal of the City of Wilmington's Dam #1 (West Street dam) proposed for the Fall 2018. Dam #1's removal is being funded by the City of Wilmington and DNREC. Data collected for these reports and key partnerships formed as a result of these research efforts have helped to launch these dam removal efforts in the watershed. Continuing to work with partners to remove dams along both of these waterways and restore the Brandywine and White Clay creeks to free-flowing streams will continue to improve the habitat and natural resources.

City of Wilmington, Dam #1, West Street Dam, slated for removal Fall, 2018. (City of Wilmington)

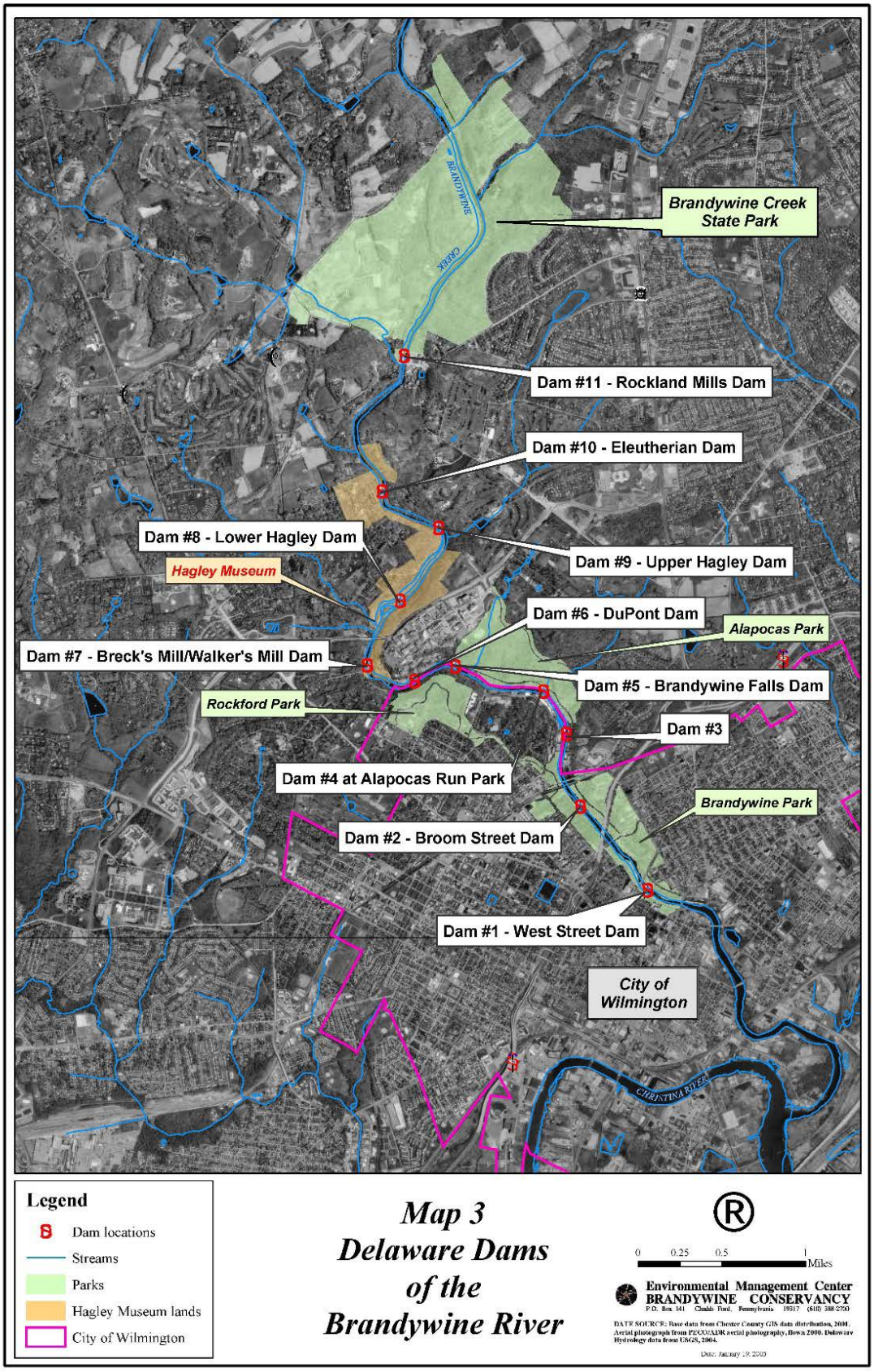


FIGURE 6-1 Delaware Dams on the Brandywine River. (Brandywine Conservancy, 2005)

WATER BODY	GEOGRAPHICAL EXTENT	SPECIES	CONTAMINANT OF CONCERN	MEALS/YR[1]	
				2015/16[2]	2018[3,4]
DELAWARE					
Tidal Brandywine River	River Mouth to Baynard Blvd.	All finfish	PCBs, dioxins, furans, dieldrin	0	2
Non-tidal Brandywine River	Baynard Blvd. to DE/PA Line	All finfish	PCBs, dioxins, furans, dieldrin	6	6
Tidal Christina River	i-95 at Peterson Wildlife Refuge upstream to Smalleys Dam (includes Nonesuch Creek)	All finfish	PCBs	0	12
	Mouth upstream I-95 at Peterson Wildlife Refuge		PCBs, dioxins, furans, dieldrin, DDT, DDD and DDE, chlordane		1
Non-tidal Christina River Smalley's Dam to DE/MD Line		All finfish	Dieldrin	6	12
Tidal White Clay Creek	River mouth to Route 4	All finfish	PCBs, dieldrin, DDT, DDD and DDE, chlordane	0	1
Non-tidal White Clay Creek	Route 4 to DE/PA Line	All finfish	PCBs, dieldrin	12	12
Red Clay Creek	Creek Mouth to DE/PA Line	All finfish	PCBs, dioxins, furans, dieldrin, DDT, DDD and DDE	6	3
Little Mill Creek	Creek Mouth to Kirkwood Highway	All finfish	PCBs, dieldrin, chlordane, heptachlor epoxide	0	1
Christina Creek	Rittenhouse Park to DE/MD Line	Stocked trout	PCBs, dieldrin	6	6
Designated Trout Streams & Ponds other than Christina Creek	See latest Delaware Fishing Guide for Designated Trout Streams	Stocked Trout	PCBs	12	12
PENNSYLVANIA					
Marsh Creek Lake (Chester County)	Entire Lake	Largemouth bass	Mercury	24	24
Red Clay Creek (Chester County)	Entire Basin (except East Branch Red Clay Creek)	American eel	PCB	12	12
West Branch Brandywine Creek (Chester County)	From business Rt. 30 (Lincoln Highway) in Coatesville to confluence with Buck Run	American eel	PCB	12	12
White Clay Creek	Entire Basin	American eel	Mercury	24	24

Improvement

Degraded

FIGURE 6-3 **Delaware and Pennsylvania Fish Consumption Advisories 2015/16 and 2018. (DNREC and PADEP)**

[1]The PA Fish Consumption Advisories meal frequency recommendations are advised in meals/month whereas the DNREC advisories are meals/year (8-ounce serving). The Pennsylvania advisories have been extrapolated to meals/year for consistency.

[2]2015-'16 Delaware Fish Consumption Advisories (http://www.dnrec.delaware.gov/fw/Fisheries/Documents/2015-16_Delaware_Fish_Consumption_Advisories.pdf)

[3]2018 Delaware Fish Consumption Advisories (http://www.dnrec.delaware.gov/fw/Fisheries/Documents/2018-Delaware-Fish-Consumption-Advisory-Table.pdf)

[4]Commonwealth of Pennsylvania Fish Consumption Advisories ((http://files.dep.state.pa.us/Water/ Drinking%20Water%20and%20Facility%20 Regulation/WaterQualityPortalFiles/FishConsumption/FishAdvisory/FishConsAdvTables2018-final.pdf)

Fish Consumption Advisories

DNREC and Pennsylvania's Fish and Boat Commission post annual Fish Consumption Advisories for the Brandywine-Christina watershed. **FIGURE 6-3** summarizes the 2015/16 and 2018 fish consumption advisories posted for the waterbodies in the Brandywine-Christina watershed. Many of the pollutants listed in **FIGURE 6-3** and responsible for the fish consumption advisories are legacy pollutants. These pollutants, such as PCBs, DDT and dioxins were released into the watersheds in significant quantities in the past and both states continue to work to reduce the significant impacts of these legacy pollutants on the Brandywine-Christina waterways and the fish populations. In Pennsylvania all of the White Clay Creek streams and Marsh Creek Reservoir are listed as impaired for Mercury. The source of this is atmospheric deposition from coal-fired plants and the Mercury impairments are rapidly expanding across the reservoirs and streams.

FIGURE 6-3 shows that based on the fish consumptions advisories several water bodies in the Delaware portion of the Brandywine-Christina watershed have shown improvement (green) from 2015-16 to 2018. Only one water body, the Red Clay Creek, shows a decline (yellow), or decrease in fish consumption in that same time period, yet a special study conducted by DNREC demonstrates improved conditions in the Red Clay Creek.

In February 2018, Delaware's new fish consumption advisories were released showing that the concentration of chemical contaminants in fish caught in Delaware waterways is declining. Specific to the Brandywine-Christina watershed, a special study conducted in 2016/17 in the Red Clay Creek in New Castle County, DE indicates that the creek can be reinstated as a stream suitable for trout stocking by DNREC's Division of Fish and Wildlife, more than 30 years after being taken off the state's trout-fishing list due to contaminant concerns. According to DNREC, "the reduction in PCB levels is attributable to several efforts, including state-of-the-science testing to identify, prioritize and control remaining sources of contaminants and to innovative clean-up strategies, including adding activated carbon and quicklime to sediments that bind contaminants and limit their transfer to the water and fish."

Water Supply

Water quality and watershed health in the Brandywine-Christina watershed is of particular importance for residents who rely on clean and plentiful water for their physical and economic well-being. The entire Brandywine-Christina watershed provides the source waters for several public water supply systems as well as extensive areas of farmland and rural commercial, industrial and residential properties in the watershed that rely on individual groundwater wells. Reducing pollution from nonpoint sources and protecting the quantity of groundwater and instream flows throughout the Brandywine-Christina watershed are vital to protecting the watershed's ability to provide this essential resource.

Northern Delaware obtains a majority of its water from surface water and groundwater originating in Pennsylvania. Over 400,000 Delaware residents, along with businesses and industry, rely on these sources for their drinking water. Approximately 50% of Chester County, PA residents, businesses and industry are served by the streams and groundwater of the Brandywine-Christina watershed.

In Delaware, public water supply customers served by the Brandywine-Christina watershed obtain approximately 65% of their water from surface water sources (including stream intakes and reservoirs), with 35% obtained from groundwater sources (based on water supply data for 2017 provided by the public and investor-owned water purveyors). In Pennsylvania, of the public water supply customers served by the Brandywine-Christina watershed, approximately 57% are served by surface water sources, with 43% served by groundwater sources (based on water supply data for 2016 obtained from the PADEP). These numbers do not reflect the population served by private wells; in Chester County, roughly 60% of the population relies on public water supplies, and the remaining population relies on private groundwater wells.

FIGURE 6-4 presents the public water suppliers in the Brandywine-Christina watershed. The largest water supply systems typically rely primarily on surface waters as the source of their water supplies, but often also have wells and/or interconnections with other adjacent systems to be used for backup supplies, if needed.

PURVEYOR	PRIMARY SOURCE	WATERSHED LOCATION
PENNSYLVANIA		
Aqua Pennsylvania	Surface water	East Branch Brandywine Creek, (Ingram's Mill)
Downingtown Municipal Water Authority	Surface water	East Branch Brandywine Creek
Pennsylvania American Water Company	Surface water	West Branch Brandywine Creek
	Surface water	Rock Run Reservoir (West Branch Brandywine Creek)
Borough of Avondale	Groundwater	Well (White Clay Creek)
Borough of Kennett Square	Groundwater	Well (Red Clay Creek)
Borough of West Grove	Groundwater	Well (White Clay Creek)
Honey Brook Water Authority	Groundwater	Well (West Branch Brandywine Creek)
Valley Township	Groundwater	Well (West Branch Brandywine Creek)
DELAWARE		
Artesian Water Company	Groundwater	Well (White Clay Creek)
SUEZ	Surface water	Red Clay and White Clay Creeks, Stanton, DE
	Surface water	Smalley's Pond
City of Wilmington	Surface water	Main Stem Brandywine Creek
City of Newark	Surface water	White Clay Creek

FIGURE 6-4 Public water suppliers in the Brandywine-Christina watershed, with source and location.

Reservoirs are an important component of water supply in the Brandywine-Christina watershed. They store water to be used during periods of dry weather when low stream flows reduce the volume of water available for surface water withdrawals, or in certain circumstances, for other unfavorable conditions, such as high stream turbidity. Certain reservoirs (e.g., Chambers Lake and Marsh Creek Lake reservoirs) are also designed to retain flood waters to alleviate flooding hazards during severe storms. Reservoirs also function as "sinks" for collecting sediment and associated nutrient and bacteria pollutants from nonpoint source runoff from lands upstream of the reservoir. The capture of these pollutants by the reservoirs assists in reducing these pollutants to streams below the reservoirs. However, the pollutants trapped within the reservoirs cause excessive harmful algal blooms and related water quality impacts. Thus, managing the land area that drains to these reservoirs to minimize sediment, nutrient and bacteria pollutants from reaching the reservoirs is an important overall strategy for watershed management.

FIGURE 6-5 presents the major water supply reservoirs in the Brandywine-Christina watershed.

The map in **FIGURE 6-6** shows the location of surface water intakes and drinking water reservoirs in the Brandywine-Christina watershed.

Public water suppliers in the Brandywine-Christina watershed report daily water demand for each of their intakes and water supply wells. This information indicates the water demand on water resources within the Brandywine-Christina watershed as well as the potential impacts to downstream flow. To assess the overall trend in water demand, the average daily

RESERVOIR	LOCATION	CAPACITY (MG)
Hoopes	Red Clay Creek, DE	2,000
Newark	White Clay Creek at Newark, DE	318
Smalley's Pond	Christina River, DE	40
Marsh Creek	East Branch Brandywine Creek, PA	4,000
Rock Run	West Branch Brandywine Creek near Coatesville, PA	200
Chambers Lake	West Branch Brandywine Creek at Hibernia Park, PA	344

FIGURE 6-5 Reservoirs, with location and capacity, in the Brandywine-Christina watershed.

water withdrawal for the month of the year with the highest daily average—also called the "maximum monthly water demand"—is calculated. This metric shows the trend in water used over the period examined. Factors that can affect the trend include population increases or decreases which may result in corresponding increases or decreases in demand; increased use of water conservation efforts and technologies resulting in corresponding decreases in demand; pricing water rates rising; and closure (or slowdowns) of water-intensive industries resulting in significantly reduced nonwater demand to many water systems in the Brandywine-Christina watershed and throughout the mid-Atlantic region.

FIGURES 6-7 AND 6-8, respectively, show the maximum monthly water demand served by withdrawals from the Brandywine-Christina watershed in New Castle County, DE and Chester County, PA. The graph for Delaware shows the total water demand for all purveyors from both groundwater and surface water sources, while the graph for Pennsylvania shows the water demand only from surface-water sources (groundwater demand data are not readily available). The Pennsylvania graph also shows the surface water demand for each purveyor as well as the composite total of those purveyors.

For both Delaware and Pennsylvania these graphs show water demand declining in the period from 2001 to 2017 (for Delaware) and 2006 to 2016 (for Pennsylvania). The total water demand in Delaware went from nearly 80 MGD in 2001 to less than 60 MGD by 2017, and in Pennsylvania the total fell from nearly 14 MGD to approximately 12 MGD. The dotted line represents the linear trend in the data for maximum monthly water demand totals. Note that these values do not reflect average demand, but rather the highest average demand in any month for a given year.

Wastewater Dischargers

The NPDES wastewater dischargers in the Brandywine-Christina watershed possess Federal and state water quality permits to treat and discharge a permitted maximum 17.64 million gallons per day (MGD) by 26 permittees (DNREC's

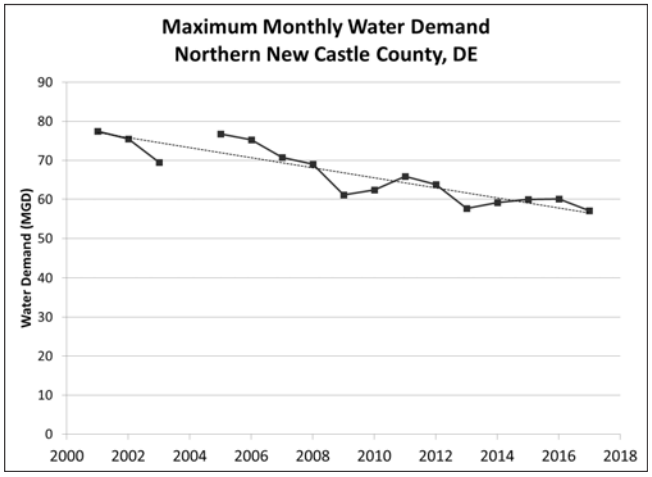


FIGURE 6-7 Total maximum monthly water demand for public water suppliers in the Brandywine-Christina watershed portion of Delaware. (Artesian Water Company, SUEZ, City of New Castle, City of Newark, City of Wilmington)

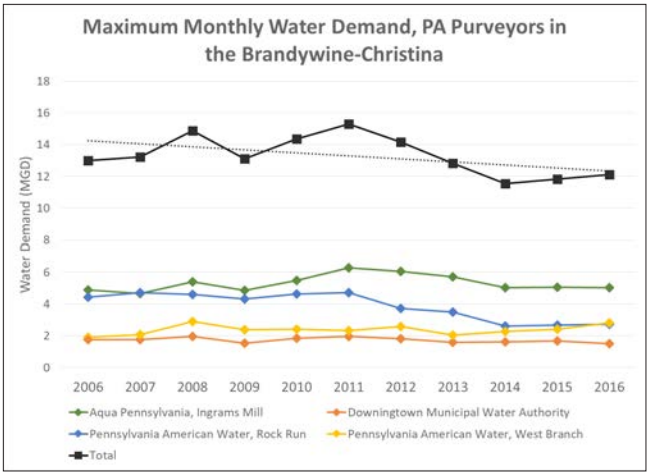


FIGURE 6-8 Total maximum monthly water demand for public water suppliers in the Brandywine-Christina watershed portion of Pennsylvania.

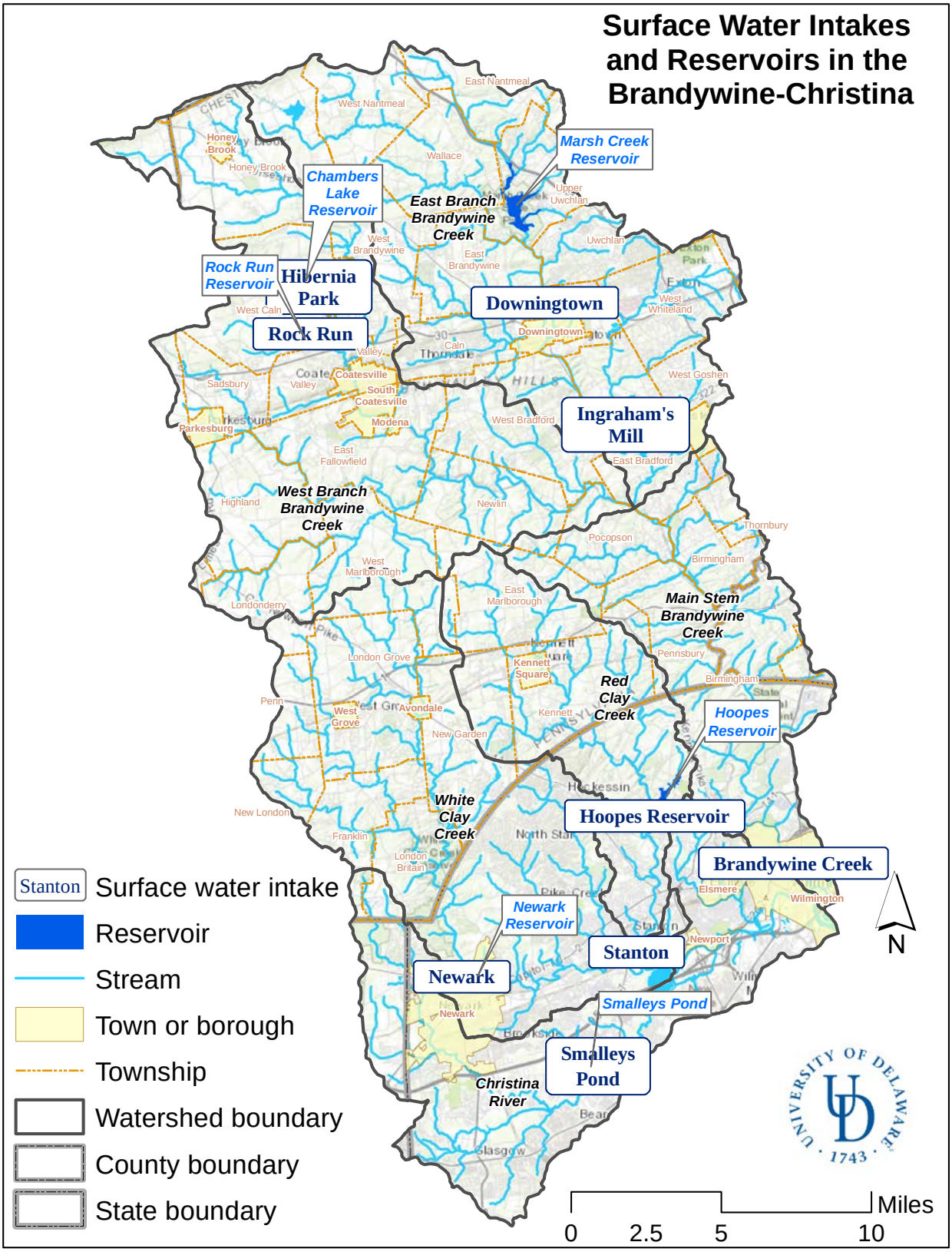


FIGURE 6-6 Surface water intakes and water-supply reservoirs in the Brandywine-Christina watershed.

NPDES ID	SEWAGE TREATMENT PLANT	DISCHARGE (MGD)
BRANDYWINE		**15.47**
Main Stem		
DE0021768	Winterthur	0.025
PA0055476	Birmingham TSA/Ridings at Chadds Ford TB Harvey Creek Municipal Small STP	0.04
PA0244031	Chadds Ford Township Harvey Run	0.15
PA0030848	Unionville-Chadds Ford Elem. School Ring Run Municipal Small STP	0.01
PA0031097	Radley Run C.C. Radley Run Municipal Small STP	0.02
PA0053449	Birmingham Twp. STP Radley Run Municipal Small STP	0.15
PA0036200	Radley Run Mews Plum Run Municipal Small STP	0.03
East Branch		
PA0026018	West Chester Borough MUA/Taylor Run Taylor Run Municipal Large STP	1.8
PA0043982	Broad Run Sew Co. EB Brandywine Creek Municipal Large STP	0.4
PA0026531	Downingtown Area Regional Authority EB Brandywine Creek Municipal Large STP	7.5
PA0054917	Uwchlan Twp. Municipal Authority Shamona Creek Municipal Eagleview CC STP	0.48
PA0027987	Eaglepoint Dev. Assoc. TB Marsh Creek Municipal Small STP	0.02
PA0050458	Little Washington Drainage Co. Culbertson Run Municipal Small STP	0.05
PA0050547	Indian Run Village MHP Indian Run Municipal Small STP	0.04
West Branch		
PA0036897	South Coatesville Borough WB Brandywine Creek Municipal Large STP	0.39
PA0026859	Coatesville City Authority WB Brandywine Creek Municipal Large STP	3.85
PA0036412	Tel Hai Retirement Community TB-WB Brandywine Creek Municipal Small STP	0.06
PA0044776	NW Chester Co. Municipal Authority WB Brandywine Creek Municipal Large STP	0.6
CHRISTINA RIVER		**0.5**
West Branch		
MD00651450	Highlands WWTP WB Christina River Municipal Small STP	0.05
MD0022641	Meadowview Utilities, Inc. WB Christina River Municipal Small STP	0.45
RED CLAY		**1.12**
Main Stem		
DE0021709	Greenville Country Club	0.015
PA0024058	Kennett Square Boro. WWTP WB Red Clay Creek Municipal Large STP	1.1
WHITE CLAY		**0.56**
Main Stem		
PA0024066	West Grove Borough Authority STP MB White Clay Creek Municipal Large STP	0.25
East Branch		
PA0052451	Frances L. Hamilton Oates STP EB White Clay Creek Municipal Small STP	0.0012
PA0025488	Avondale Borough Sewer Authority Indian Run Municipal Large STP	0.3
PA0040436	Chadds Ford Investment Co./Red Fox GC TB-EB White Clay Creek Municipal Small STP	0.01
Brandywine-Christina Watershed		17.64

FIGURE 6-9 **Surface dischargers in the Brandywine-Christina watershed. (DNREC and PADEP)**

Surface Discharges Section and the U.S. EPA's High Flow TMDL) (FIGURE 6-9). The majority of the 26 dischargers are located in Pennsylvania with only two in Delaware and two in Maryland. Federal and state water quality permits allow a maximum 15.47 MGD to be treated and discharged to the Brandywine Creek watershed. There are two permitted surface discharge sewage treatment plants in the Christina River watershed, both facilities are located in Maryland and possess permits to treat and discharge a maximum of 0.5 MGD. In the Red Clay Creek watershed there are two permitted surface discharge sewage treatment plants, one in Pennsylvania and one in Delaware, and together they are permitted to discharge 1.12 MGD. In the White Clay Creek watershed there are a total of four permitted surface water discharges, three in Pennsylvania and one in Delaware, and are permitted to treat and discharge 0.56 MGD to the waters of the White Clay Creek watershed.

FIGURES 6-10 & 6-11 show the total discharge for the Brandywine Creek and Red Clay Creek watersheds from 1995-2015 in the Pennsylvania portion of the watershed. Dischargers in the Delaware portion of the Brandywine Creek and Red Clay Creek watersheds contribute minimally to the total discharge (.025 MGD and .015 MGD respectively). Discharges are in MGD as an annual average for each discharger. Numbers represent total of all discharges in the specific watershed. The Brandywine Creek watershed discharge is broken down into the East Branch and West Branch as well as a cumulative value. The Red Clay Creek is for the total watershed. The 20-year trend shows changing levels of discharge, generally lower but up in years of high rainfall, due to some dischargers closing and some converting to spray irrigation (especially in the Red Clay Creek watershed). In the Brandywine Creek watershed, a large discharger closed in 2005. In the Red Clay Creek watershed three dischargers moved to land application in 2001-2002 and two larger dischargers closed in 2007-2009. Other factors which may explain this trend include water conservation by commercial, industrial and residential users and reducing groundwater infiltration into the sewer lines. ■

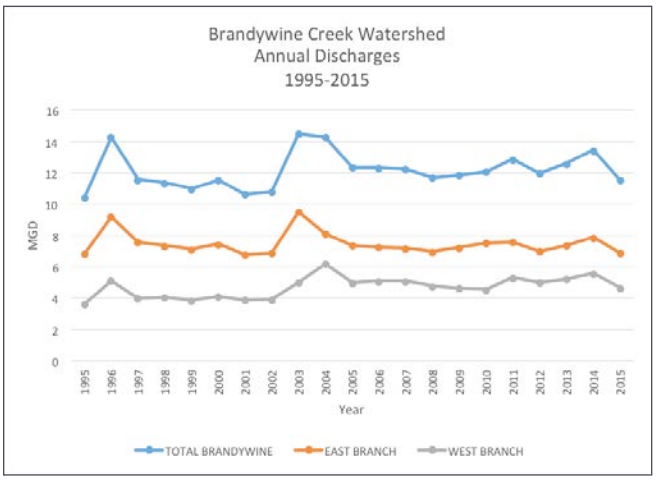


FIGURE 6-10 Dischargers in the Brandywine Creek watershed. (BRC)

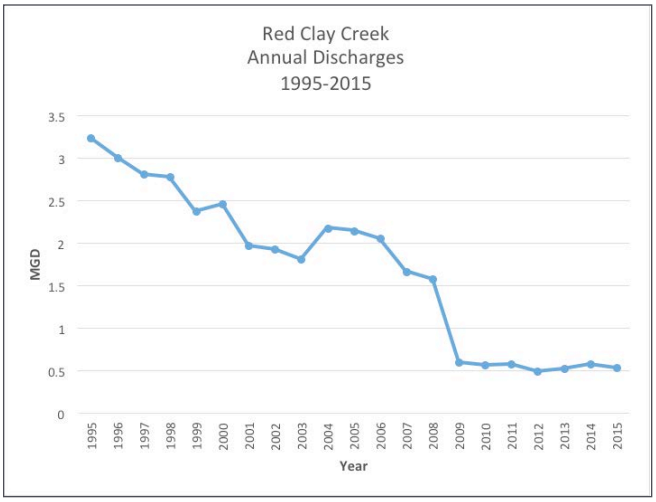


FIGURE 6-11 Discharges in the Red Clay Creek watershed. (BRC)

Chapter 7

Conclusions

The Brandywine-Christina is a diverse watershed spanning three states—Pennsylvania, Delaware and Maryland—and many localities. It comprises a wide variety of landscapes and people, providing a livelihood, as well as drinking water, for its inhabitants. The habitats of the watershed foster great diversity in plant, animal and other life. The waters of the Brandywine-Christina serve as an economic engine for businesses and residents alike, and provide wide-ranging recreational opportunities. The quality of life and well-being for those in the region are tied inextricably to the health of the watershed.

Enhancing and preserving the quality of the habitats and waters of the Brandywine-Christina watershed depends on the coordinated efforts of many of the partners that appear in this report. The state of the watershed is only as strong as the organizations and individuals who work to protect and foster its health. Continuing the ongoing collaboration among the watershed's academic institutions, nonprofit organizations, commercial and industrial entities, and federal, state, county, and municipal governments is critical to its future health.

The information presented in this report demonstrates the challenges that face the watershed, the opportunities for enhancing watershed health, and some of the successes that have been realized in the course of the long history of watershed protection and collaboration in the Brandywine-Christina, including during the first phase of the DRWI.

Key challenges to the maintenance of water quality and watershed health include:

- Significant increases in the amount of developed land and impervious cover, trends which are projected to continue
- Renewed attention on watershed restoration programs to continue the measurable improvement in dissolved oxygen and phosphorus levels to meet fishable water quality standards.
- Redouble efforts to continue the reduction in sediment loads and bacteria levels to meet swimmable water quality and safe drinking water standards.
- Nitrogen levels in waterways that have increased or remained constant across much of the watershed
- A concerning increase in chloride levels in many streams
- An impairment rate of streams in the watershed of more than 50%, despite many decades of effort and millions of dollars of investment by watershed stakeholders

While there are many challenges within the watershed, there are also opportunities presented by a collaborative planning, protection and restoration approach. A number of strategies employed in the highly varied context of the Brandywine-Christina watershed have shown promise. These opportunities stem from the strong base of collaborating partners, the increasingly forward-looking regulatory atmosphere in both Pennsylvania and Delaware, and the increasing awareness of watershed health and protection as a priority on the part of planners, managers, the private sector and members of the public.

Successes realized within this context through the first phase of the DRWI include:

- Preservation of 19 farms totaling more than 1,200 acres
- Planting of forested buffers along twenty two miles of streams
- Installation of nearly nine miles of stream fencing to exclude livestock
- Planting of over 34,000 trees
- Implementation of 185 agricultural BMPs on 44 critical farms in sensitive headwater areas
- Restoration of over five miles of stream in the Brandywine and Red Clay Creek watersheds
- Adoption of riparian buffer ordinances in six municipalities in the watershed
- Leveraging of Phase I DRWI funds to raise an additional $19.4 million for watershed projects

These efforts and the decades of work prior to this initiative have helped result in:

- Improvements in dissolved oxygen (DO) levels in many streams
- A decline in phosphorus levels
- Reductions in sediment loads upstream from water supply intakes.
- Decreases in bacteria levels in recreational paddling and drinking water streams.
- Reestablishment of the Red Clay Creek as suitable for trout stocking
- Extensive amounts of protected open space

With the infusion of an additional $42 million over the next three years, the William Penn Foundation has made a significant commitment of over $100 million to the protection of not just the Brandywine-Christina watershed but also to the entire 13,000 square mile Delaware River Basin. To ensure that this broad effort has maximal positive effect, the partners within the watershed must extend their decades of collaborative work to leverage capital in a concerted and focused way.

This document—the *Brandywine-Christina State of the Watershed Report*—has sought to present a snapshot of the current status of the natural resources and watershed-related initiatives that impact water quality in the Brandywine-Christina. For the collaborative efforts of watershed partners to be effective, and ultimately make a lasting difference in the health of the watershed and well-being of its many inhabitants, continued cooperation is needed.

The struggle for clean water and healthy watersheds for today and future generations must continue, for the challenges remain. Meeting the needs of an ever-growing population will increasingly strain the resources of the watershed and its capacity to sustain the environment, society and the economy on which the well-being of the region is based. ■

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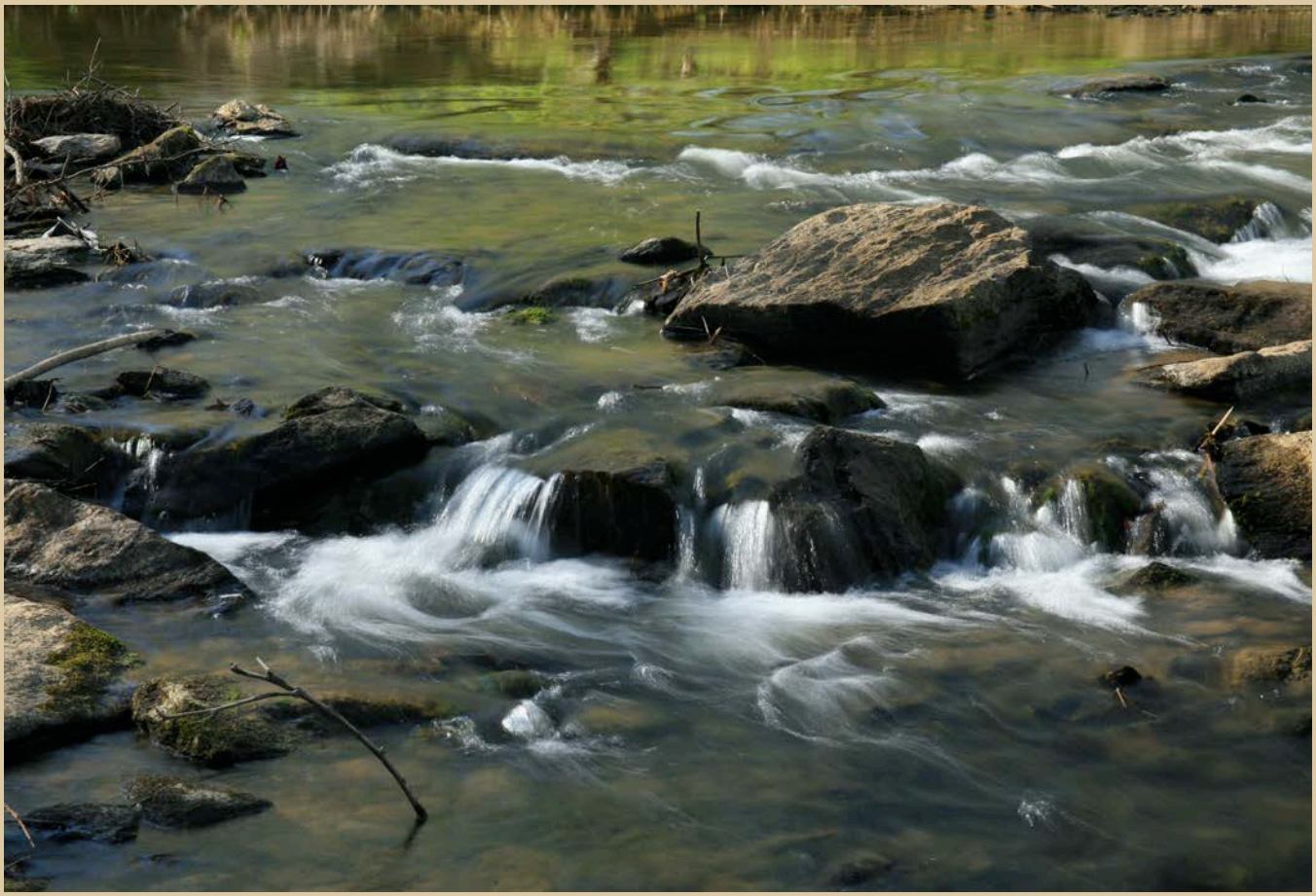
List of Terms

ACS	American Community Survey
BMP	Best Management Practice
BRC	Brandywine Red Clay Alliance (formerly known as Brandywine Valley Association and Red Clay Valley Association)
C-CAP	Coastal Change Analysis Program
CCCD	Chester County Conservation District
CCWRA	Chester County Water Resources Authority
CEMA	Center for Environmental Monitoring and Analysis
CFS	Cubic Feet Per Second
CLUS	Center for Land Use and Sustainability
CSC	Coastal Services Center
CSO	Combined Sewer Overflow
CWMP	Christina Watersheds Municipal Partnership (formerly known as Christina TMDL Implementation Partnership (CTIP))
DDT	Dichlorodiphenyl Trichloroethane
DGS	Delaware Geological Survey
DNREC	Delaware Department of Natural Resources and Environmental Control
DO	Dissolved Oxygen
DRBC	Delaware River Basin Commission
DRWI	Delaware River Watershed Initiative
EB	East Branch
ERES	Exceptional Recreational or Ecological Significance
EV	Exceptional Value
FMRP	Freshwater Mussel Recovery Program
HOA	Homeowner Association
LT2	Long Term 2
MGD	Million Gallons per Day
MHP	Mobile Home Park
MS4	Municipal Separate Storm Sewer System
MRLC	Multi-Resolution Land Characteristics Consortium
MUA	Municipal Utilities Authority
NCC	New Castle County
NCCD	New Castle Conservation District
NFWF	National Fish and Wildlife Foundation
NLCD	National Land Cover Database
NPDES	National Pollutant Discharge Elimination System
NPV	Net Present Value
NRCS	Natural Resources Conservation Service
NWIS	National Water Information System
PADEP	Pennsylvania Department of Environmental Protection
PCS	Pollution Control Strategy
PDE	Partnership for the Delaware Estuary
PPT	Parts Per Thousand
PRP	Pollution Reduction Plan
RM	River Mile
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TNC	The Nature Conservancy
TP	Total Phosphorus
TSS	Total Suspended Sediment
TWG	Targeted Watersheds Grant
UDC	Unified Development Code
USDA	United States Department of Agriculture
USEPA	United States Environmental Protection Agency
USFS	United States Forest Service
USGS	United States Geological Survey
VPP	Vision Partnership Program
WB	West Branch
WCRF	The White Clay Creek Wild and Scenic River Restoration Fund
WPF	William Penn Foundation
WRC	Water Resources Center
WWTP	Wastewater Treatment Plant



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