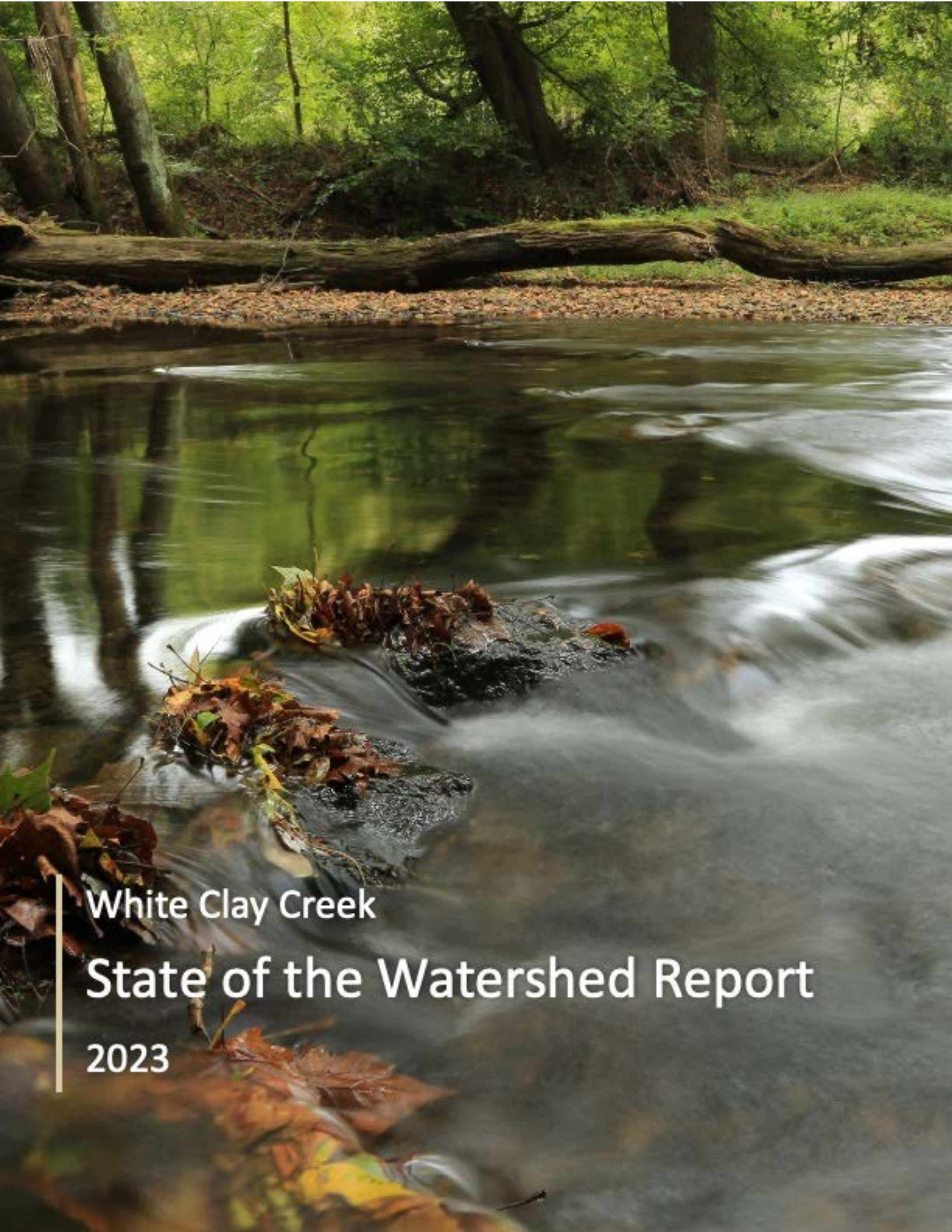

White Clay Creek

State of the Watershed Report

2023

WHITE CLAY CREEK STATE OF THE WATERSHED

Technical report of the assessment of the White Clay Creek Wild and Scenic Watershed in Delaware and Pennsylvania

March 2023

PREPARED BY

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EDITING AND DESIGN SUPPORT PROVIDED BY

Brandywine Conservancy

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Executive Summary

Goal

This report provides an overview of the White Clay Creek watershed and an assessment of the health of the watershed based on five key categories and 20 indicators within each category. The grading for each indicator is provided for each 12-digit Hydrologic Unit Code (HUC 12) and the entire White Clay Creek watershed. This report is an update to the 2016 and 2008 editions of the *State of the Watershed Report*.

Overview

The nationally designated Wild & Scenic White Clay Creek spans 108 square miles in southeastern Pennsylvania, northeastern Delaware and a slight segment in Maryland. Within Delaware and Pennsylvania, the White Clay Creek watershed includes two counties and thirteen towns and municipalities. The White Clay Creek consists of three main branches (West, Middle and East). The rolling hills of the headwaters are agriculturally prevalent and flow through to the more urbanized Coastal Plain downstream.

The watershed's population centers, located in Newark, Delaware and Avondale and West Grove in Pennsylvania, have grown between 2010 and 2020. Population in the northern portion of the watershed is less dense than the lower portion of the watershed with 77% of the total watershed population (2020) in the HUC 12 watersheds downstream. Demographically the population in the watershed is predominantly white and most of the gains from 2010 to 2020 have come in minority (non-white) populations. In 2020, the total population was 124,921. The land cover in the White Clay Creek watershed (2016), based on three major categories, is evenly divided between the natural land (forest/wetland) and agriculture (approximately 30% each) and development is nearly 39% of the total land area of the watershed. Within each HUC 12, the Middle Branch has the largest proportion of agriculture, the Lower White Clay Creek has the highest proportion of developed land area and the Upper White Clay Creek has the highest proportion of forest/wetland. In considering percentages of development, the upper three watersheds—East, Middle and West Branches—have a lower percentage while the Lower White Clay Creek (main stem) is the most highly developed. Overall, the White Clay Creek watershed has experienced increased development from 1996-2016. Although the watershed has experienced increased development in the past decade, the watershed encompasses significant areas of open space with close to 25% of the watershed protected (fee-owned and easements) and the Upper White Clay Creek with the highest percentage of protected lands. Most of the fee-owned land in the watershed is state-owned land, with conservation as the highest proportion of easement type. The watershed is essential to the drinking water and wastewater needs of the occupants in the watershed, and it contains four drinking water supply wells and four surface water intakes along the White Clay Creek, along with two wastewater treatment plants.

Key Findings of the Report

Hydrology

Stream Flow

Baseflow is critical for sustaining flow in streams and rivers and is crucial to the health of the stream's habitat. Using the last five years of data at the five USGS gaging stations in the watershed, the stream flow assessment quantified the proportion of baseflow relative to the average annual flow and evaluated the data based on season (October-March and April-September). The White Clay Creek watershed scores an "A" (Excellent) for stream flow. All of the scores for each HUC 12 were Good or above, while the Middle Branch White Clay Creek near West Grove, PA ranked as Fair/Degrading.

Peak Flow

Peak flow refers to the maximum instantaneous flow of water in a stream at a given point, over a fixed time span. Peak flow is influenced by the amount of rainfall as well as the surplus of water that runs off the landscape instead of being intercepted or diverted to groundwater. Peak flows often coincide with flooding, which can result in a variety of harmful effects that have a negative impact on the long-term health of a watershed. The USGS maintains a network of stream gages that measure annual peak flows. The gage on the White Clay Creek near Newark, DE (USGS 01479000) was used to assess the trend in frequency and intensity of peak flows in the Lower Main Stem. It was chosen for its position in the watershed and its long-term data record. There was no assessment conducted (nor grade assigned) for the four remaining subwatersheds. Overall, it was found that in the White Clay Creek there was a significant increase in peak stream flow incidence in the past 20 years, translating to a "D+" score.

Groundwater

Groundwater is a key indicator of stream baseflows and availability of drinking water. Groundwater levels at a USGS groundwater monitoring station in close proximity to the White Clay Creek watershed were analyzed to assess the groundwater conditions in the watershed. The score was determined for the overall watershed using a comparison of the long-term trend and the median summer water table depth for the latest five-year period. The White Clay Creek watershed scores a "B" for groundwater levels.

Habitat

Impervious Cover

Impervious cover has an impact on the overall health of both streams and the entire watershed. The White Clay Creek watershed is highly variable in terms of imperviousness.

Watersheds are considered impacted if the percentage of imperviousness is above 10% of the total watershed area. Using data from the Conservation Assessment and Prioritization System (CAPS) and procedures for the USGS National Land Cover Dataset (NLCD) Impervious Cover layer, the imperviousness is lowest in the West Branch White Clay Creek subwatershed and highest in the Lower White Clay Creek subwatershed. The change over time shows an opposite trend with the highest increase in the West Branch White Clay Creek subwatershed and the lowest in the Lower White Clay Creek subwatershed. Based on the USGS thresholds, only the Lower White Clay Creek subwatershed is considered “altered” with over 20% impervious cover. Overall the White Clay Creek watershed receives a “B+” for imperviousness.

Terrestrial Connectivity (Buffers/Riparian)

The extent of forestation surrounding streams, rivers and waterbodies is a measure of the overall health of the watershed. The White Clay Creek watershed has many areas with robust forested riparian corridors, particularly in the White Clay Creek State Park (Delaware) and Preserve (Pennsylvania). A 100-meter buffer metric and a ranking system relative to all HUC 12s within the Piedmont watershed of PA in the Delaware Estuary was used to assess and rank the White Clay Creek watershed forested riparian buffer. The Upper White Clay Creek subwatershed (main stem) has the highest percentage (67%) of stream buffer that is forested. The Lower White Clay Creek and the East Branch have the lowest percentage, 42% and 44% respectively, of forested buffer cover. Using an area weighted average of all the HUC 12 watersheds the White Clay Creek has a total forested buffer of 51%, which earns it a “B+” score.

Terrestrial Connectivity (Forest Fragmentation)

The connectivity of natural land cover is important to habitat and impacts watershed health. Using Fragstats and the cohesion index to determine the degree of cohesion and connectedness in the White Clay Creek, a comparison with the HUC 12 watersheds in the Delaware Estuary and the White Clay Creek provided a determination of the natural landscape cohesion in the watershed. The Upper White Clay Creek has the highest cohesion score due to the extensive forest cover in the White Clay Creek State Park (DE) and Preserve (PA). The Lower White Clay Creek, as well as the East and Middle Branches have low cohesion scores. Although there is variability of forest fragmentation within the watershed, overall the White Clay Creek watershed has a low cohesion “D+” score.

Aquatic Connectivity (Culverts and Pipes)

Culverts, structures that channelize water, have a negative impact on the overall health of streams due to the interruption of hydrologic flow and natural habitat. Using the Designing Sustainable Landscapes (DSL)—an assessment of the aquatic connectedness in the streams of New England and the Mid-Atlantic Coast—and the key metric of aquatic passability, the watersheds in the White Clay Creek were compared to the overfall range of scores determined for the Piedmont Estuary. Using the culverts and pipes inventory, the Lower and East Branch

White Clay Creek subwatersheds have the highest passability score, each earning a “C,” and the overall score for the White Clay Creek watershed equates to a “C-.”

Aquatic Connectivity (Dams/Fish Passage)

The White Clay Creek has multiple dams that impact the natural hydrology and habitat of the watershed. Most of the dams in the White Clay Creek watershed were built for water power, and many date to the colonial period. In the Delaware portion of the watershed there are currently six dams, with ongoing work toward removal of the remaining dams. Like the culvert data source, DSL developed an inventory and metrics to determine aquatic connectedness based on the dams located in the watershed. Similar to the culvert analysis the White Clay Creek scores were compared to the overall range of scores for the Piedmont Estuary. Based on the analysis, the Upper White Clay Creek and East Branch White Clay Creek subwatersheds have the lowest passability score (“C+”), with the remaining subwatersheds scoring “A” and above and the entire watershed earning a “B” score.

Water Quality

Water Temperature

Water temperature in streams is an important component of water quality. Temperature has an impact on many processes, including chemical and biological activity. Oxygen levels, salt solubility, photosynthesis, fish metabolism and life history (e.g., adult weight, growth rate, reproductive success) of aquatic species are all temperature dependent. For the White Clay Creek, point data on temperature were collected from sites around the watershed, and a representative score based on average temperature was developed for three classes of designations: coldwater fisheries, warmwater fisheries and warmwater aquatic life environments. Each class has unique characteristics in terms of potential impacts due to temperature pollution (e.g., warmwater pollution from industrial effluent, or coldwater pollution from reservoir releases). The three upper branches of the White Clay Creek were scored based on the criteria for coldwater fisheries. The East Branch received a grade of “C,” the Middle Branch received a “D,” and the West Branch a “B.” For warmwater fisheries, the Upper Main Stem received a “B-" and the Lower Main Stem received a “B.” Overall, the entire White Clay Creek watershed receives a “C+” for water temperature.

Dissolved Oxygen

Dissolved oxygen (DO) is a critical component of water quality as it relates to the ability of aquatic organisms to survive. Each organism has a level of oxygen required to thrive. If levels in the water drop below that threshold for a particular species, that species can become stressed; if the levels are sufficiently low, that organism can die. DO is affected by temperature, as well as biological and chemical processes that consume oxygen. Microbial growth due to nitrification or presence of waste effluent, low flows and higher temperatures can all lead to drops in oxygen levels in streams. To assess the water quality of the White Clay Creek watershed based on DO, samples were averaged at sampling sites across the watershed. Using criteria developed by the OARS River Report Card Grade Calculation document (Nov. 2021) for several designated uses (e.g., warm- and coldwater fisheries, warmwater aquatic life), scores for each branch of the White Clay Creek were calculated. The three upper branches of the White Clay Creek were scored based on dissolved oxygen criteria for coldwater fisheries. The East and Middle Branches receive a grade of “A,” and the West Branch an “A+.” For subwatersheds designated as warmwater fisheries, the Upper Main Stem receives an “A” and the Lower Main Stem receives an “A-.” Overall, the entire White Clay Creek watershed receives an “A” for DO.

Phosphorus

Phosphorous is a key nutrient for cell growth and physiological function, but at elevated concentrations is considered a pollutant that can result in eutrophication of waterbodies. In recent decades, the amount of phosphorous entering streams and waterways has declined (for example, through a voluntary nationwide ban of phosphates from laundry detergent in 1994, improvements in wastewater treatment, and other measures). To assess water quality based on phosphorous levels, TP was measured at 27 sites across the White Clay Creek watershed. Based on TP levels, the East Branch receives a “B+,” the Middle Branch receives a “C+,” the West Branch an “A+,” the Upper Main Stem an “A-,” and the Lower Main Stem an “A.” Overall the White Clay Creek watershed receives an “A-" for phosphorous.

Nitrogen

Nitrogen, like phosphorous, is a nutrient crucial to cell processes and biological function. An excess of nitrogen, however, can be harmful, leading to eutrophication and overabundance of algal and microbial growth (and a concomitant drop in dissolved oxygen levels). Much of the nitrogen loads in the streams of the White Clay Creek derive from agricultural land uses, when excess fertilizer and manure runs off from farms into waterways. Other sources include wastewater treatment plants, urban runoff, and atmospheric deposition. Nitrogen as nitrate ($N0_3$-N) was measured at 41 sites across the White Clay Creek watershed. Based on average nitrate levels at these stations, the East, Middle and West Branches of the White Clay Creek all receive a grade of “F,” the Upper Main Stem receives an “F,” and the Lower Main Stem receives a “D+.” Overall, the White Clay Creek receives a grade of “F” for nitrogen.

Chloride

Salt as a pollutant in water is often expressed either in terms of specific conductance or chloride concentrations. Both measures were used to determine impairments across the subwatersheds of the White Clay Creek, but for the purposes of this report, only chloride was used in determining final water quality grade, due to the confounding effects of underlying geology on conductance. Elevated dissolved salt levels in water can have detrimental impacts on the physiology of aquatic organisms; too much salt can affect viability, reproduction, and can be lethal at sufficiently high concentrations. Major sources of salts in waterways include road deicing and wastewater treatment. Based on the scoring, the East Branch receives an “A,” the

Middle and West Branches receive an "A+," the Upper Main Stem receives an "A+," and the Lower Main Stem an "A." Overall, the White Clay Creek receives a grade of "A" for chlorides.

Total Suspended Sediment

Total suspended sediments (TSS), or solids, are inorganic (silt, sand, etc.) or organic particles (algae, bacteria, leaf detritus, etc.) in the water column. Turbidity (lack of clarity) in water is closely related to TSS, and both vary with stream flow. At very high flows the amount of sediment/solids in the water can be many orders of magnitude more than at baseflow conditions. High levels of TSS can negatively impact aquatic species that rely on clear water and rocky substrates, and excess organic material in sediments can bring DO levels down as decomposition occurs. TSS was measured at 12 sites around the White Clay Creek watershed. Based on the average concentration values, the East Branch receives a grade of "C" for TSS, the Upper Main Stem receives a "D," and the Lower Main Stem receives a "D." There were no sites in the Middle or West Branches, so no grade was given. Overall, the White Clay Creek receives a "C" for total suspended sediment.

Macroinvertebrates

Due to their sensitivity to persistent and acute water quality, aquatic macroinvertebrates are a commonly used indicator to assess pollution levels and impairments in streams. Various species have quite different reactions to a wide range of aquatic conditions, and therefore provide an excellent measure of stream health. This method of water quality determination has been used for over a century, and is widely-accepted as a key measure in any assessment of stream health. Relative abundance of sensitive species (or their absence) can indicate a great deal about the overall conditions in a stream, and can help identify potential stressors such as pollutants, flow issues, or other sources of degradation. Across the White Clay Creek, 33 sites were sampled and a multimetric Macroinvertebrate Aggregated Index for Streams (MAIS) was calculated for each. Sampling and inventorying the aquatic macroinvertebrates is time- and effort-intensive, so only one sample per site was used in calculating the multimetric MAIS score. MAIS scores are classed as Good, Fair, or Poor, with dramatic differences in terms of stream condition between them. Based on this scoring system, the East Branch receives a "D" for macroinvertebrates, the Middle Branch receives a "D," the West Branch receives a "D+," the Upper Main Stem a "D-," and the Lower Main Stem an "F." The White Clay Creek as a whole receives a grade of "D" for macroinvertebrates.

Scenery

Scenic Quality and View Importance

The visual and aesthetic qualities of a watershed enhance the value of its resources as places that people want to spend time in and to protect. The National Park Service (NPS) has developed a methodology—the Visual Resource Inventory (VRI)—to assess the scenic quality and view importance of NPS lands. The VRI seeks to capture the qualities of the visual landscape in a qualitative way to they may be assessed using a standardized set of measures. For the visual assessment of the White Clay Creek watershed, the White Clay Wild and Scenic river administrator recruited 10 volunteers to perform the VRI within the watershed. The volunteers received training in VRI protocols from NPS personnel prior to conducting the assessments in the field. A series of 10 views were selected as representative of views in the White Clay Wild and Scenic river system. There were two views selected from the East Branch, two from the Middle Branch, and six from the Upper Main Stem. These views were assessed using VRI protocols based on both the Scenic Quality and View Importance criteria. Each view was mapped, and described, then assessed as to 1.) its overall scenic quality (aesthetics), and 2.) importance to the viewer's experience. Scores were tabulated for each separate metric, then combined into a single, blended score. Since there were no views assessed in either the West Branch or the Lower Main Stem subwatersheds, those were not given scores or grades, and were not considered in any of the overall calculations. Based on the grading criteria, the East Branch receives a "B" for scenic qualities, the Middle Branch receives a "B," the Upper Main Stem receives a "B+," and the White Clay Creek watershed as a whole receives a "B."

Recreation

Trails

Access to the natural resources of a watershed is an important component of its recreational value. Trails, encompassing a diversity of uses and landscapes, allow people to access natural environments such as streams and forests, benefitting well-being, health and quality of life. The White Clay Creek watershed has a variety of trails encompassing many different habitats, from urban parks to highly natural forests in the White Clay Creek State Park (in Delaware) and Preserve (in Pennsylvania). While the human uses generated by trails can have a deleterious effect on riparian ecosystems, stream health and water quality if not sensitively managed, appropriately planned and maintained trails can greatly enhance the value of a watershed to visitors and inhabitants. To assess trails as an indicator of the recreational value of the White Clay Creek watershed, an inventory of trails was analyzed in GIS to calculate the density of recreational trails in proximity (within 100-meters) to streams. Based on this measure, each subwatershed's riparian trail density was compared to the mean to derive a relative score. Grades ranged from a "D" for the West Branch, to a high of "A" in the Upper Main Stem, with an overall watershed grade of "B" for trails.

Fish Consumption Advisories

Fish consumption advisories (FCAs) are guidelines promulgated by individual state agencies that indicate the safety to human health due to potential contamination of fish consumed from local waters. In Delaware, the Department of Natural Resources and Environmental Control (DNREC), along with the Department of Public Health, has identified consumption restrictions in tidal and non-tidal reaches of the White Clay Creek up to the state line. These restrictions are due primarily to the presence of PCBs, dioxins and furans (commonly produced during combustion processes), as well as pesticides such as Dieldrin. In Pennsylvania the PA Fish and Boat Commission has identified mercury as the primary toxic substance of concern for fish consumption. Delaware is seeing an improvement since 2018 in the restrictiveness of FCAs (indicating that contaminant levels in the water are improving), while in Pennsylvania the level of advisories has held steady. Each state has recommended frequencies of consumption by area and species; for instance, Delaware recommends no more than one meal per year of any finfish caught in the tidal portion of the watershed, and Pennsylvania recommends that no more than one meal of American eel be consumed per month. There is also a general recommendation not to eat more than one meal per week of any fish caught in any of the states' waters. While no single grade was given to the White Clay Creek watershed or its subwatersheds due to the wide variability of guidelines (geographic area and species of fish), based on the advisories the tidal portion (Delaware only) was assigned a grade of "F" and the non-tidal portion (in Delaware and Pennsylvania) a grade of "C."

Bacteria (*E. coli* and *Enterococcus*)

Bacteria, viruses and parasites are omnipresent in the environment and are often naturally occurring. These organisms, when they are in forms that can cause diseases, are collectively called pathogens. Protecting human health and drinking water supplies has been the main focus of tracking pathogens, particularly animal fecal waste. Though generally not a danger to human health, their presence in water can be an indicator of impairment, and has the potential to cause harm through primary contact (swimming) or ingestion. Concentration of total coliform bacteria has been used as an indicator of potentially harmful bacteria from human or animal waste in streams and water bodies. Because there are also non-animal sources of coliform bacteria, there has been a shift toward higher taxonomic resolution by measuring *Escherichia coli* (*E. coli*) and *enterococci* (*Enterococcus* spp.). Both *E. coli* and *Enterococcus* concentrations (in colony forming units per 100mL, or cfu/100mL) were measured at 45 sites across the White Clay Creek watershed. Based on the Recreational Water Quality Criteria standards for Pennsylvania, the geometric mean was calculated for both forms of fecal bacteria to derive a score for each branch of the White Clay Creek and for the watershed overall.

E. Coli — Based on the scoring metrics for *E. coli*, the East Branch receives a "B," the Middle Branch receives an "A," the West Branch receives a "B," the Upper White Clay an "A-," and the Lower White Clay a "B+." The White Clay Creek as a whole receives a "B+" for *E. coli*.

Enterococcus — Based on the scoring metrics for *Enterococcus*, the East Branch receives a "C," the Middle Branch receives a "D+," the West Branch receives a "C," the Upper White Clay a "B," and the Lower White Clay a "C." The White Clay Creek as a whole receives a "C+" for *Enterococcus*.

Overall Assessment

Using the data and analysis from the key findings in the report, a color wheel for the entire watershed and five subwatersheds provides a snapshot of the watershed health. Overall, the White Clay Creek receives a "B-" for the overall watershed health. The subwatersheds score similarly in the "B" to "B-" range for watershed health, with the West Branch and Upper Main Stem scoring a "B" and the Middle and East Branches and Lower Main Stem scoring a "B-." Of the five watershed health categories, Water Quality ranks the lowest in the White Clay watershed and four of the five subwatersheds, excluding the West Branch where water quality is ranked in good health. The indicators with the most prevalent low scores in the watershed and subwatersheds are bacteria (*E. coli)* and Nitrate. The indicator with the highest ranking in the White Clay Creek watershed and all five subwatersheds is Dissolved Oxygen (DO) and chloride. The Scenic Quality indicator was measured in three of the five subwatersheds and all three subwatersheds (Upper Main Stem, East Branch and Middle Branch) achieve a high value for scenic quality.

1. Introduction

1.1 Key Features of the Report

The White Clay Creek State of the Watershed is designed to bring information from multiple data sources together to provide a snapshot and assessment of the health of the White Clay Creek watershed. This report provides an overview of the watershed with data for demographics and land use parameters. This data is summarized based on the entire White Clay Creek watershed and the associated HUC 12 which include East Branch, Middle Branch, West Branch, Upper White Clay and Lower White Clay. The report then lays out five distinct categories to characterize the health of the White Clay Creek watershed. Within each of the five categories there are multiple indicators, ranging from two to seven in each category, with a total of 20 indicators. Each indicator is assessed using the best available data and the most applicable methodology. The data and methodology used for each category and/or indicator is provided in the corresponding section of the report. Many of the grades (noted in the text) follow the grading methodology as laid out by OARS group, whose mission is the protection of the Sudbury, Assabet and Concord Rivers in Massachusetts (Flint, 2019). Scores are derived from a variety of indices for many indicators, and given a corresponding letter grade, which is helpful for the public to understand the watersheds conditions using a familiar scale. Table 1 shows the grading rubric developed in the OARS project.

Table 1. Letter grade scale used for many indicators

Grades	Points
A+	95-100
A	85-94
A-	80-84
B+	75-79
B	65-74
B-	60-64
C+	55-59
C	45-54
C-	40-44
D+	35-39
D	25-34
D-	20-24
F	0-19

The methodologies developed for the analysis of each indicator are based on local expertise, research conducted on regional and local watershed reports and data availability. In the development of this report multiple watershed assessment methodologies were reviewed and assessed for application in the White Clay Creek watershed. The University of Delaware Water Resources Center (UDWRC) has completed two White Clay State of the Watershed reports, 2008 and 2016. In 2018 UDWRC worked with the William Penn Foundation's Brandywine-Christina Cluster partners to compile the *Brandywine State of the Watershed.* These reports provided local examples and data points to build upon and use for comparison in the completion of this report. Additionally, the *Sudbury, Assabet and Concord River Report Card (June 2019)*—developed by OARS in partnership with the University of Maryland Center for Environmental Science, the Massachusetts Environmental Trust, the Sudbury Foundation, the

Sudbury-Assabet-Concord Wild & Scenic River Stewardship Council, and in-kind contributions from the National Park Service and US Fish & Wildlife Service—provided methodologies and graphical representations at a regional level that were instrumental in developing this report. All of these reports played an important role in determining the most critical watershed indicators, developing a grading methodology for each indicator and identifying a scoring system to assess the current health of the White Clay Creek watershed.

This project, led by the University of Delaware Water Resources Center, is funded through the William Penn Foundation, the National Park Service, and the Stroud Endowment for Environmental Research and developed in partnership with the Brandywine-Christina Cluster partners and the White Clay Wild and Scenic Management Committee. The University of Delaware Water Resources Center collaborated with the Brandywine-Christina Cluster and the White Clay Wild and Scenic Management Committee to understand and identify the critical indicators to provide a valuable assessment and reporting system for the watershed. The Stroud Water Research Center and the White Clay Wild and Scenic Management Committee are key partners in the data collection, processing and analysis provided in the report.

1.2 The Wild and Scenic White Clay Creek Watershed

The White Clay Creek watershed spans almost 108 sq. miles from southeast Pennsylvania to northwest Delaware (Figure 1). Fifty-five percent of the watershed lies in Pennsylvania, while 45% lies in Delaware and less than 1% lies in Maryland. The Chester County, Pennsylvania, portion includes the East, Middle and West Branches and the top of the mainstem; the White Clay Creek then flows into New Castle County, Delaware, and is joined by Middle Run, Pike and Mill Creeks. The main stem runs through the City of Newark, Delaware and joins the Christina River just west of Newport, Delaware, at Churchman's Marsh. Only the lower portions of the White Clay Creek are tidally influenced, up to approximately the confluence with the Red Clay Creek at Stanton, Delaware.

In October 2000, the President and Congress signed a law adding 190 miles of the White Clay Creek and its tributaries to the national wild and scenic river system. The White Clay is the first National Wild and Scenic River protected in its entirety, designated on a watershed basis rather than a river corridor basis. In 2014 the White Clay Expansion Act added approximately nine miles of river segments to the existing 190 miles designated as Wild and Scenic Rivers. This expansion brings the total number of designated stream miles to 199. The White Clay Creek Watershed Management Committee, along with local partners and municipalities (refer to Table 2), represents several watershed stakeholders, binds these diverse interests together in a common purpose, and guides the decision making and strategic plan for the White Clay Wild and Scenic Management Committee.

Table 2. Governing Entities in the White Clay Creek Watershed

States	Towns and Boroughs	
Delaware	Avondale	London Grove
Pennsylvania	East Marlborough	New Garden
Counties	Franklin	New London
New Castle	Kennett	Penn
Chester	Londonderry	West Grove
Municipality	London Britain	West Marlborough
City of Newark		

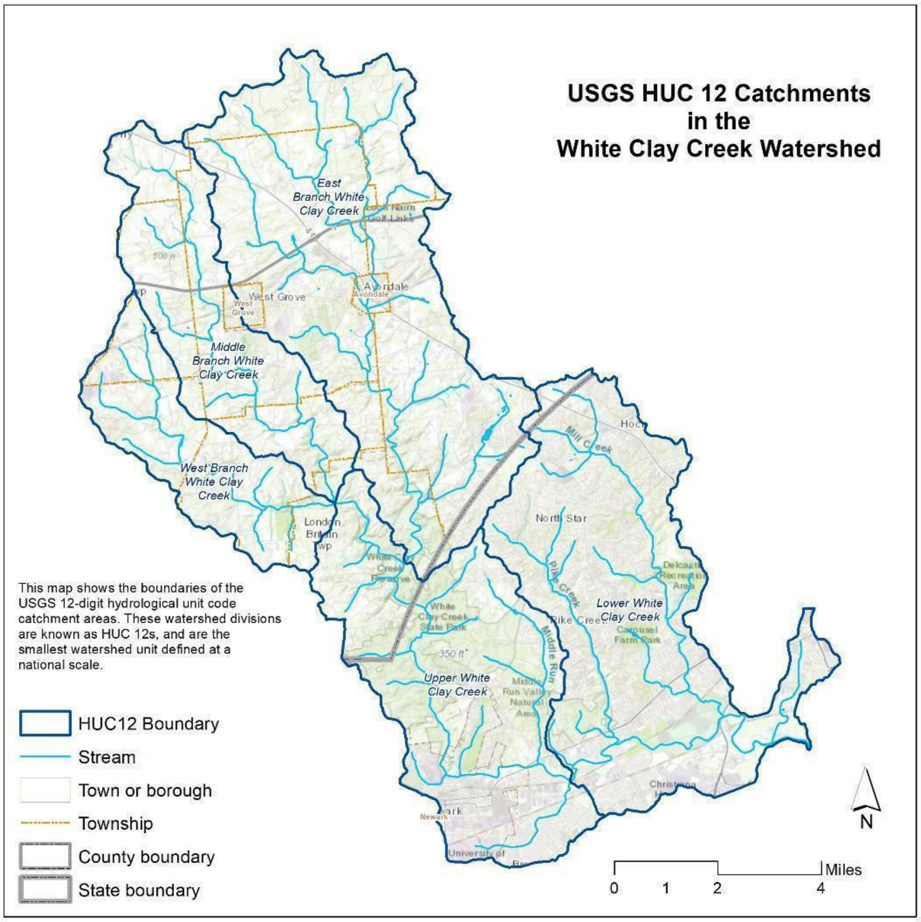


Figure 1. Subwatersheds (HUC 12) in the White Clay Creek watershed

1.3 Topography, Geology and Soils

The White Clay Creek watershed primarily straddles two states, Delaware and Pennsylvania, and falls into two broad physiographic provinces—the Piedmont and the Coastal Plain. The City of Newark lies on the main stem of the White Clay Creek at the fall line, which divides the watershed into two regions topographically and physiographically. Much of the early human development in the region occurred along the fall line, as native populations as well as European settlers used the waters for transportation, fishing, agriculture, and later, hydraulic power for mills. Figure 2 shows the location of the physiographic provinces of the mid-Atlantic and location of the White Clay Creek watershed.

Figure 2. Physiographic provinces of the mid-Atlantic. Source: National Park Service

The topography, geology and soils of a watershed determines many of its surface flow and groundwater characteristics as well as development patterns that ultimately affect watershed quality and health. The White Clay Creek watershed extends into Chester County, to an elevation of over 600 feet above sea level. The White Clay Creek consists of three main branches, originating in the largely agricultural headwaters, joining immediately north of the Delaware state, and flowing through Newark into the Coastal Plains until the confluence with the Christina River near the outlet to the Delaware River, at near sea level.

Topography

Topographically, the White Clay Creek watershed is characterized by a transition from gently rolling hills in the north to flat Coastal Plain topography in the south. The White Clay Creek is navigable for a short distance upstream from its confluence with the Christina River. The map in Figure 3 represents the topography of the Brandywine-Christina watershed.

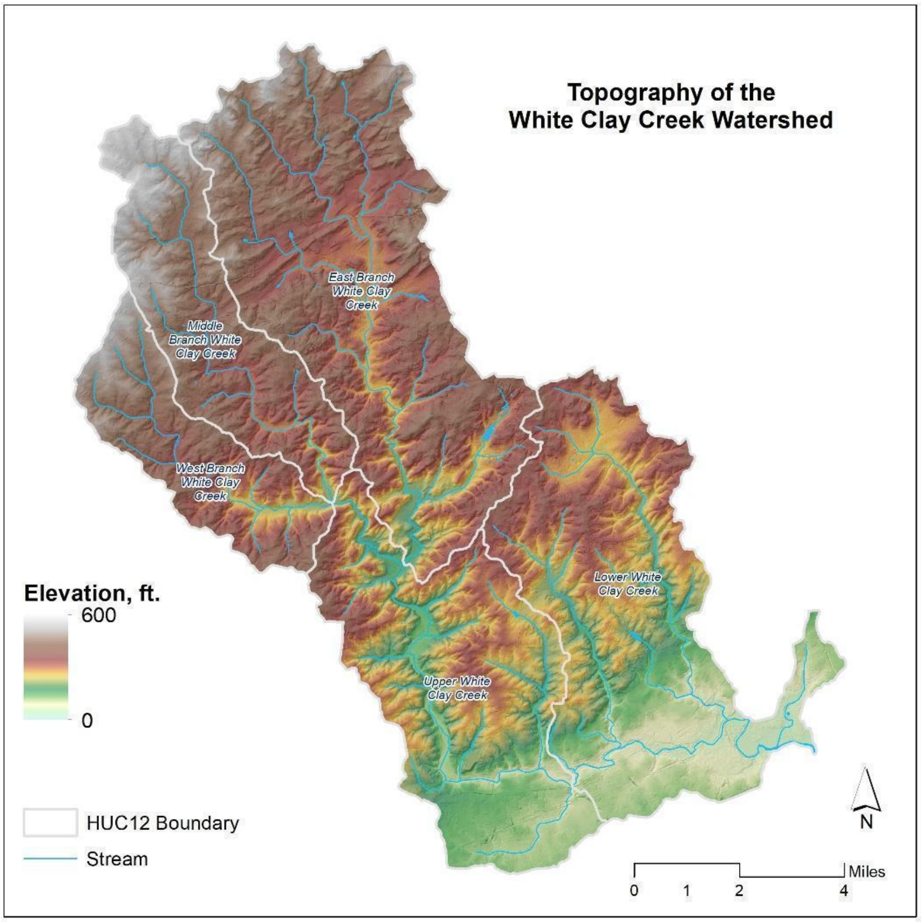


Figure 3. Topography of the White Clay Creek Watershed. Source: USGS 10m Digital Elevation Model

Geology

The upper portion of the watershed is underlain by metamorphic bedrock (diabase, gneiss and marble). There are several outcroppings of Cockeysville Marble, an important feature for groundwater recharge due to its transmissibility. The metamorphic surficial geology in the upper watershed includes several igneous formations in the Delaware portion, at Newark and the Pike Creek areas.

Along the main stem below Newark, Coastal Plain sedimentary formations (Columbia and Potomac sediments) predominate all the way downstream to the tidal portion of the stream near Newport, Delaware. Figure 4 presents the geology of the White Clay Creek watershed, showing underlying rock formation types.

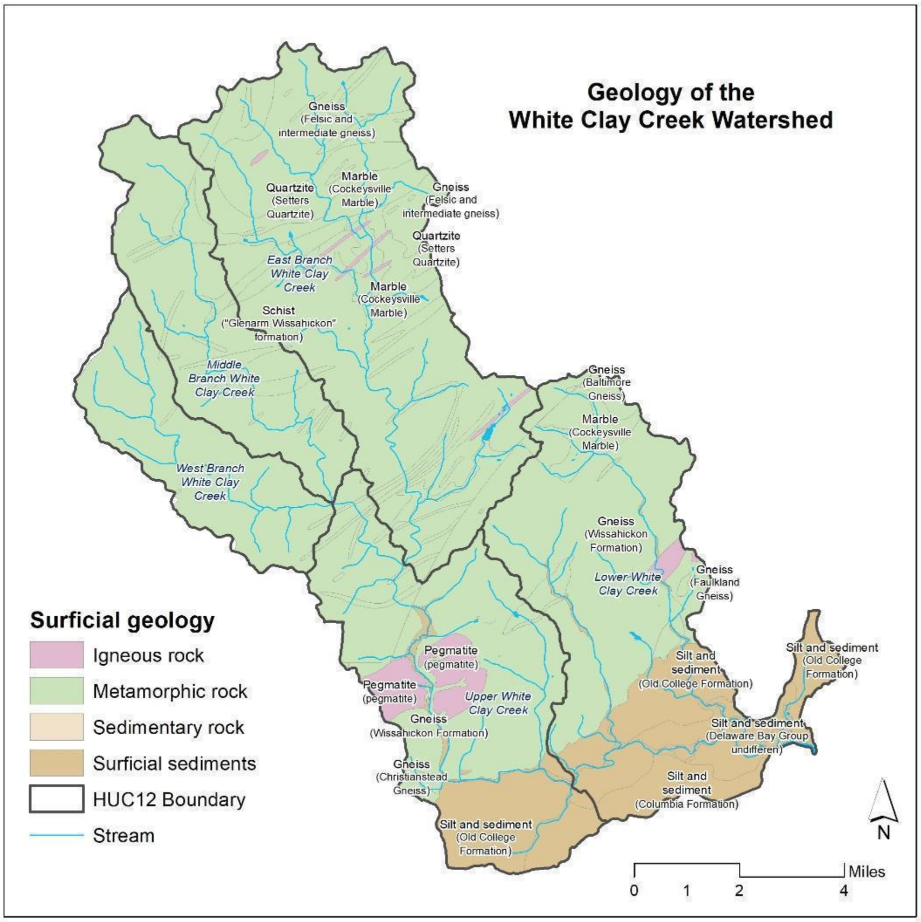


Figure 4. Geology of the White Clay Creek Watershed. Sources: Delaware Geological Survey, Maryland Geological Survey, Pennsylvania Geological Survey

Soils

Soil characteristics such as permeability and drainage are important within a watershed to determine hydrologic characteristics such as groundwater recharge, erodibility and floodplain characteristics. Clay or silty soils are generally less permeable, and promote more runoff, while coarser, grainier soils promote infiltration. Within the White Clay Creek 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 5 presents the soils of the White Clay Creek watershed, based on the USDA Natural Resources Conservation Service (NRCS) State Soil Geographic (STATSGO) dataset, showing drainage characteristics. The labels indicate soil series, with texture type and hydrologic group in parentheses.

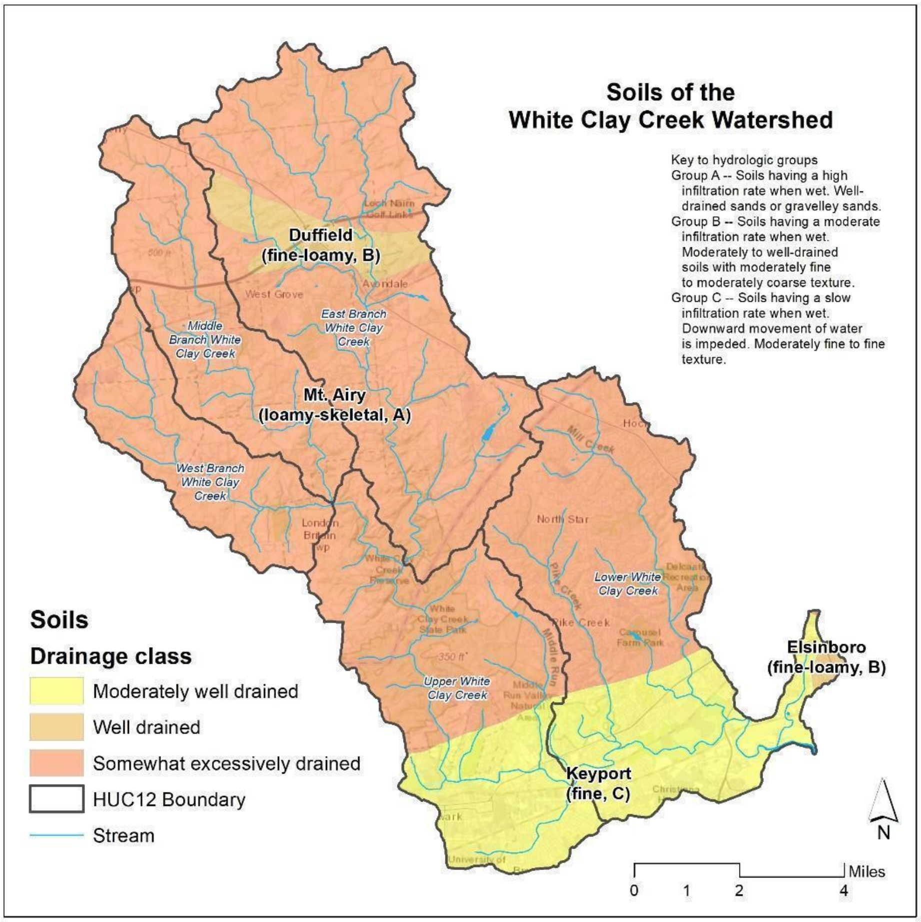


Figure 5. Soils Characteristics in the White Clay Creek watershed. Source: NRCS STATSGO Soils Map

1.4 Population

The White Clay Creek watershed is characterized by a population distribution focused mainly in the lower portions located in Delaware. The principal population centers are Newark in Delaware, and Avondale and West Grove, in Pennsylvania. The Delaware portion of the watershed is more highly urbanized. Upstream in Pennsylvania the population tends to be less dense, with more extensive suburban development and an increasing prevalence of farmland and pasture. The White Clay Creek Park & Preserve lies in the central portion of the watershed, dividing the region, and is characterized by lower population densities due to more protected open space.

The map in Figure 6 shows the population density, based on the US Census Bureau's 2020 Decennial data.

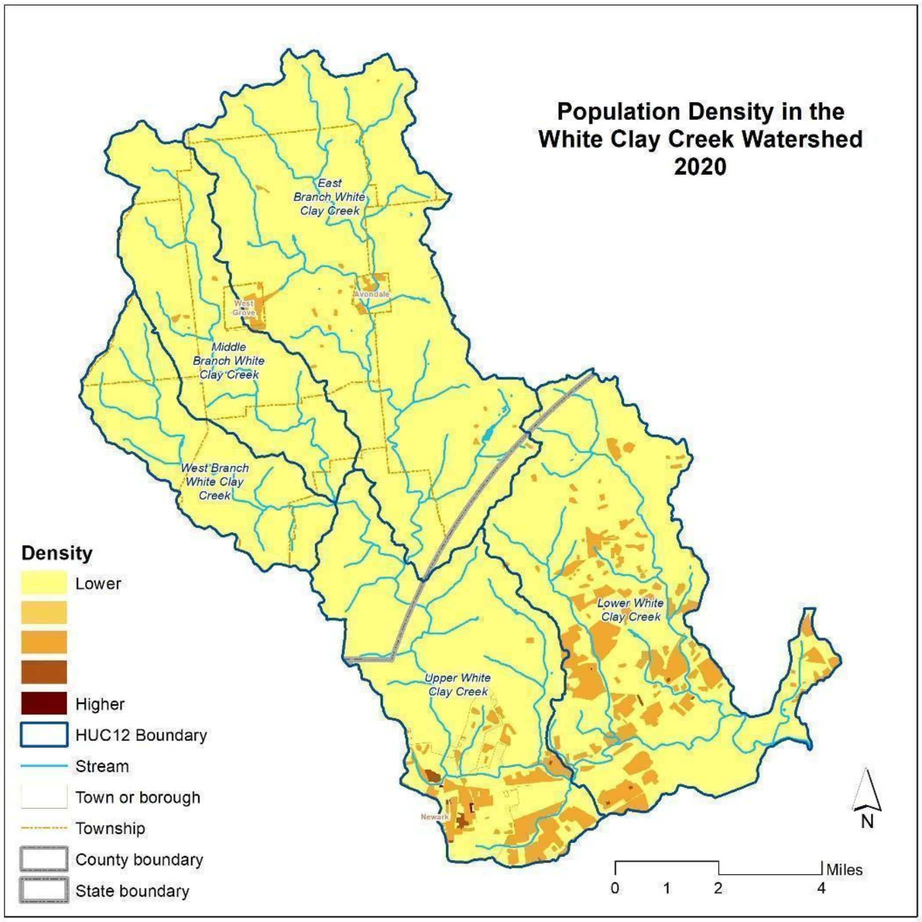


Figure 6. Population Density in the White Clay Creek Watershed, based on US Census 2020 Decennial Data

The downstream HUC 12 watersheds, lying mainly in Delaware, are the most highly populated (with 96,010 people, or nearly 77% of the total population, in 2020), while the upstream watersheds—mostly in Pennsylvania—had a population of 28,911 in 2020 (23% of the total). Figure 7 shows the population in each watershed as a percentage of the total, in 2020.

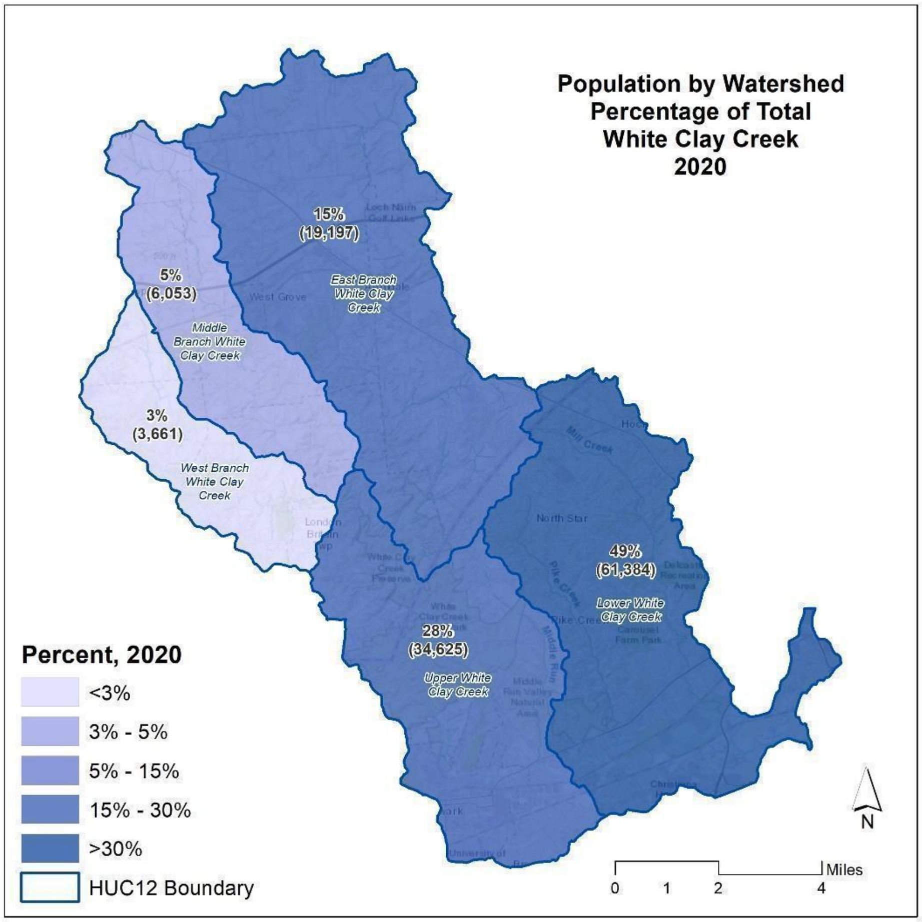


Figure 7. Population by Watershed, Percentage of Total White Clay Creek

Population Change and Demographics

Overall population in the White Clay Creek watershed has grown between 2010 and 2020, based on US Census Bureau Decennial data, from 123,906 to 124,921 people, an increase of 1,015 (nearly 1%). Table 3 summarizes the change in the decade between 2010 and 2020, and shows the percentage of the population in each HUC 12 watershed relative to the total population.

Table 3. Population Change, 2010-2020

Watershed	Popluation, 2010	Population, 2020	Percent, 2020	Change (2010-2020)
Lower White Clay Creek	60,659	61,384	49%	725
Upper White Clay Creek	36,109	34,625	28%	(1,484)
West Branch White Clay Creek	3,644	3,661	3%	17
Middle Branch White Clay Creek	5,774	6,053	5%	280
East Branch White Clay Creek	17,720	19,197	15%	1,477
TOTAL	**123,906**	**124,921**	**100%**	**1,015**

Figure 8 shows the population change by HUC 12 watershed as a percentage. Note that the Upper Main Stem has seen the highest loss of population (-1,484), while the East Branch saw the most gain (+1,477).

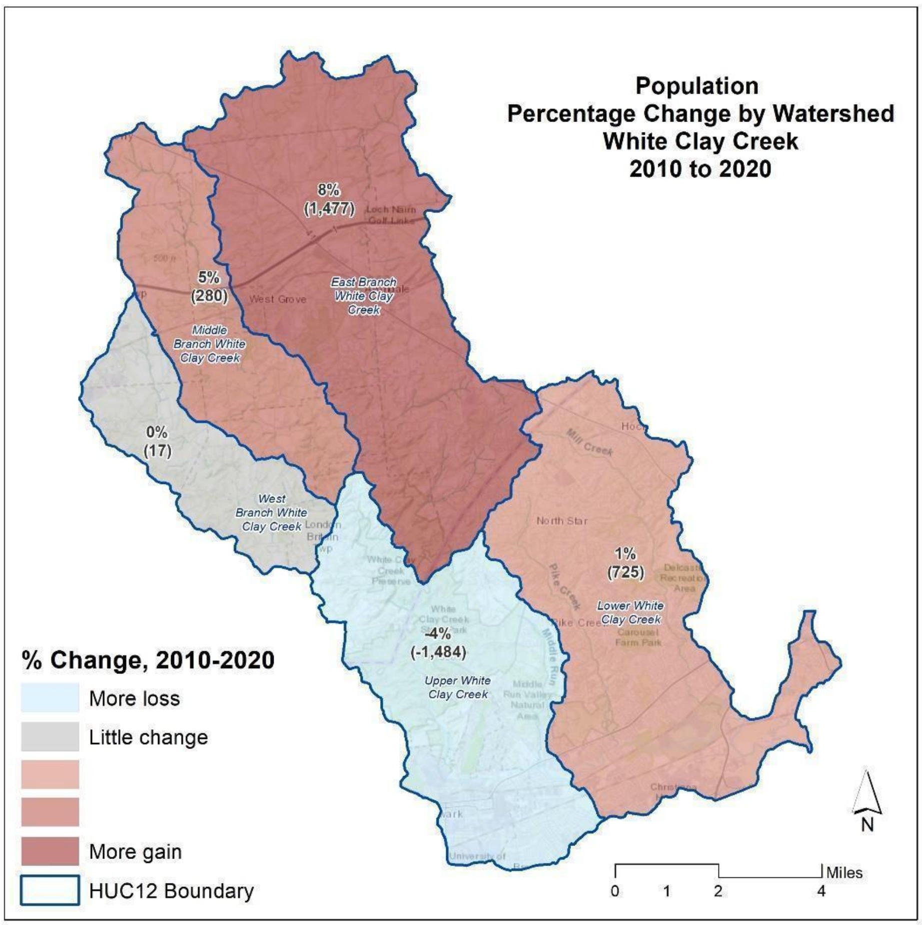


Figure 8. Population in 2010 and 2020 by HUC 12 Watershed

Figure 9 compares the population in 2010 and in 2020, by HUC 12 watershed in the White Clay Creek.

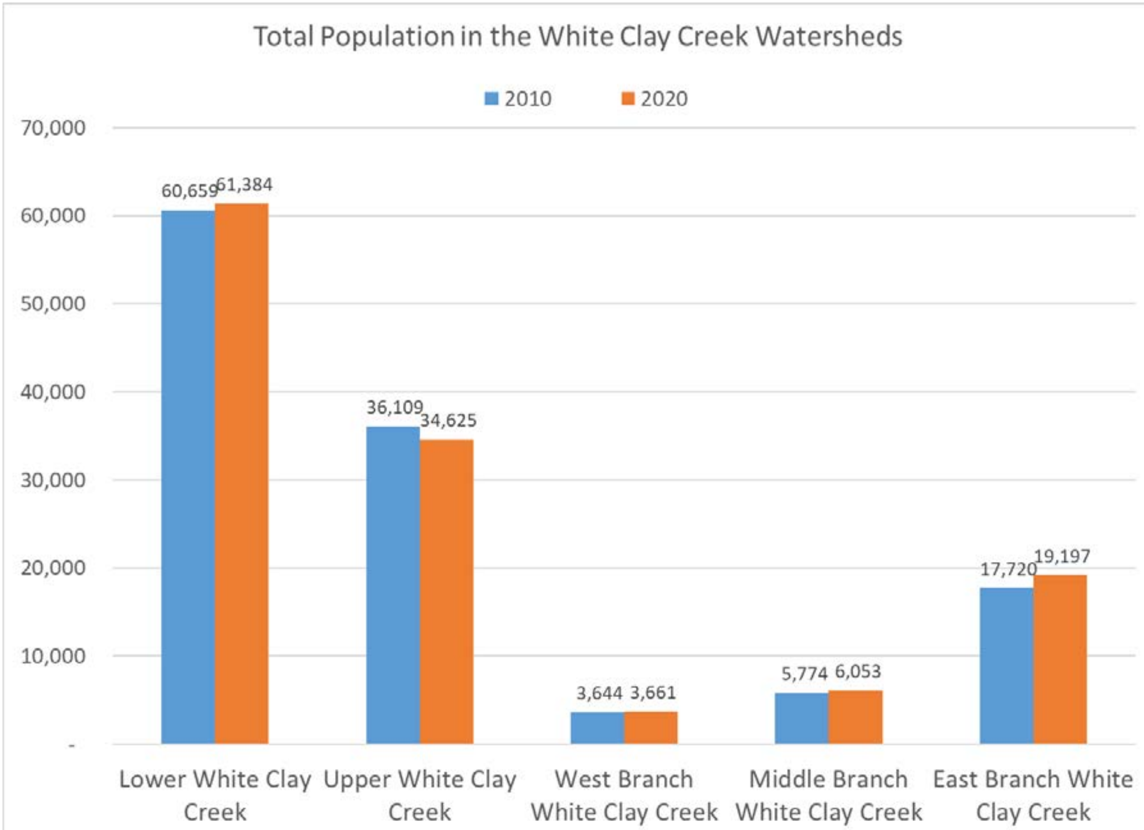


Figure 9. Total Population in the White Clay Creek Watersheds

Demographically, the changes in the watershed have not been equally distributed. Although the white population is still predominant in the watershed in 2020, most of the gains have come in minority (non-white alone) populations. Likewise, Hispanic populations have seen gains in all HUC 12 watersheds in the White Clay Creek watershed.[1]

The graphs in Figures 10-12 summarize the population and show the changes between 2010 and 2020, for white, minority and Hispanic populations, by HUC 12 watershed in the White Clay Creek.

[1] For the purposes of this analysis, minority population is considered any individual who does not report race as "white-alone," which includes people of two or more races. Hispanic population is not based on race, but on ethnicity, so the category of Hispanic can include both white and minority (non-white) individuals. Note that census information is self-reported.

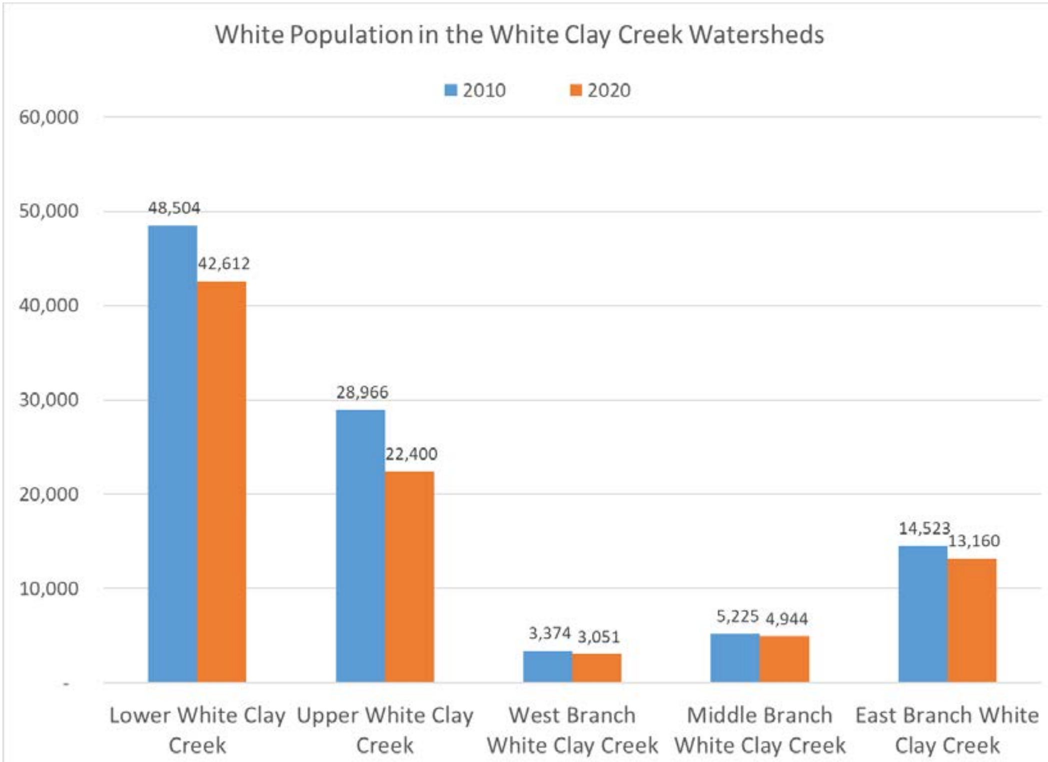


Figure 10. White population in the White Clay Creek watersheds

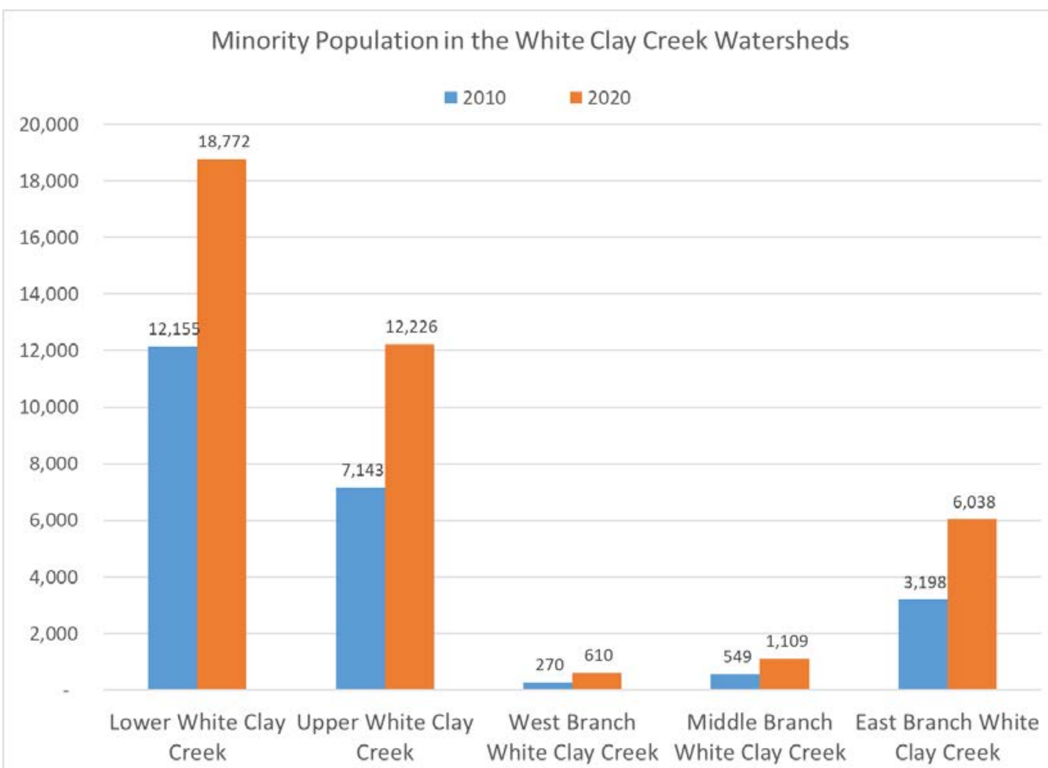


Figure 11. Minority population in the White Clay Creek watersheds

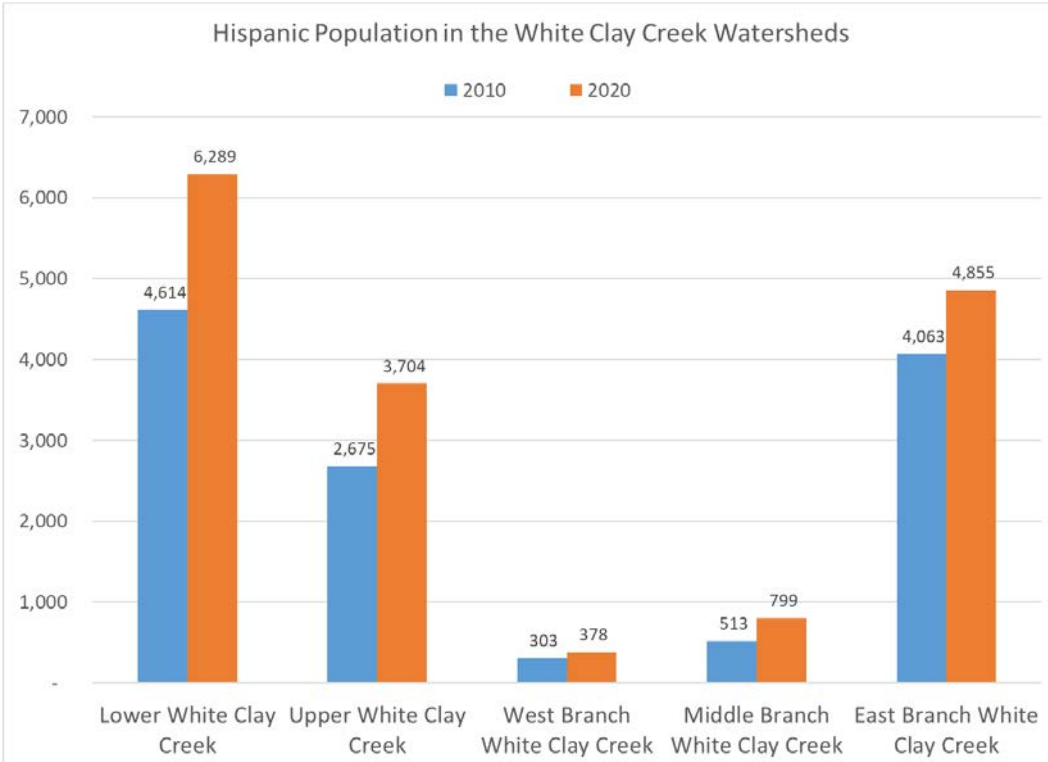


Figure 12. Hispanic population in the White Clay Creek watersheds

Table 4 presents the population—by watershed—by race/ethnicity, between 2010 and 2020, showing total and percentage change. Overall, while the total basin population over this period grew by less than 1% (1,015), the minority population grew by 61% (15,439 people), and the Hispanic population grew by 27% (3,855 people).

Table 4. Population by Watershed and Race/Ethnicity (2010-2020)

Watershed	Total				Minority				Hispanic			
	2010	2020	Change	%	2010	2020	Change	%	2010	2020	Change	%
Lower White Clay Creek	60,659	61,384	725	1%	12,155	18,772	6,617	54%	4,614	6,289	1,675	36%
Upper White Clay Creek	36,109	34,625	(1,484)	-4%	7,143	12,226	5,082	71%	2,675	3,704	1,029	38%
West Branch White Clay Creek	3,644	3,661	17	0%	270	610	340	126%	303	378	74	25%
Middle Branch White Clay Creek	5,774	6,053	280	5%	549	1,109	560	102%	513	799	285	56%
East Branch White Clay Creek	17,720	19,197	1,477	8%	3,198	6,038	2,840	89%	4,063	4,855	791	19%
Total	**123,906**	**124,921**	**1,015**	**1%**	**25,324**	**40,774**	**15,439**	**61%**	**14,179**	**18,044**	**3,855**	**27%**

1.5 Land Cover

Land cover indicates what is physically on the ground, such as forest, wetlands, grasslands, etc. It differs from land use, which indicates how humans use a particular landscape. Land cover information over time helps document land use trends and changes and helps us to better understand the processes affecting watershed health.

Current Land Cover

Land cover is defined as that which is physically present on a particular area of ground. It is a broad category, generally independent of the human use of that area of ground, describing the types of features which occur there. It is distinct, but related to “land use,” which describes how the land is used, for instance for commercial purposes or as parkland. What happens on the land has a significant impact on the overall health of the watershed, and of the waterbodies which lie downstream.

The White Clay Creek watershed is characterized by land cover divided roughly into several regions of similar characteristics. The downstream portion (Lower Main Stem, which includes several major tributaries), below Newark, is largely suburban in nature, with extensive residential development, and a limited amount of open space. The City of Newark, in the Upper Main Stem, is the most urbanized portion of the watershed, while immediately upstream—to beyond the Pennsylvania state line—lies the most extensive natural landscapes in and around the White Clay Creek State Park (in DE) and Preserve (in PA).

The central portion of the three upstream HUC 12 watersheds (the East, Middle and West Branches) are a mix of suburban, agriculture and town landscapes. The upper, headwater portions are more highly agricultural, with the upper headwaters of these watersheds characterized by more agricultural uses, including row crop, cattle and horse farms, as well as significant areas of wooded riparian corridors.

To characterize the current and recent land cover in the White Clay Creek, data from the NOAA’s Coastal Change Analysis Program (C-CAP) were used for three dates at 10-year intervals. The first data are from 1996, with additional data from 2006 and 2016 (the latest available version of the dataset). C-CAP data are produced on a regular basis by NOAA’s Office for Coastal Management. The data are based on satellite imagery at 30-meter ground resolution and are consistent across periods and political boundaries. For this reason, the data series provides a good indication of the status of land cover and how it has changed over time.

For the purposes of this study, C-CAP data has been generalized from the original 22 distinct categories into five broad categories. This eliminates areas of confusion among similar classes and enables a more robust comparison across time periods. The five categories are:

1. **Developed –** Any land with significant human impact, such as residential, commercial and industrial areas, as well as open recreational areas such as ball fields and some parks.
2. **Agriculture –** Land under active cultivation, or currently fallow, pasture and grasslands.
3. **Forest/Wetlands –** Natural landscapes, including forested areas and wetlands; in terms of watershed health these are both beneficial.
4. **Barren/Transitional –** Areas that are open, mined or in transition; this is a very small proportion.
5. **Open Water –** Areas of water, including ponds, lakes, bays and open river channels.

Figure 13 presents land cover in the White Clay Creek watershed in 2016, categorized into the five generalized classes.

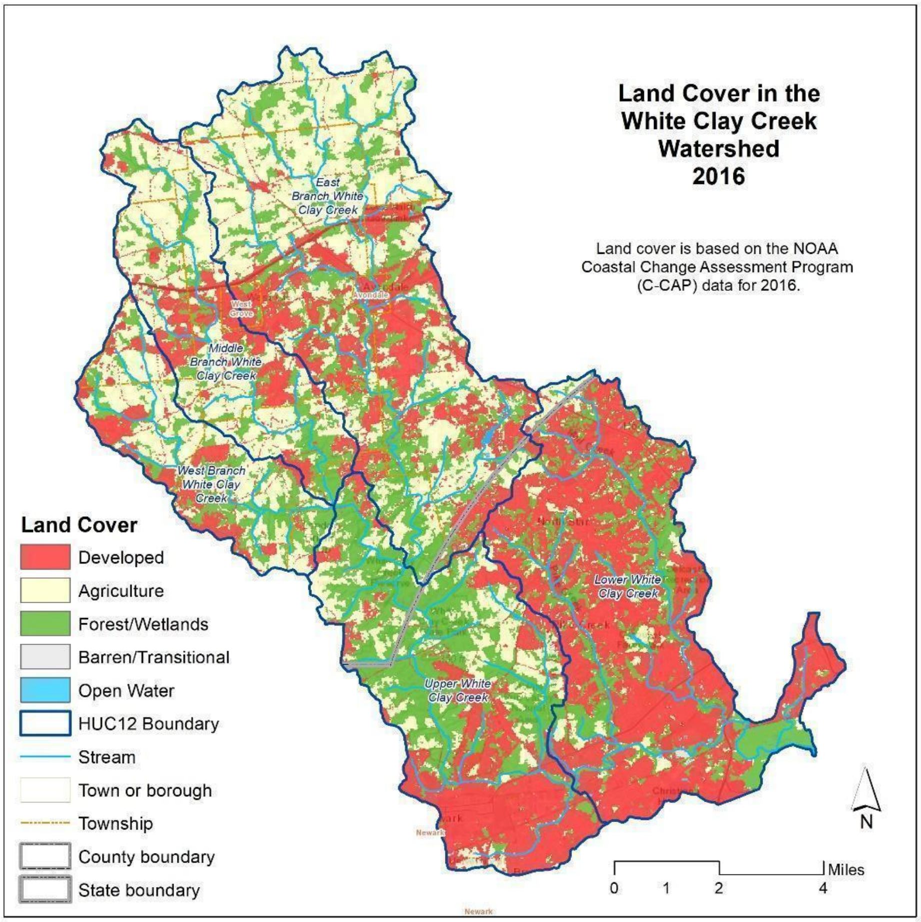


Figure 13. Land Cover in the White Clay Creek Watershed, 2016

Figure 14 presents the summary of land cover type for the three major categories (Developed, Agriculture and Forest/Wetlands) in square miles, for 2016. Note that the area for the categories Other and Open Water are negligible and not presented in the following graphs.

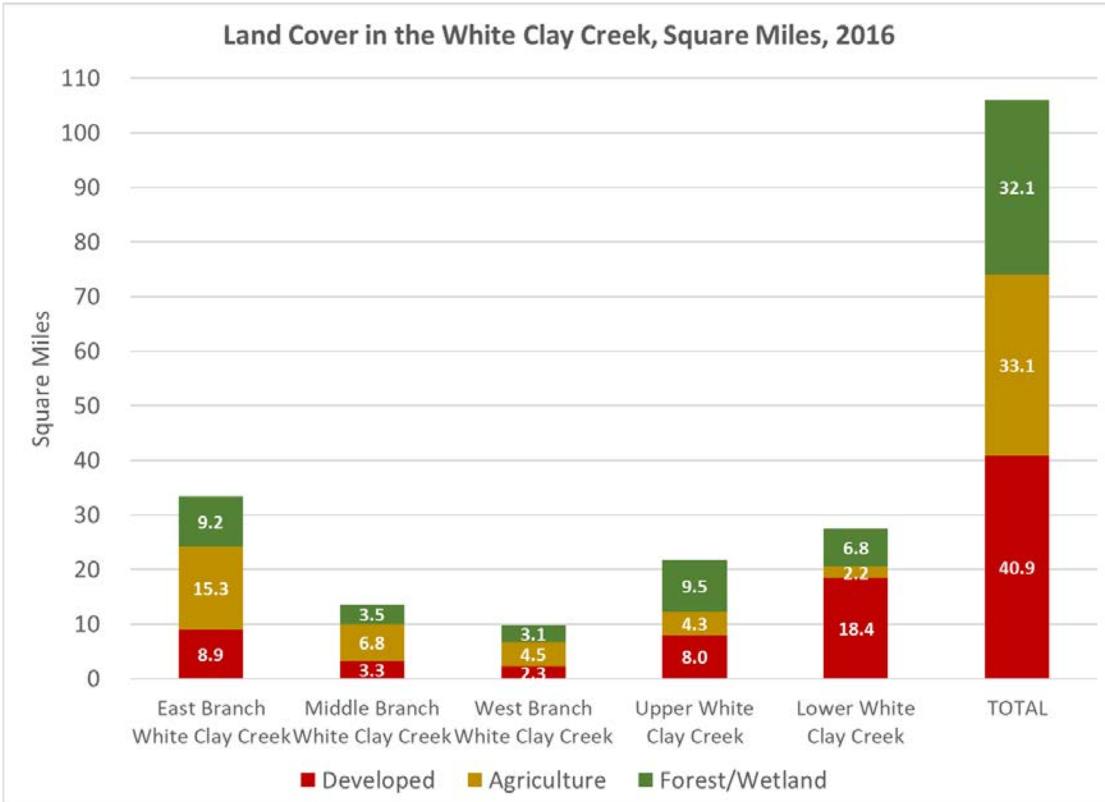


Figure 14. Summary of Land Cover Type in White Clay Creek Watersheds

In the White Clay Creek watershed, the proportion of natural land (Forest/Wetland) and Agriculture are evenly divided at approximately 30% each, while the area of development is nearly 39% of the total land area. Figure 15 shows the proportion of these land cover types as a percentage of the entire White Clay Creek watershed, for 2016. Total square miles are also shown.

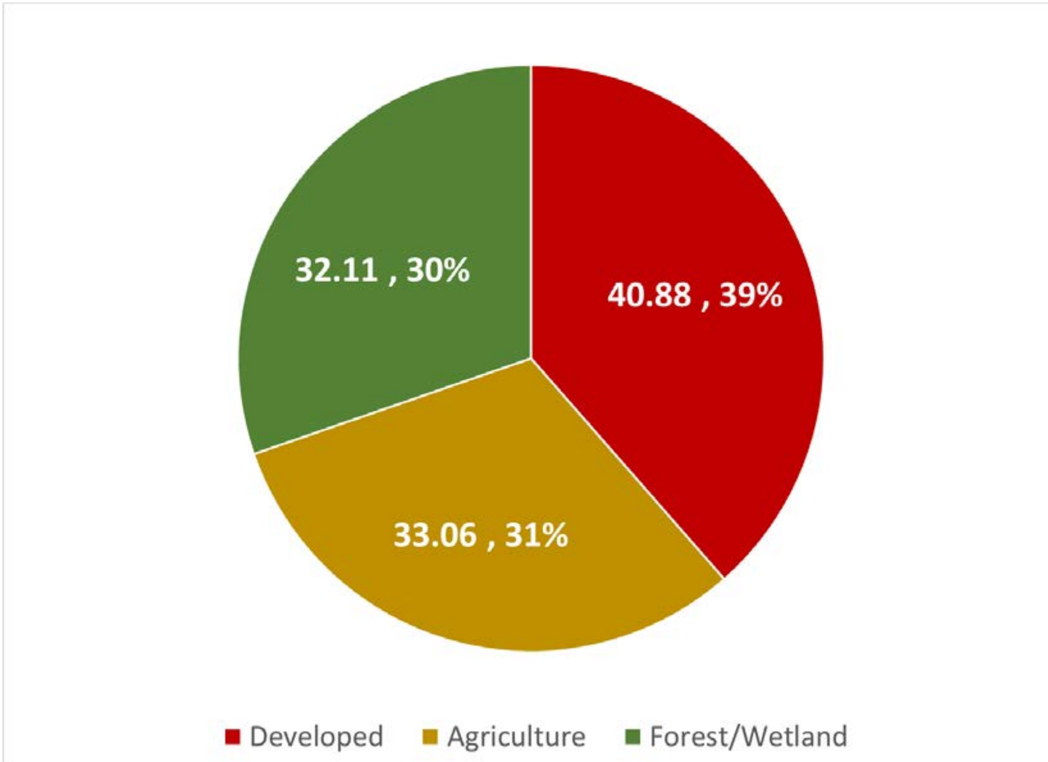


Figure 15. Proportion of Land Cover Types as Percentage of White Clay Creek Watershed

Figure 16 shows the proportion of each of the three major land cover classes for 2016 within each of the five HUC 12 catchments and the White Clay Creek watershed as a whole. Labels show the total area, in square miles of each land cover type. Table 5 summarizes land cover by each of the major classes in 2016.

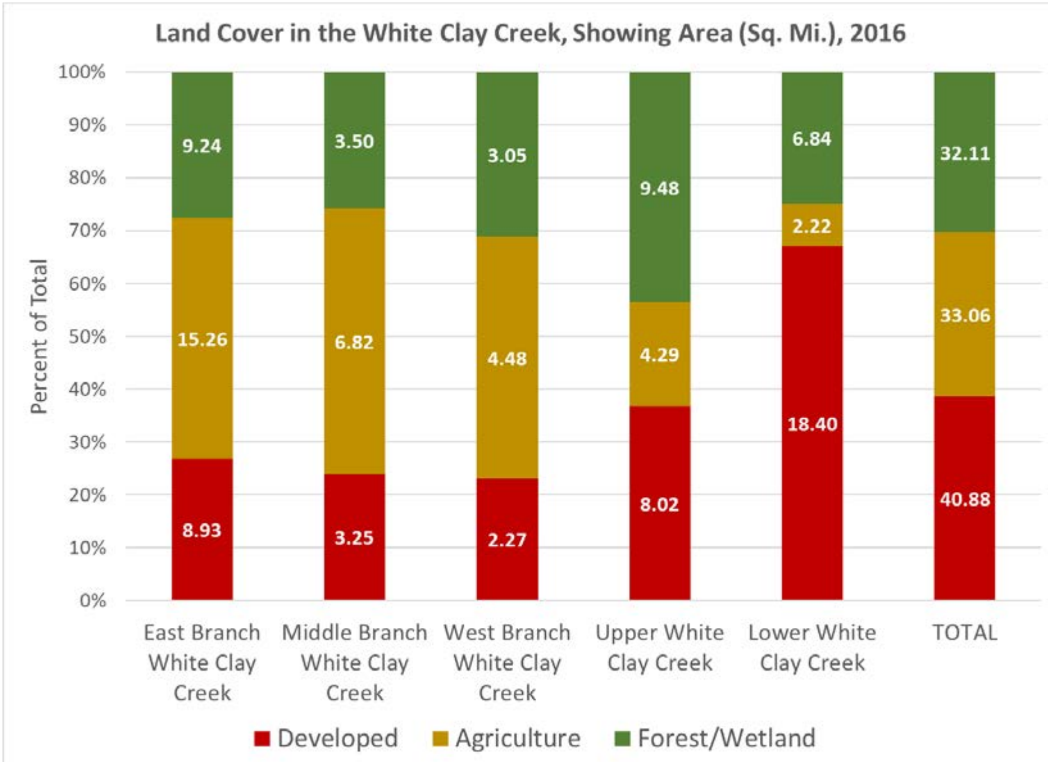


Figure 16. Proportion Within Each HUC 12 of the White Clay Creek Watershed

Table 5. Land Cover by Major Classes, 2016

HUC_12	Watershed	Developed	Agriculture	Forest/Wetland	Other
020402050303	East Branch White Clay Creek	8.93	15.26	9.24	0.10
020402050301	Middle Branch White Clay Creek	3.25	6.82	3.50	0.01
020402050302	West Branch White Clay Creek	2.27	4.48	3.05	0.00
020402050306	Upper White Clay Creek	8.02	4.29	9.48	0.03
020402050308	Lower White Clay Creek	18.40	2.22	6.84	0.12
	TOTAL	**40.88**	**33.06**	**32.11**	**0.28**

The maps in Figures 17-19 show the percentage of developed, agricultural and natural land, respectively, in the HUC 12 watersheds of the White Clay Creek watershed. The Lower Main Stem watershed in Delaware is the most highly developed (over two-thirds), while the Upper Main Stem is slightly over one-third developed; though the City of Newark is here, there are also large areas of open land within the White Clay Creek Park and Preserve. The upper watersheds have lower rates of development, though there is a slightly higher percentage in the East Branch, which contains the Borough of Avondale. Agricultural land cover occurs primarily in the upper three watersheds of the White Clay Creek, with the highest percentage (over 50%) found in the Middle Branch. The highest percentage of natural land (forest and wetlands) occurs in the Upper Main Stem, comprising the City of Newark and the White Clay Creek State Park and Preserve. The upper three watersheds (East, Middle and West Branches) have a somewhat lower percentage (between 25% and 32%), due in large part to the greater percentage of agricultural uses found in these areas. The Lower White Clay Creek (main stem) is the most highly developed, and consequently has the lowest overall percentage of natural land.

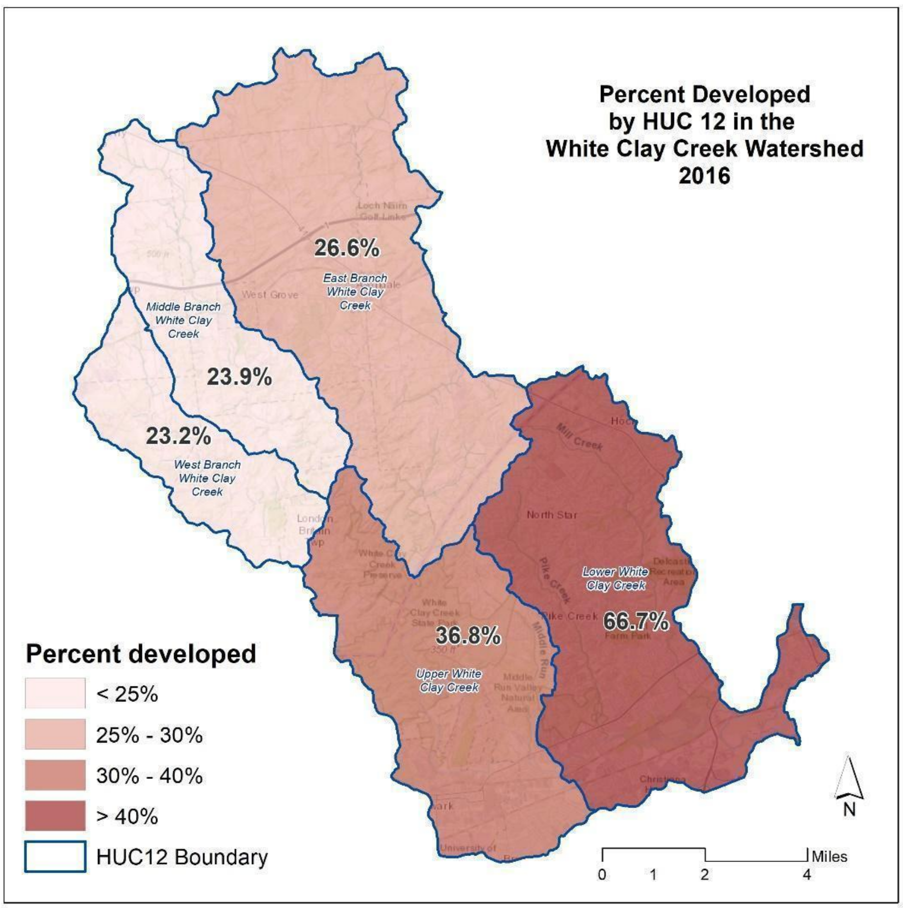


Figure 17. Percent Developed by HUC 12 in the White Clay Creek Watershed, 2016

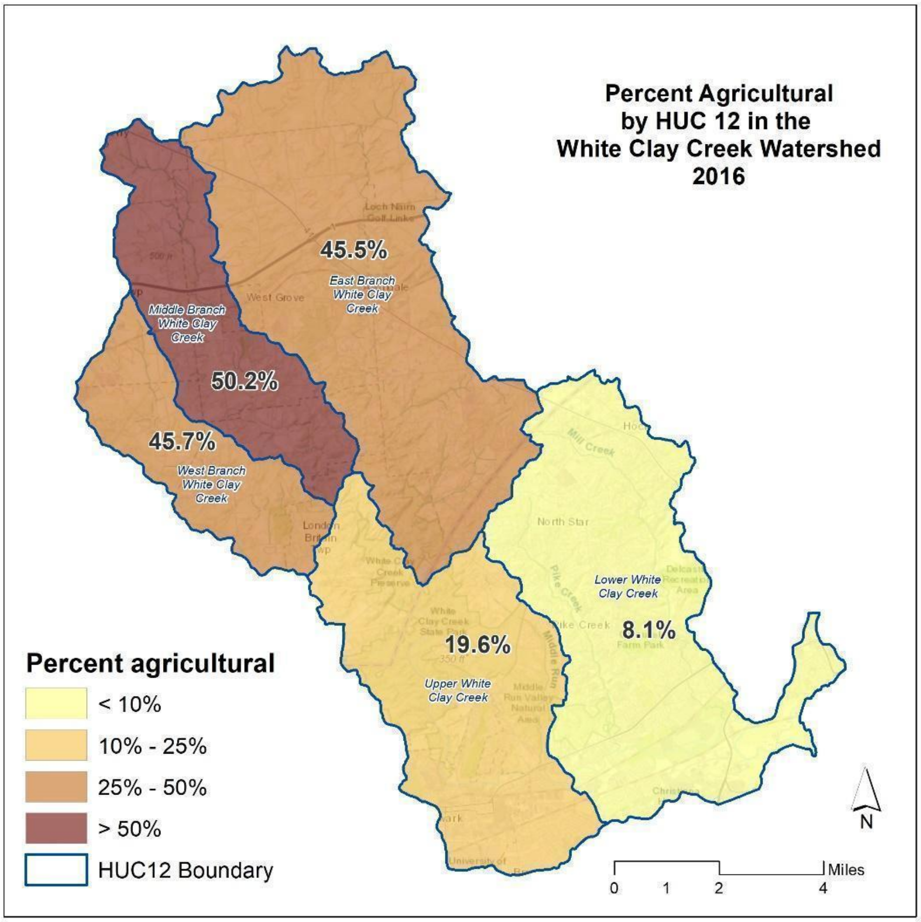


Figure 18. Percent Agricultural by HUC 12 in the White Clay Creek Watershed, 2016

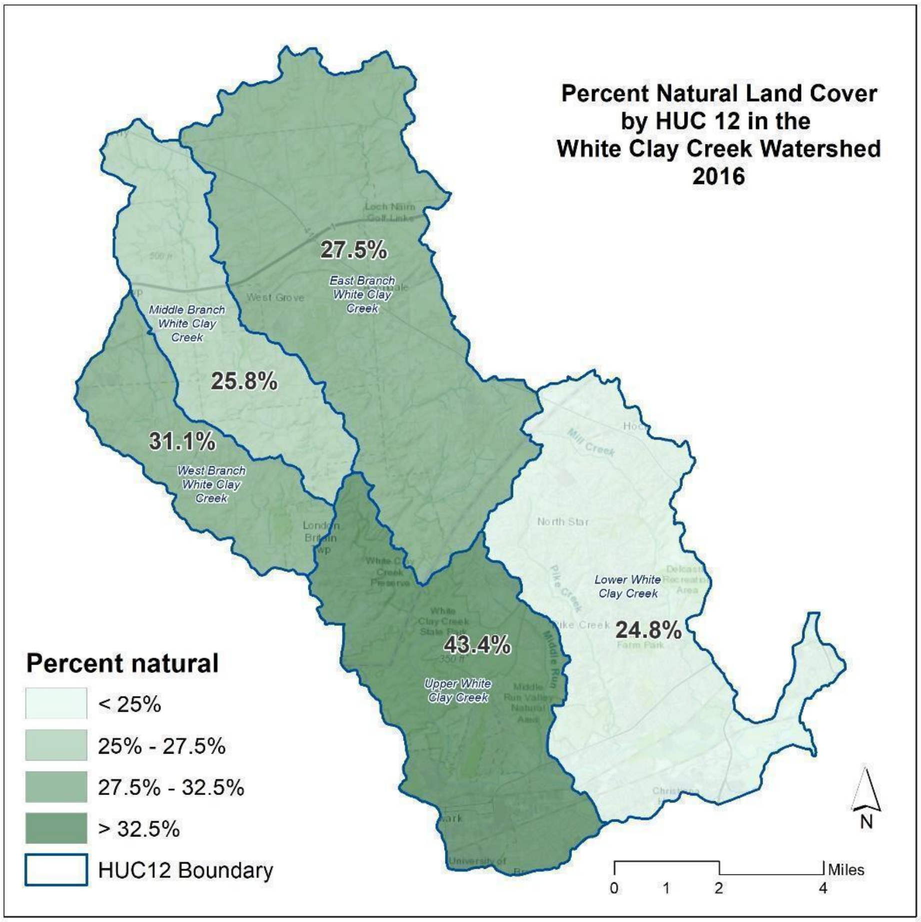


Figure 19. Percent Natural Land Cover by HUC 12 in the White Clay Creek Watershed, 2016

Land Cover Trends

Based on C-CAP data from 1996 and 2016, the trend in each major land cover type was analyzed. During that period, the White Clay Creek watershed as well as each HUC 12, experienced increased development. Concomitantly, there was an overall decrease in both agricultural land cover across the watershed. This shift was particularly marked in the East Branch. Natural areas saw a slight increase overall, particularly in the East Branch, with the greatest loss coming in the more highly developed Lower White Clay Creek. Figure 20 presents the changes, by watershed, in each of the three major land use classes, between the years 1996 and 2016.

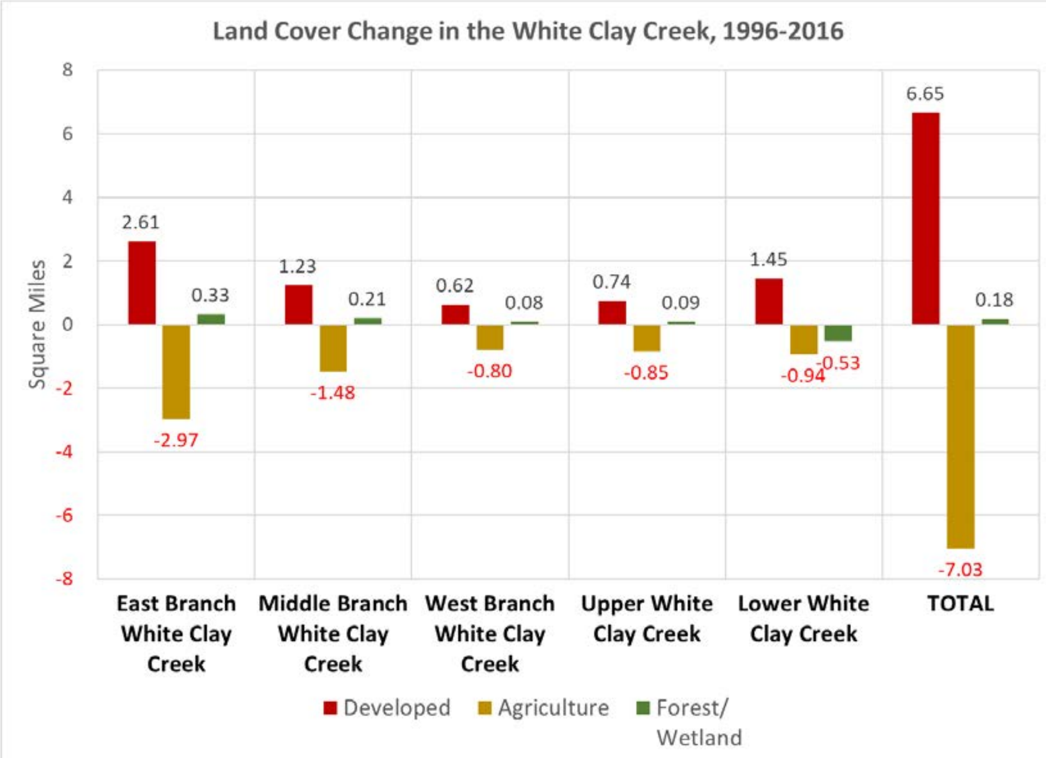


Figure 20. Land Cover Change in the White Clay Creek, 1996-2016

Table 6 shows the total changes in major land cover type between 1996 and 2016, in square miles and in percentage change from 1996.

Table 6. Total Changes in Major Land Cover Type, 1996-2016

HUC_12	Watershed	Developed	% Chg. Dev.	Agriculture	% Chg. Ag.	Forest/ Wetland	% Chg. Nat.
020402050303	East Branch White Clay Creek	2.61	41%	-2.97	-16%	0.33	4%
020402050301	Middle Branch White Clay Creek	1.23	61%	-1.48	-18%	0.21	6%
020402050302	West Branch White Clay Creek	0.62	38%	-0.80	-15%	0.08	3%
020402050306	Upper White Clay Creek	0.74	10%	-0.85	-16%	0.09	1%
020402050308	Lower White Clay Creek	1.45	9%	-0.94	-30%	-0.53	-7%
	TOTAL	**6.65**	**19%**	**-7.03**	**-18%**	**0.18**	**1%**

1.6 Open Space and Preserved Land

Just as the types of land cover and land use in a watershed largely determine its character and overall health, the amount of undeveloped open space has an implication for water quality, habitat value and watershed health. Natural open space (particularly forests and wetlands, but also uncultivated grasslands) provide environmental benefits to the biota, habitats, water quality, as well as contributing to the well-being of human inhabitants. To ensure that those benefits persist, it is important that such lands get protections to limit or remove the potential for development (transformation to a less environmentally beneficial land cover type).

Determining Land Protection

Protections can take the form of legal or ownership protections; land may be purchased outright by public, private or non-profit entities and protected from development. Alternatively, an entity (e.g., a land trust, local or state government) can purchase or be donated the development rights to land through a legally-binding easement agreement with a land owner. Land ownership (through fee-simple purchase or holding) and easements are both mechanisms used in the field of land protection to safeguard existing open spaces or other desirable land cover types.

Data for protected open spaces is generally derived from multiple and disparate sources, since such lands are the purview of a diversity of entities. Fortunately, the USGS has developed, through their Gap Analysis Program (GAP)[2], a system to inventory and compile these data from original sources. This resource—the Protected Areas Database of the United States (PAD-US)—inventories protected land nationally, including those owned by federal, state, regional and local government entities, as well as land owned by private and non-profit organizations for the specific purpose of protecting their resources. Additionally, land that is eased by various public, private, and nonprofit entities is included in the database. The program also tracks which lands are open to the public and to what degree (e.g., open access versus restricted due to fees or other constraints). The data are updated on a regular basis to include new protected areas and refinements/corrections.

The White Clay Creek watershed is characterized by many extensive areas of protected open space. These include land such as state parks, preserves, municipal parks and recreation areas, historic and cultural sites, and open spaces such as those owned by homeowner associations (HOAs) or other private entities. Figure 21 shows the location and status of both fee-owned and eased lands in the White Clay Creek watershed. The ownership categories mapped include: state, county, municipal, nonprofit (NGO) and privately-protected land. Primary easement types are conservation easement and agricultural easement. Areas that are not accessible to the public are shown with yellow hatching.

[2] See https://gapanalysis.usgs.gov/padus/vision/ for a more complete description of the Gap Analysis Program.

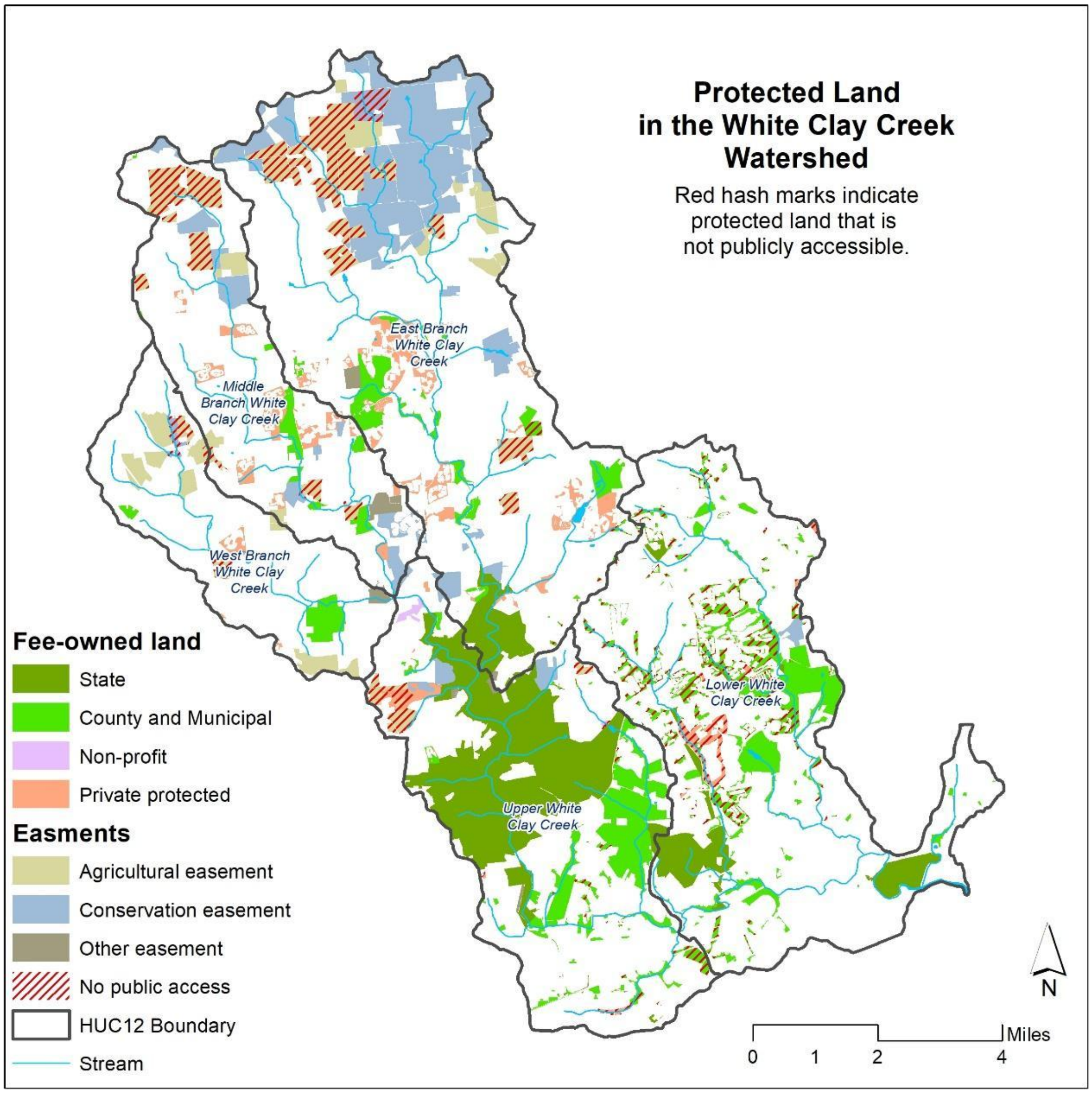


Figure 21. Protected Land in the White Clay Creek Watershed

The White Clay Creek encompasses significant areas of open space with much of the fee-owned land within the White Clay Creek State Park (in Delaware) and Preserve (in Pennsylvania). The Park and Preserve constitute over 8% of the total watershed area of the White Clay Creek. The upper reaches of the East, Middle and West Branches include large areas of lands in easement, both for conservation and agriculture (mostly falling in the Upper East Branch).

The charts in Figures 22 and 23 show the proportion of fee-owned land in the White Clay Creek watershed by owner type and of eased land by easement type, respectively.

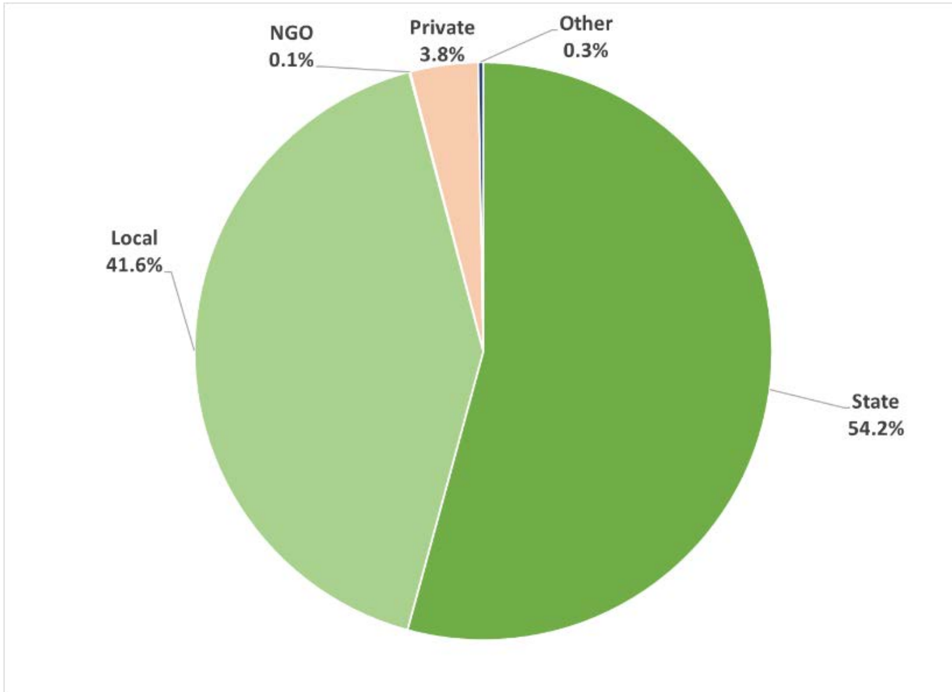


Figure 22. Proportion of Fee-Owned Land in the White Clay Creek by Owner Type

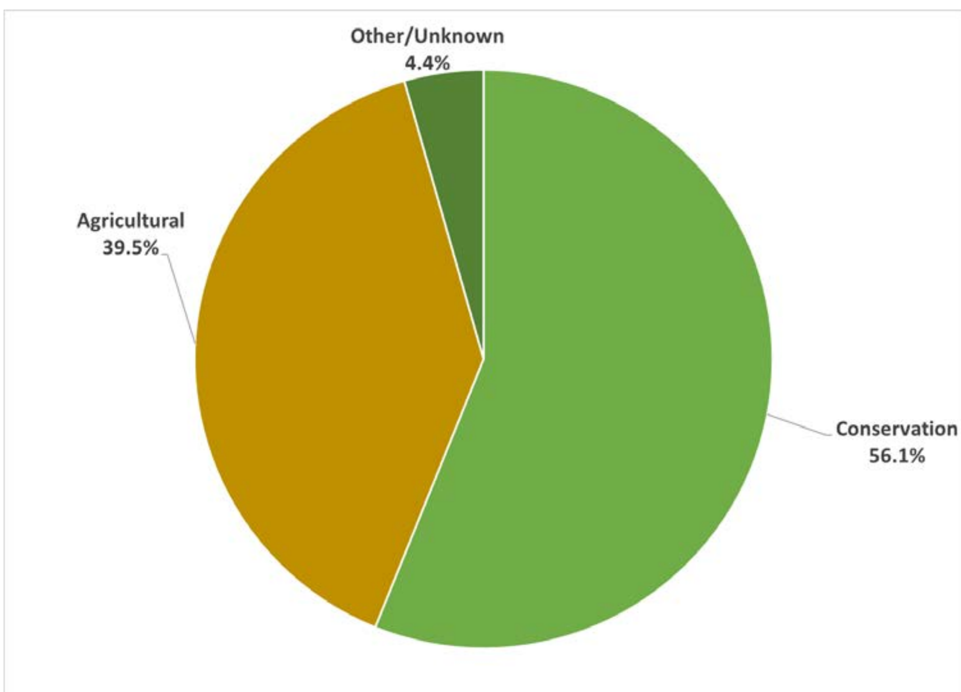


Figure 23. Proportion of Fee-Owned Land in the White Clay Creek by Easement Type

The maps in Figures 24 and 25 show the proportion of protected land within the HUC 12s of the White Clay Creek watershed. The map on the left presents the amount of fee-owned protected land as a percentage of total catchment area, and the map on the right presents the amount of easement-protected land as a percentage of total area.

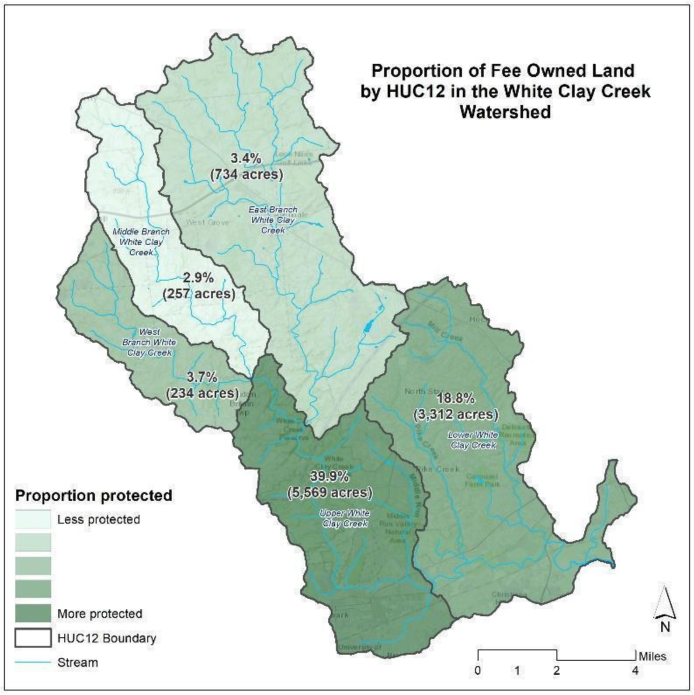


Figure 24. Proportion of Protected Land Within the HUC 12s of the White Clay Creek Watershed

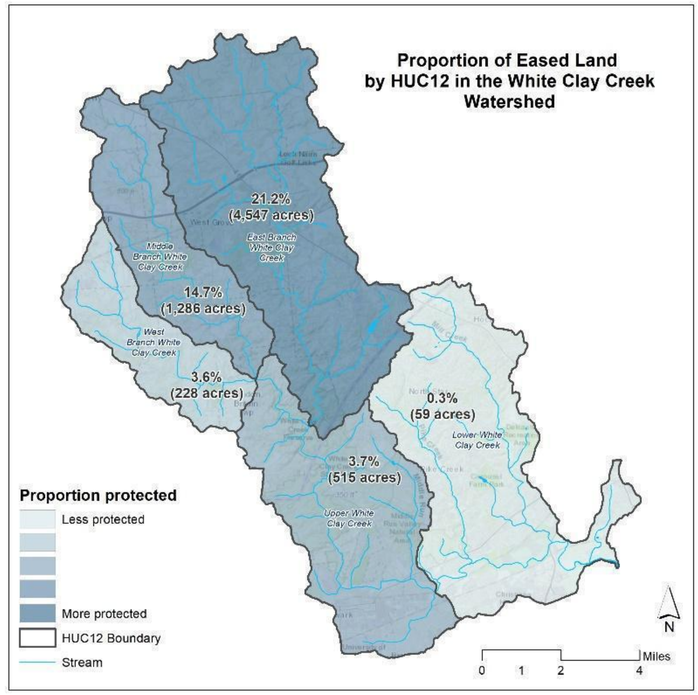


Figure 25. Proportion of Eased Land by HUC 12 in the White Clay Creek Watershed

Table 7 summarizes the acreage of land protected through ownership in 2020, by owner type, with the percentage of the total land area of White Clay Creek watershed that each represents. Over 8% of the land is protected through state ownership (Delaware and Pennsylvania), and over 6% is protected by local municipal (county, city, borough, township) ownership.

Table 7. Acreage of Fee Owned Land Protected, by Owner Type and Land Area

Protected Land, Fee Owned	Acres 2020	% 2020
State	5,481	8.04%
Local	4,207	6.17%
NGO	6	0.01%
Private	383	0.56%
Other	29	0.04%
Total	**10,106**	**14.83%**

Table 8 summarizes the acreage of land protected through easements in 2020, by type of easement. Nearly 5.5% of the land in the White Clay Creek watershed is protected by conservation easement and over 3.8% is protected by agricultural easement.

Table 8. Acreage of Land Protected Through Easements in 2020

Protected Land, Easements	Acres 2020	% 2020
Conservation	3,723.80	5.46%
Agricultural	2,617.91	3.84%
Other/Unknown	293.64	0.43%
Total	**6,635.35**	**9.73%**

Table 9 shows the summary by protection type (fee-owned land or easements) for the watersheds of the White Clay Creek. In total, the White Clay has over 10,000 acres (14.8% of the total land area) of land protected by fee-ownership, and over 6,600 acres (9.7% of the land area) of easements. A total of 16,742 acres of land are protected in the White Clay Creek watershed, representing nearly one quarter (24.6%) of the entire watershed.

Table 9. Summary of Land Protection Type for the White Clay Creek Watersheds

		Fee Owned		Easements		Total Protected	
Watershed	**Total Acres**	Acres	%	Acres	%	Acres	%
Lower White Clay Creek	17,652	3,312	18.8%	59	0.3%	3,371	19.1%
Upper White Clay Creek	13,972	5,569	39.9%	515	3.7%	6,084	43.5%
East Branch White Clay Creek	21,461	734	3.4%	4,547	21.2%	5,282	24.6%
Middle Branch White Clay Creek	8,723	257	2.9%	1,286	14.7%	1,543	17.7%
West Branch White Clay Creek	6,356	234	3.7%	228	3.6%	462	7.3%
White Clay Creek Total	**68,164**	**10,106**	**14.8%**	**6,635**	**9.7%**	**16,742**	**24.6%**

1.7 Drinking Water and Wastewater

Public Drinking Water

The public water suppliers in the White Clay Creek watershed are shown in Table 10. Two major water suppliers—the City of Newark and Veolia (SUEZ)—maintain surface water intakes along the White Clay Creek. The boroughs of Avondale and West Grove in Pennsylvania, and Artesian Water Company and the City of Newark in Delaware operate public drinking water supply wells.

Table 10. Public Water Suppliers in the White Clay Creek Watershed

Purveyor	Primary Source	Watershed Location
Pennsylvania		
Borough of Avondale	Groundwater	East Branch
Borough of West Grove	Groundwater	East Branch
Delaware		
Artesian Water Company	Groundwater	Lower Main Stem and Upper Main Stem
City of Newark	Groundwater	Upper Main Stem
City of Newark	Surface water	Upper Main Stem at Newark
Veolia (SUEZ)	Surface water	Lower Main Stem at Stanton

There is one public drinking water supply reservoir in the White Clay Creek watershed—the Newark Reservoir at Newark, Delaware, owned and operated by the City of Newark. The reservoir was built in 2006 and has a capacity of 318 million gallons (MG)—enough water for up to a 100-day supply. The reservoir serves as a supplemental water supply to Newark water customers and is generally used when the creek surpasses the maximum turbidity threshold[3], or in times of low-flow. Figure 26 shows the locations of public drinking water supplies in the White Clay Creek watershed.

[3] The turbidity threshold is 20 nephelometric turbidity units (NTU).

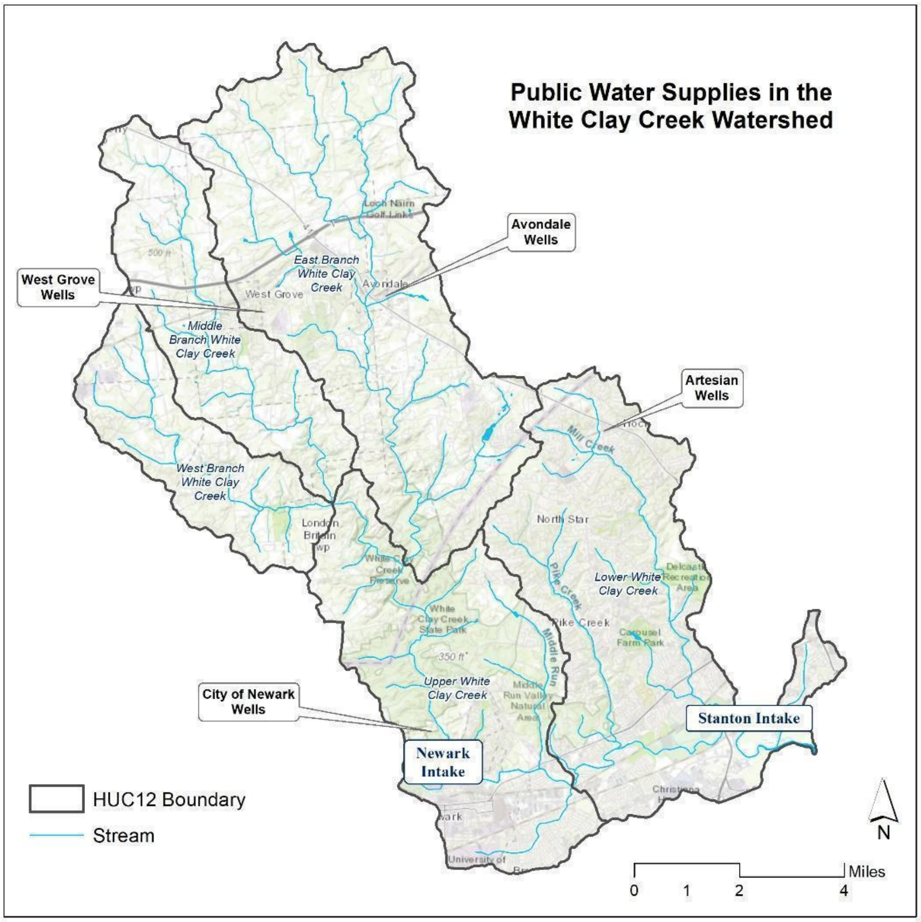


Figure 26. Public Water Supplies in the White Clay Creek Watershed

Wastewater Discharges

The National Pollution Discharge Elimination System (NPDES) is a program administered through the US Environmental Protection Agency (US EPA) that regulates the discharge of pollutants into waterways. Any wastewater treatment facility which has an outfall to a stream or waterbody must receive a permit. The state agencies responsible for overseeing this program are the Department of Environmental Protection (PA DEP) in Pennsylvania and the Department of Natural Resources and Environmental Control (DNREC) in Delaware.

Within the White Clay Creek watershed there are four permitted wastewater dischargers, all in Pennsylvania. There are two major wastewater treatment plants in the watershed, located in Avondale and West Grove. Based on existing permits, a maximum of slightly more than 500,000 gallons of treated effluent may be introduced into the White Clay Creek each day. Table 11 lists the dischargers (treatment plants) within the White Clay Creek watershed and total permitted flow, in millions of gallons per day, for each.

Table 11. Wastewater Treatment Plants in the White Clay Creek Watershed

NPDES ID	Wastewater Treatment Plant	Discharge (mgd)
East Branch		
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
PA0052451	Frances L. Hamilton Oates STP EB White Clay Creek Municipal Small STP	0.0012
Main Stem		
PA0024066	West Grove Borough Authority STP MB White Clay Creek Municipal Large STP	0.25
	White Clay Total	**0.56**

2. Watershed Assessment and Methodology

2.1 Summary of Watershed Categories and Indicators

The White Clay Creek watershed assessment includes five categories: Hydrology, Habitat, Water Quality, Scenery and Recreation. Within each of these five categories there is a range from two to seven indicators to assess the health of the watershed within each category. Each category and indicator was chosen based on data availability, scientific research, literature review and stakeholder input. The following five categories and 20 indicators will be discussed in detail in the following sections of the report.

Hydrology
- Stream Flow
- Peak Flow
- Groundwater Levels

Habitat
- Impervious Cover
- Terrestrial Connectivity (buffers/riparian)
- Terrestrial Connectivity (forest fragmentation)
- Aquatic connectivity (culverts and pipes)
- Aquatic Connectivity (dams/fish passage)

Water Quality
- DO
- Phosphorus
- Nitrogen
- Total Suspended Sediment
- Chloride/Conductivity
- Water Temperature
- Macroinvertebrates

Scenery
- Scenic Quality
- View Importance

Recreation
- Trails
- Fish Consumption Advisories
- Bacteria

The following sections in Chapter 2 derive watershed rankings for the indicators and provide an overall score and ranking for the five categories. Each indicator within each of the five categories has a unique methodology to assess the status and assign a score and subsequent grade for each specific indicator. The methodologies for each indicator are determined based on literature review and best available data in the White Clay Creek watershed. When applicable, a score is determined for each of the 20 indicators based on a subwatershed (HUC 12) or the entire White Clay Creek watershed. When computing an overall score for the entire watershed the project team used HUC 12s as the most appropriate hydrologic unit for extrapolation. The aggregated scores are weighted by subwatershed area (Table 12). Not all indicators are weighted by HUC 12 units and the detailed methodology for each individual indicator will indicate if weighting was applied for that specific indicator. Using the data and analysis conducted for each indicator, the White Clay Creek watershed—along with each of its five subwatersheds—has been assessed, where appropriate, and given a score along with a letter grade ("A" through "F"). A grade of "N/A" (not applicable) is given in cases where a score is not appropriate or possible due to data or other limitations. The detailed methodology used to devise the scoring and grades for each indicator is detailed in the corresponding sections in Chapter 2.

Table 12. White Clay Watershed Areas for Score Weighting

Watersheds (HUC 12)	HUC 12 ID	Area (acres)	Area (sq.mi.)	% WCC
East Branch	20402050303	19675	30.7422	30%
Middle Branch	20402050301	8729	13.6391	13%
West Branch	20402050302	6360	9.9375	10%
Upper White Clay	20402050306	13978	21.8406	21%
Lower White Clay	20402050308	17652	27.5813	27%
Totals:		**66394**	**103.741**	**100%**

2.2. Category 1: Hydrology

Three key indicators were used in the Hydrology category to assess the health of the White Clay watershed and subwatersheds. The following table (Table 13) summarizes the grading for the three Hydrology category indicators for the White Clay Creek watershed and subwatersheds:

Table 13. White Clay Creek, overall grades for Hydrology

	Lower Main Stem	Upper Main Stem	East Branch	Middle Branch	West Branch	Watershed
Hydrology	B-	B+	B+	B-	B+	B-
Stream Flow	A-	A-	A	B-	A	A-
Peak Flow	D+	N/A	N/A	N/A	N/A	D+
Groundwater Levels	B	B	B	B	B	B

Scores for the Peak Flow metric were derived from a single monitoring location—the gage at White Clay Creek near Newark, DE. Grades were only applied to the Lower Main Stem, where the gage is located, and for the overall watershed. Scores for Groundwater Levels were derived from Chester County well CH 10/USGS 395450075485401. Grades for the entire watershed, and for each subwatershed, are represented by that single monitoring well, and all subwatersheds receive the same grade as the overall watershed.

Stream Flow

Stream flow represents the dry weather baseflow for rivers and creeks. Baseflow is critical for sustaining flow in streams and rivers and is essential to sustain ecological and human water needs. Natural rivers tend to have high baseflow while heavily impacted watersheds have altered regimes.

The metric used to determine watershed health based on flow characteristics is the proportion of baseflow relative to the average annual flow, for each of five USGS gaging stations in the watershed with flow data. Figure 27 shows a map of all stream gages in the White Clay Creek watershed, with those used in this analysis shown in red. This approach uses the "Montana Method" developed by Tennant as a tool to assess stream habitat (Tennant, 1976). Baseflow regimens are examined for a stream gage station and evaluated according to season (October to March and April to September). The ratio of base to average annual flow is one indication of the overall health of a stream and its ability to support stream-related biota. The determination of this ratio is then ranked based on empirical observation of stream condition under varied flow regimes, and scored based on the calculated ration. Table 14 summarizes the scoring, for each period, based on the metric.

Table 14. Stream flow scoring

Narrative description of flows *	Recommended base flow regimens Oct.-Mar.	Apr.-Sept.
Flushing or maximum	200% of the average flow	
Optimum range	60%-100% of the average flow	
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or degrading	10%	30%
Poor or minimum	10%	10%
Severe degradation	10% of average flow to zero flow	

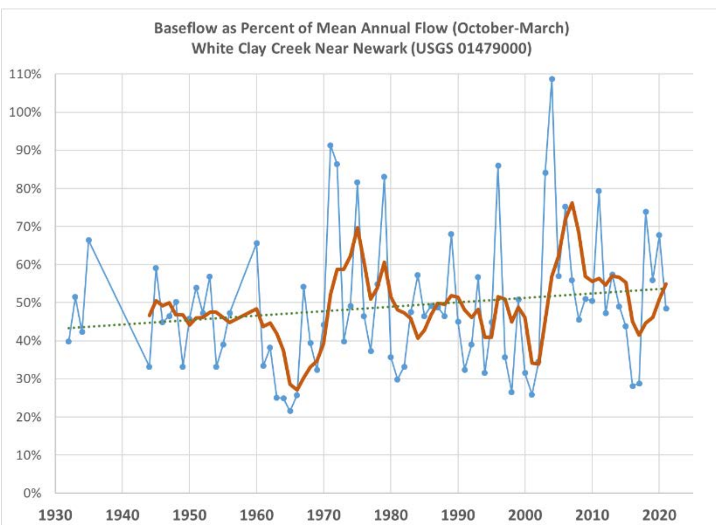
This criterion was applied to the stream flow gages in the White Clay Creek watershed to rank the watersheds based on stream flow at each of the five USGS stream gages. Three Pennsylvania gages monitoring flow data are operated under a cooperative program between the USGS and Chester County Water Resources Authority (CCWRA). Two Delaware gages are administered by the USGS. These stations monitor and collect flow data. To determine baseflows, daily mean flow for the period of record at each gaging station was determined within each six-month period, and the first quartile values used to determine baseflow values. Table 15 lists each of the gaging stations used to determine stream flow, including the period of record for each. The scoring for each stream flow gage is based on the latest five-year period, with the ranking determined by percentage of annual flow, as prescribed in Table 14, above.

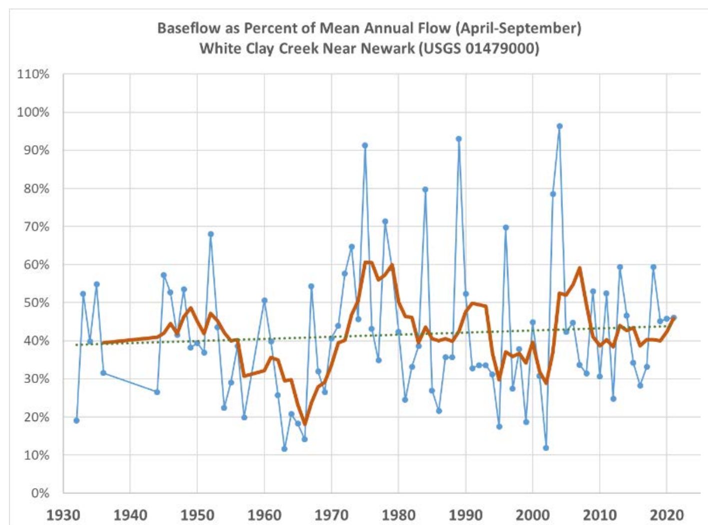
Figure 27. USGS Stream Gages in the White Clay Creek Watershed

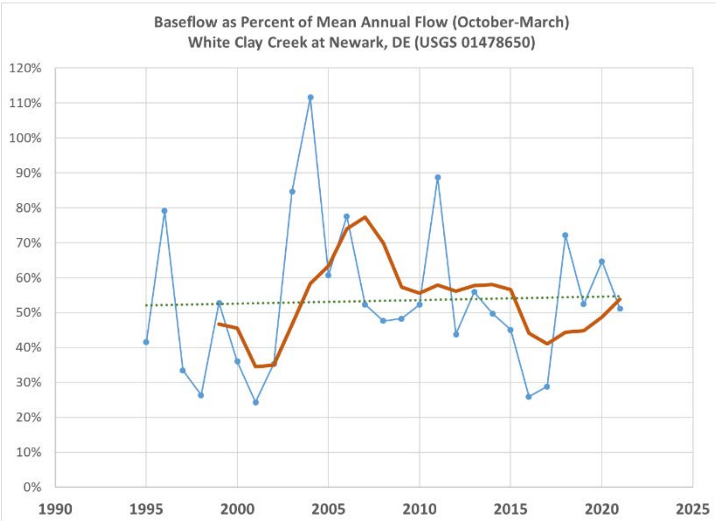
Table 15. USGS Stream Gages in the White Clay Creek Watershed Used in This Analysis

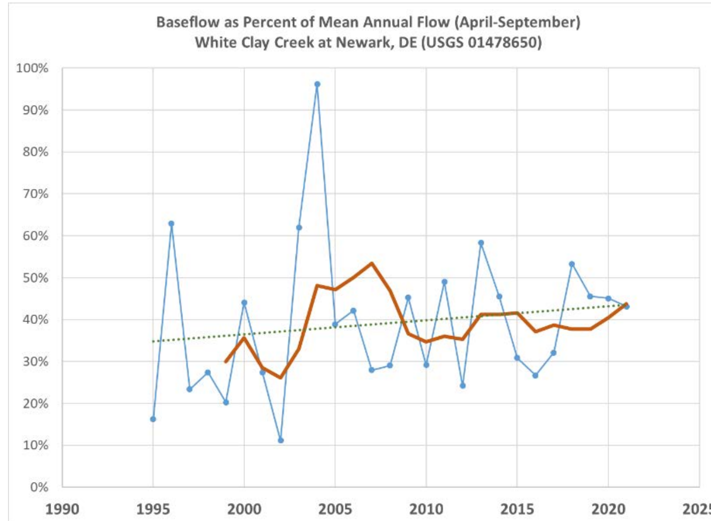
Gage	Location	Period of record
USGS 01479000	White Clay Creek Near Newark, DE	October 1931 to September 1936, June 1943 to September 1957, October 1959 to current year. Monthly discharge only for some periods.
USGS 01478650	White Clay Creek At Newark, DE	March 1994 to current year.
USGS 01478220	West Branch White Clay Creek near Chesterville, PA	March 2020 to current year.
USGS 01478185	Middle Branch White Clay Creek near West Grove, PA	February 2020 to current year.
USGS 01478120	East Branch White Clay Creek at Avondale, PA	October 2007 to current year.

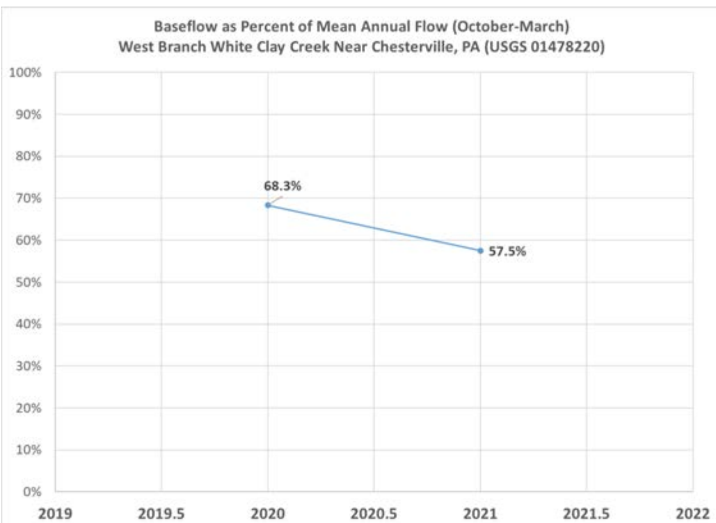
Figure 28 shows the percentage, for each USGS gaging station, of baseflow to annual average flow, for each station’s period of record. The orange line shows the five-year moving average of the values. The charts on the left represent the period from October to March, and the figures on the right represent the period from April to September.






Baseflow as Percent of Mean Annual Flow (October-March)
White Clay Creek at Newark, DE (USGS 01478650)


Baseflow as Percent of Mean Annual Flow (April-September)
White Clay Creek at Newark, DE (USGS 01478650)


Baseflow as Percent of Mean Annual Flow (October-March)
West Branch White Clay Creek Near Chesterville, PA (USGS 01478220)
68.3%
57.5%

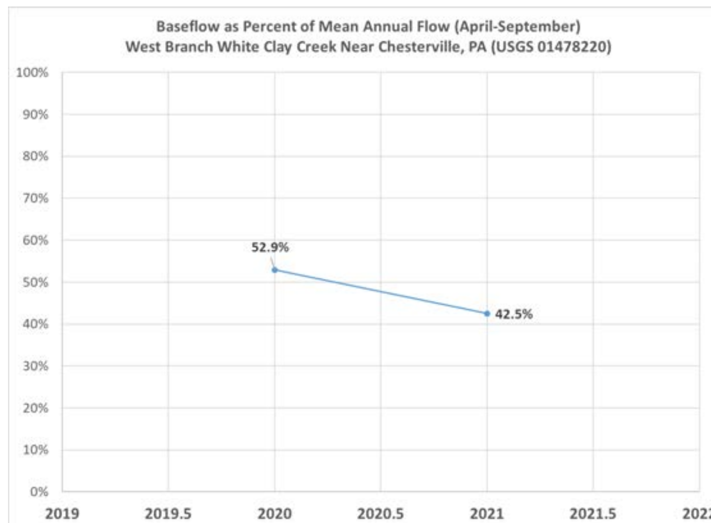

Baseflow as Percent of Mean Annual Flow (April-September)
West Branch White Clay Creek Near Chesterville, PA (USGS 01478220)
52.9%
42.5%

Figure 28. Percentage of Baseflow to Annual Average Flow for Period of Record

To derive a score for each station, the latest five-year period of data was averaged, and the resultant score based on that period. Stations with fewer than five years of data were considered, but the scores are based only on the available data. The number of years used in the calculation is noted in the table of results. Figure 29 presents a map of the gages used in scoring showing the ranking for each. Table 16 summarizes the scores for each of the five USGS gaging stations.

Figure 29. Gaging station and grades based on flow

Table 16. White Clay Creek Scores for Each USGS Gaging Station

Gage	Location (HUC 12)	# Years	Oct.-Mar.	Score	Apr.-Sep.	Score	Grade
USGS 01479000	White Clay Creek Near Newark, DE (Lower White Clay Creek)	5	54%	Outstanding	40%	Good	**A-**
USGS 01478650	White Clay Creek At Newark, DE (Upper White Clay Creek)	5	53%	Outstanding	43%	Good	**A-**
USGS 01478120	East Branch White Clay Creek at Avondale, PA (East Branch White Clay Creek)	5	58%	Outstanding	51%	Excellent	**A**
USGS 01478185	Middle Branch White Clay Creek near West Grove, PA (Middle Branch White Clay Creek)	2	43%	Outstanding	37%	Fair/ Degrading	**B-**
USGS 01478220	West Branch White Clay Creek near Chesterville, PA (West Branch White Clay Creek)	2	63%	Optimum	48%	Good	**A**
	WCC Total						**A**

All stations reviewed had scores of "Outstanding" or better for the October-March period. For the period April-September, only one station (East Branch White Clay Creek at Avondale, PA) had a score of "Excellent," with three ranked as "Good," and only one (Middle Branch White Clay Creek near West Grove, PA) ranked as "Fair/Degrading." Overall, based on this scoring criterion, the White Clay Creek watershed has a grade of "A" ("Excellent") for stream flow.

Peak Flow

Peak flow is defined as the maximum amount of water passing by a point in a stream within a specified time interval. For instance, the maximum flow recorded for a stream in a given calendar year is the annual peak flow for that stream.

Peak flow is related to flooding in cases where that flow exceeds the ability of the stream channel to contain the water, resulting in overbank conditions. Flooding is a natural occurrence that can help recharge groundwater, transport sediment downstream that would otherwise negatively affect stream health, and stimulate the reproductive cycles of certain species of fish and plants. However, flooding can also result in rapid downstream transport of pollutants, cause excess sedimentation, degradation of habitats, and destruction of natural and developed areas. Stream flow is impacted by many factors, including upstream development and impervious cover, increased rainfall intensity and storm frequency, and changes in groundwater levels.

The USGS is the agency most directly responsible for measuring and reporting stream flow and water level (gage height) for thousands of gaging stations across the nation. These stations typically monitor stream flow volume, gage height and water quality parameters.[4] Many have been in continuous operation over many years or decades, and therefore provide an essential historical record that can be used to determine frequency and intensity of flooding.

The USGS maintains three gaging stations along the main stem of the White Clay Creek in the White Clay Creek watershed. The following table (Table 17) summarizes these stations and shows their periods of record.

Table 17. USGS Gaging Stations Along the White Clay Creek main stem, showing period of record

USGS Gaging Station	Period of record
East Branch White Clay Creek at Avondale, PA (USGS 01478120)	2007 – Present
White Clay Creek near Strickersville, PA (USGS 01478245)	1996 – Present
White Clay Creek at Newark, DE (USGS 01478650)	1994 – Present
White Clay Creek near Newark, DE (USGS 01479000)	1932 – Present

Table 18 presents the top 10 peak discharges at the four White Clay Creek gaging stations over each period of record. Based on the data collected at the gaging stations in the White Clay Creek, the highest storm of record for all three gage stations was Hurricane Floyd, in September 1999. In Hurricane Floyd, White Clay at Strickersville, PA peaked at 14,400 cubic feet per second (cfs), White Clay Creek at Newark, DE peaked at 16,800 cfs, and White Clay Creek near Newark, DE peaked at 19,500 cfs. East Branch White Clay Creek at Avondale, PA was not installed at that time, but had a peak flow of 24,602 cfs in August, 2020, due to the effects of Hurricane Isaias.

[4] https://www.usgs.gov/special-topics/water-science-school/science/floods-things-know

Table 18. USGS Gaging Stations in the White Clay Creek watershed, major flow events and equivalent storm return interval

East Branch White Clay Creek at Avondale, PA (USGS 01478120) *			
Date	**Peak Discharge (cfs)**	**Named Storm**	**Flood Frequency**
9/1/2021	2,600	Ida	-
8/7/2020	2,460	Isaias	-
8/28/2011	1,690	Irene	-
4/30/2014	1,310	Unnamed	-
2/25/2016	975	Unnamed	-
11/25/2018	935	Unnamed	-
7/13/2013	880	Unnamed	-
12/9/2009	817	Unnamed	-
7/14/2017	782	Unnamed	-
12/12/2008	671	Unnamed	-
White Clay Creek near Strickersville, PA (USGS 01478245) *			
9/16/1999	14400	Floyd	-
8/28/2011	9910	Irene	-
9/15/2003	9750	Henri	-
9/28/2004	9390	Jeanne	-
8/4/2020	7800	Isaias	
4/30/2014	7700	Unnamed	-
9/2/2021	7170	Ida	
10/1/2010	5250	Unnamed	-
6/28/2013	4600	Unnamed	-
8/13/2018	4520	Unnamed	-

White Clay Creek at Newark, DE (USGS 01478650)			
9/16/1999	16800	Floyd	>10-yr
9/28/2004	12100	Jeanne	10-yr
8/28/2011	10300	Irene	<10-yr
9/15/2003	9980	Henri	<10-yr
5/1/2014	8410	Unnamed	<10-yr
8/4/2020	7890	Isaias	<10-yr
9/2/2021	7590	Ida	<10-yr
1/19/1996	7540	Blizzard of '96	<10-yr
1/28/1994	5370	Unnamed	<10-yr
10/19/1996	4780	Unnamed	<10-yr
White Clay Creek near Newark, DE (USGS 01479000)			
9/16/1999	19500	Floyd	>100-yr
8/28/2011	17000	Irene	>100-yr
9/29/2004	15000	Jeanne	100-yr
5/1/2014	14700	Unnamed	>50-yr
9/15/2003	13900	Henri	>50-yr
8/4/2020	12100	Isaias	>25-yr
7/5/1989	11600	4th of July	>25-yr
1/19/1996	9150	Blizzard of '96	>10-yr
6/22/1972	9080	Unnamed	>10-yr
9/2/2021	8530	Ida	>10-yr

*USGS does not provide flood frequency information for this station.

For White Clay Creek near Newark (USGS 01479000), the first peak flow of record (since at least 1932) greater than 10,000 cfs was recorded in 1989 (11,600 cfs). Since then, there have been six peak flows that exceeded that number: 19,500 cfs in 1999 (Hurricane Floyd), 13,900 cfs in

2003 (Hurricane Henri), 15,000 cfs in 2004 (Hurricane Jeanne), 17,000 cfs in 2011 (Hurricane Irene), 14,700 cfs in 2014 (Unnamed Storm), and 12,100 cfs in 2020 (Hurricane Isaias).

For reference, at this station the National Weather Service (NWS) defines a minor flood event based on a gage height (water level) of 13 feet. This translates to approximately 3,800 cfs of flow. Similarly, USGS defines a two-year storm (event with a 50% annual recurrence interval) as a flow of 3,820 cfs at this station (Ries and Dillow, 2006). Any flow above this value (3,800 cfs at the White Clay Creek near Newark gaging station) is therefore designated a flood stage, based on USGS, NWS and FEMA definitions. A 50-year storm (event with a 2% annual recurrence interval) and a 100-year storm (1% annual recurrence interval) have associated flows at this station of approximately 12,600 cfs and 15,000 cfs, respectively.

Stream flow is directly related to precipitation. While increases in impervious cover that coincide with urbanization can increase runoff and the amount of water in streams during a rain event, more intense and longer-duration rainfall is the principal drive of stream flow. For the 20-year period 2002-2022, the annual precipitation measured at the Wilmington Airport in Delaware averaged 47 inches, from a low of 36.29 in 2012 to 61.37 in 2018. This is a slight increase from an average of 44 inches per year for the 20-year period 1994-2014, as reported in the White Clay Creek State of the Watershed Report 2016 for the same location. Figure 30 shows the average annual precipitation for the period from 1948 to 2021. Note that there is a slight increase in average annual rainfall over this 74-year period.

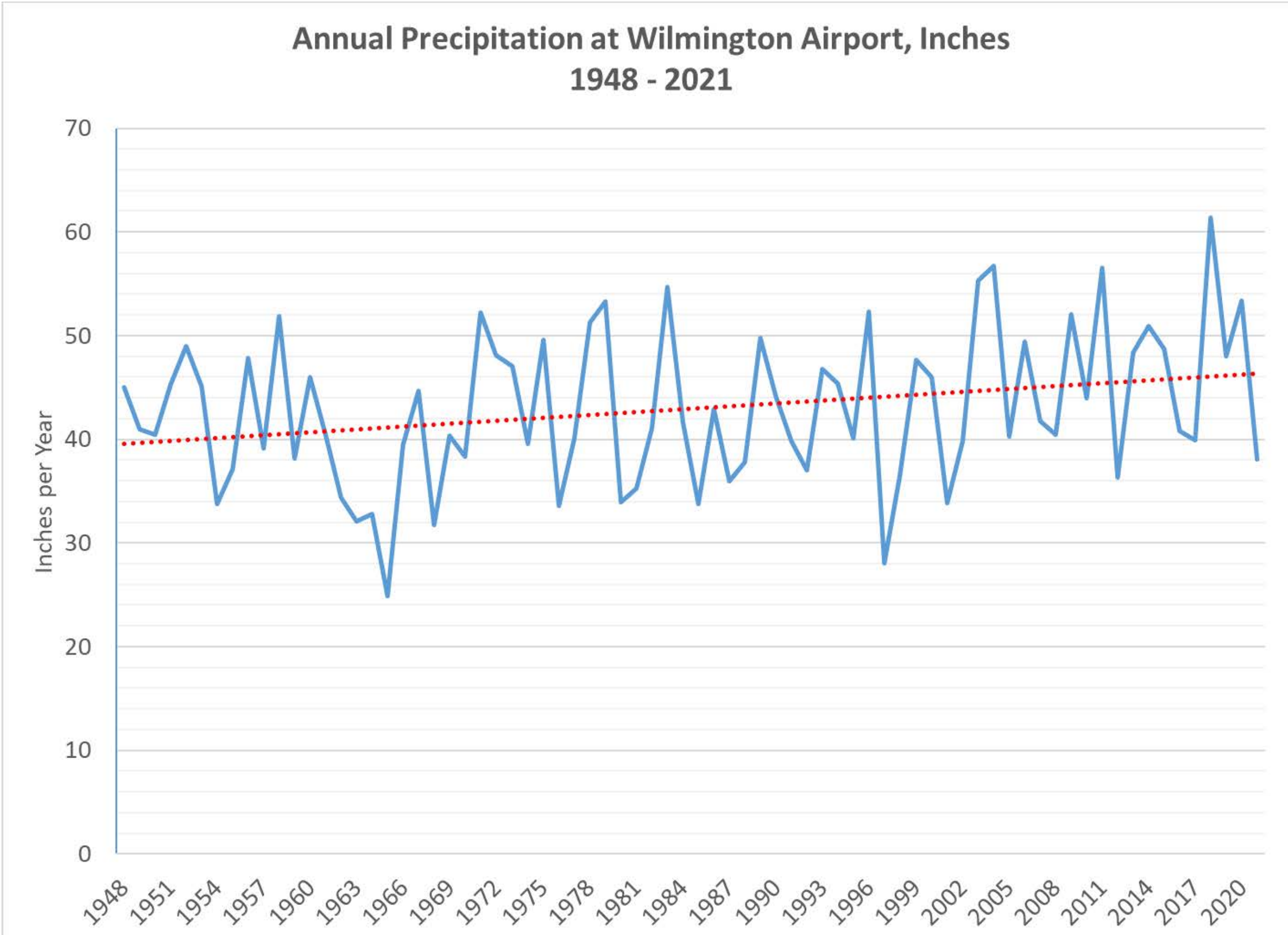


Figure 30. Annual precipitation at Wilmington Airport, 1948 - 2021

The White Clay Creek near Newark (USGS 01479000) gaging station was selected for analysis based on its location along the main stem and long period of record (1932-2021). Annual peak flow (single largest stream flow recorded during one calendar year) was graphed for all data dating back to 1932, as shown in Figure 31.

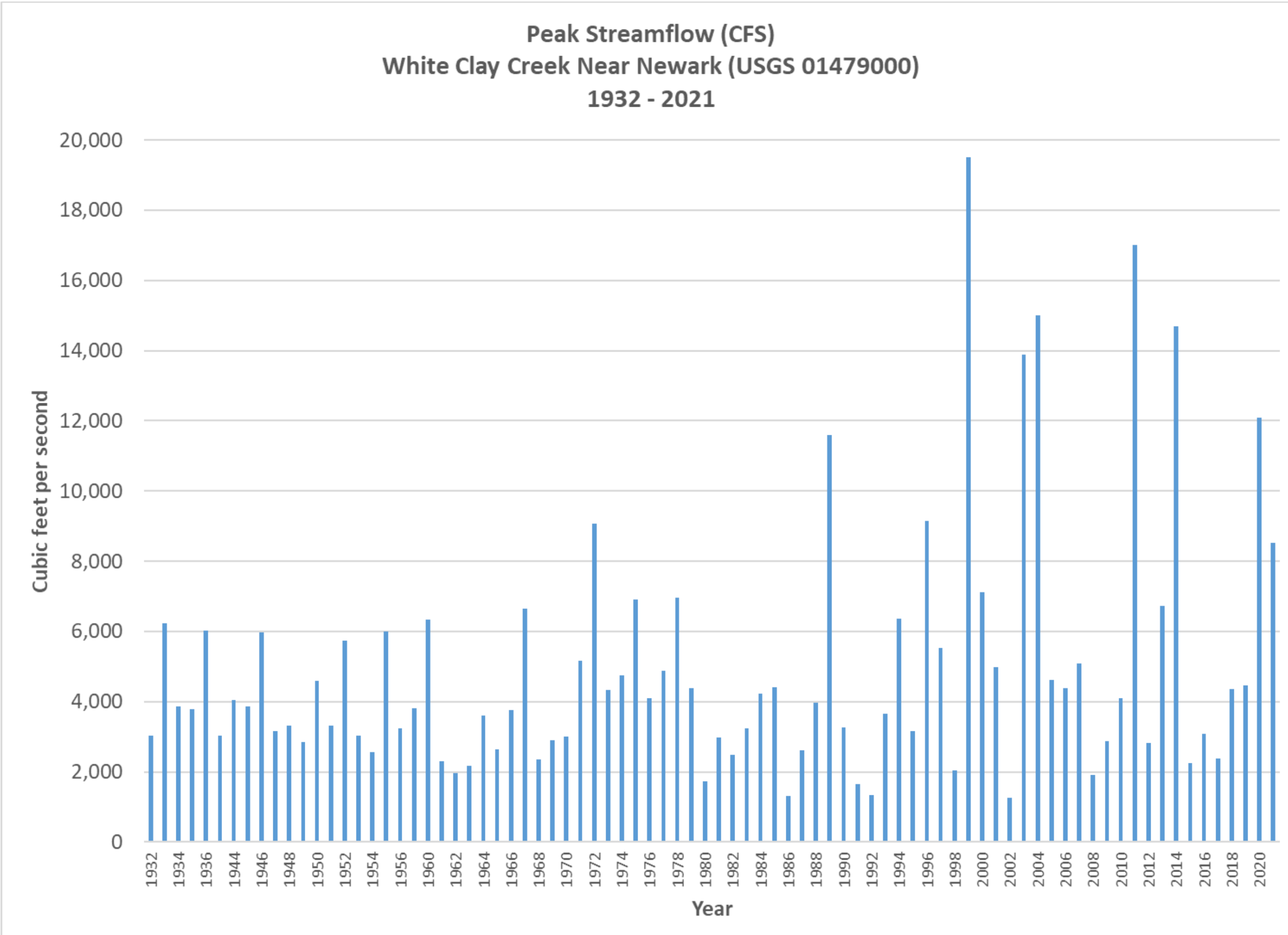


Figure 31. Peak stream flow (CFS), White Clay Creek Near Newark, 1932 - 2021

Figure 32 shows the anomaly, in cubic feet per second, for peak annual stream flow compared to the average across the period 1932 to 2021. The linear trend line for the anomaly shows an increase in flows over the period, and a distinctly higher incidence of much higher than average peak flows. The average peak flow did not exceed the average for the period by more than 5000 cfs until 1990, after which that level was exceeded seven times through 2021.

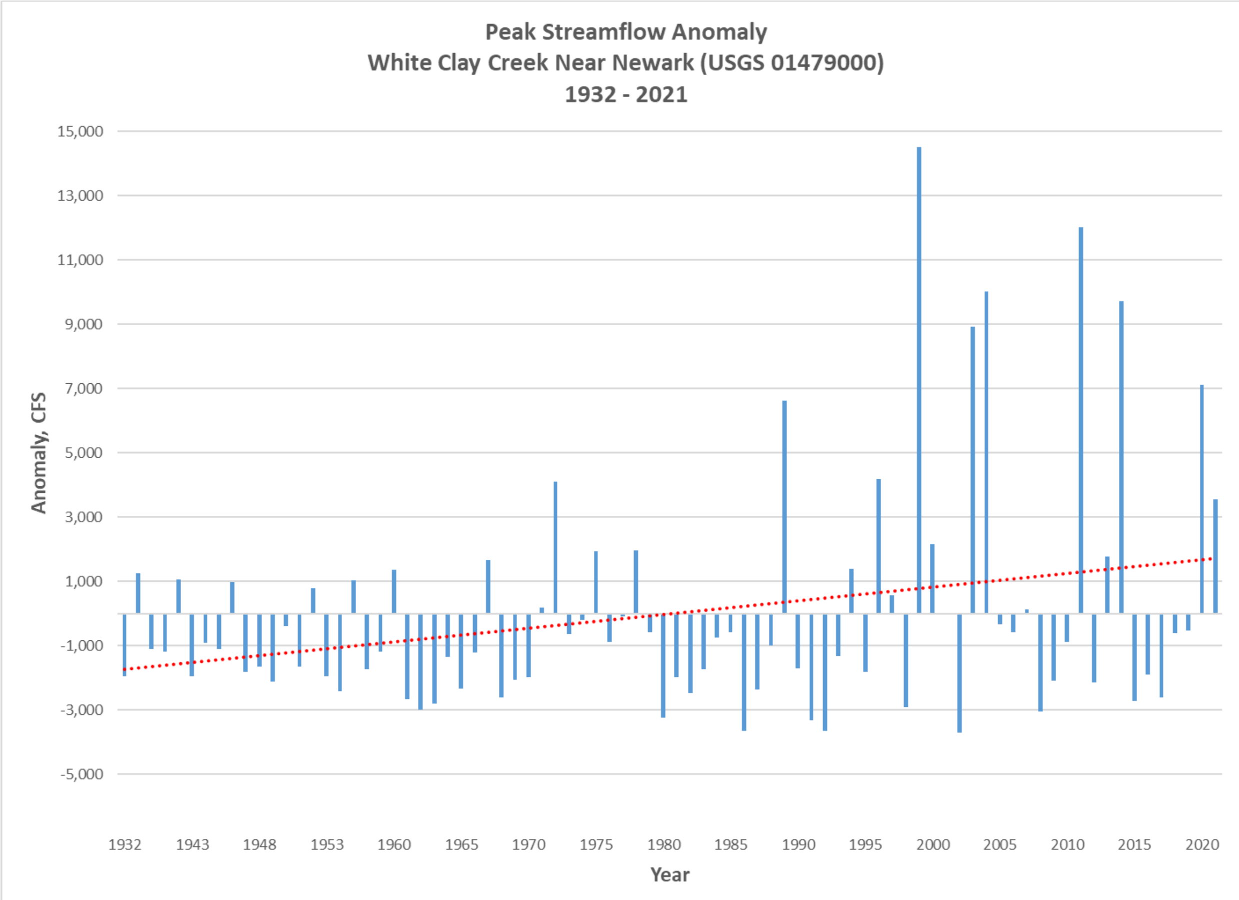


Figure 32. Peak stream flow anomaly, White Clay Creek Near Newark, 1932 - 2021

The Mann-Kendall test for monotonic trend was run on the five-year central moving average of the peak flow anomaly. Based on this measure, the data do indicate a significant positive trend upward in the data ($\tau = 0.304$, p-value = 8.4758e-05). Figure 33 shows the five-year moving average and linear trend line.

The distribution and frequency of high flow events as represented by annual peak maximum flows shows a distinct increase in the past 30 years. This trend has an impact on the overall health of the watershed and can result in more severe effects of significant flooding events across the period.

To arrive at a peak flow grade, the range for tau values of -1 (monotonic negative trend) to +1 (monotonic positive trend) was re-scaled to 0-100 by subtracting the tau value from 1, dividing by 2 and multiplying by 100. The tau of 0.304 leads to a rescaled score of 34.8, or an overall grade of "D+" for peak flow in the Lower Main Stem subwatershed, where the gage is located. This grade is also assigned to the White Clay Creek as a whole given an assumption of similar climatic conditions throughout the watershed. No separate grade is assigned to the other subwatersheds. Based on these peak flow trends, flooding in the White Clay Creek should be considered an issue of increasing concern.

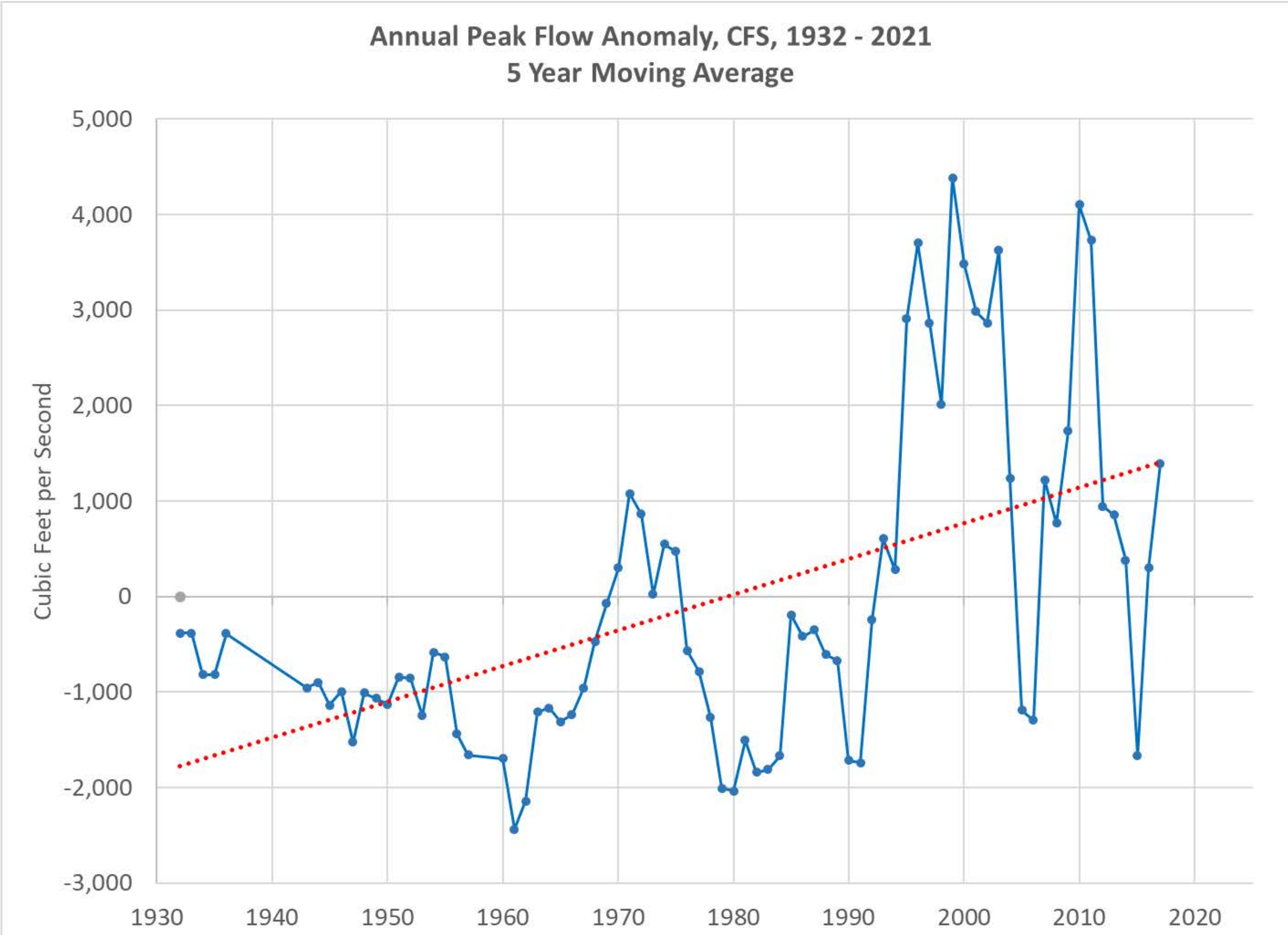


Figure 33. Annual peak flow anomaly, 1932 - 2021, 5-year moving average

Groundwater Levels

Groundwater levels are an indicator of long-term availability of both drinking water and of stream baseflows. While stream baseflows may increase and decrease very quickly, groundwater responds much more slowly, and is a better indicator of overall water availability than surface flow.

There are several monitoring wells that track groundwater levels (in feet below surface elevation) within, or in close proximity to, the White Clay Creek watershed. Maps in Figure 34 show the USGS monitoring wells in Chester County, PA and DGS wells in northern Delaware. The observation well (CH-10) used for long-term trends is circled in red (https://www.chesco.org/3189/Chester-County-Observation-Well-Network and https://data.dgs.udel.edu/dgir/draft/). In Pennsylvania the Chester County Water Resources

Authority (CCWRA) maintains the network of observation wells in collaboration with the USGS. The Delaware Geological Survey maintains groundwater observation wells in Delaware.

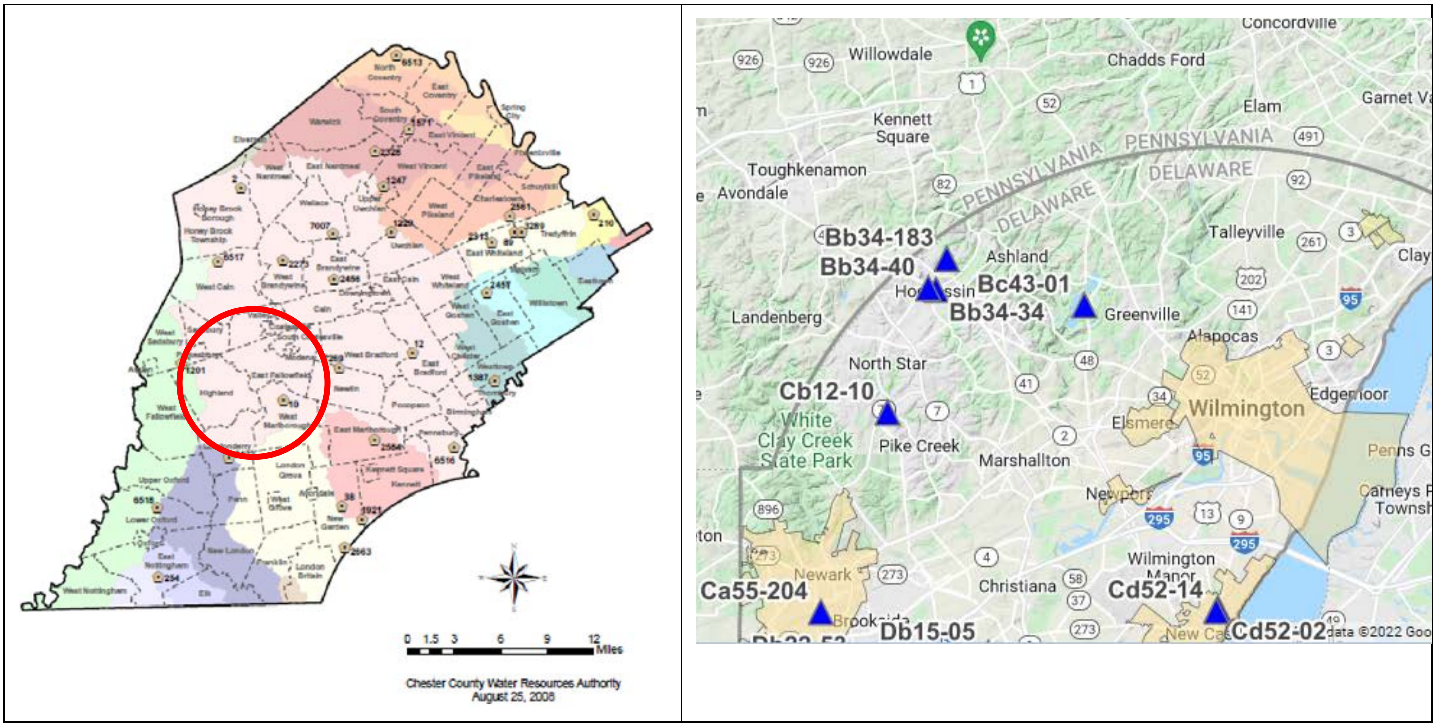


Figure 34. USGS Monitoring Wells in Chester County, PA (left) and DGS Wells in Northern Delaware (right)

To assess the groundwater conditions within the White Clay Creek watershed, Chester County Observation Well (Chester County well CH 10, or USGS 395450075485401[5]), a long-term groundwater monitoring station maintained by the USGS, was selected to represent the watershed-wide groundwater condition (red circle on map in Figure 34). While this well does not lie in the boundary of the White Clay Creek watershed, it is approximately 1.3 miles to the north. Well CH-10 is a long-term well, with over 50 years of continuous monitoring data measuring the water table level (unconfined aquifer). Other wells in the watershed were not considered, as they have much shorter periods of observation, or discontinuous data records. For the period of record (February 15, 1966 to present) well CH-10 has over 20,000 observations.

The long-term trend in water table levels was graphed based on minimum, maximum and quartile values for the summertime (June-September) daily average water levels in the well, see Table 19. A second-order polynomial trend line was generated to approximate the data distribution for the period of record (see Figure 35). Current conditions were assessed by

[5] https://nwis.waterdata.usgs.gov/nwis/uv?site_no=395450075485401

comparing the trend line with the median summer water table depth for the latest five-year period (2017-2021) to derive a score based on current (i.e., latest five-year period) conditions.

Table 19. Long-term Trend in Water Table Levels

Historic groundwater level statistics (1966-2021)	GW Level (ft. below surface)					
	June	July	August	September	**June-Sept**	Score
Highest Monthly Reading	8.68	8.35	9.41	8.61	**8.35**	100
Upper Quartile	11.72	12.06	12.47	12.59	**12.12**	80
Median	12.54	13.26	13.65	13.99	**13.32**	60
Lower Quartile	13.59	13.98	14.33	14.67	**14.25**	20
Lowest Monthly Reading	15.48	16.02	16.39	16.54	**16.54**	1

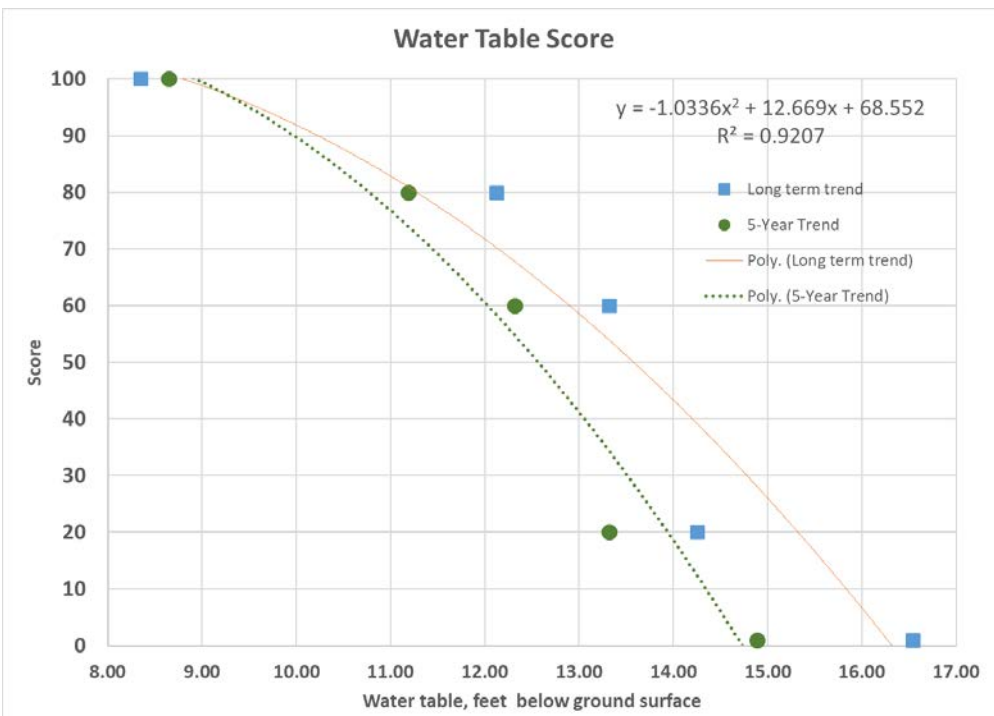


Figure 35. Minimum, Maximum and Quartile Values for the Latest 5-year Period

The graph in Figure 35 also shows the minimum, maximum and quartile values for the latest five-year period, with a second order polynomial trend line shown (the formula is not displayed). The curves indicate that in recent years, water table levels at well CH-10 have shown an increase in the minimum (deepest, lowest water table) level, with little change in the maximum (shallowest value, highest water table). The five-year median groundwater level for Chester County well CH-10 was 12.32 feet below surface, while the median for the period of record was 13.32 feet below surface. Table 20 shows the median water table for the latest assessed five-year period, and the resultant score, as measured against the long-term median. The latest data translate to an indicator score of 67.8, as measured against the trend line derived from the long-term data. This translates to a watershed-wide grade of "B" for groundwater levels.

Table 20. Median Water Table for the Latest Assessed 5-Year Period

Five-Year (2017-2021)	June-Sept.
Median	**12.32**
Score	**67.8**
Grade	**B**

2.3 Category 2: Habitat

The Habitat category indicators are important to consider when determining the status of the White Clay Creek's watershed health. The following table (Table 21) summarizes the grading for the five Habitat category indicators for the White Clay Creek watershed and subwatersheds:

Table 21. White Clay Creek, overall grades for Habitat

	Lower Main Stem	Upper Main Stem	East Branch	Middle Branch	West Branch	Watershed
Habitat	**C+**	**B-**	**C+**	**B-**	**B**	**C+**
Impervious Cover	C+	B	A	A	A	B+
Aquatic Connectivity, Dams	A	C+	C	A+	A+	B
Aquatic Connectivity, Culverts	C	D-	C	D+	D	C-
Terrestrial Connectivity, Forest Buffer	C	A-	C+	B-	B	B-
Terrestrial Connectivity, Forest Fragmentation	D-	A-	D+	D-	C+	D+

Impervious Cover

Impervious cover is any surface on the ground that inhibits the infiltration of rainwater that falls on the ground or runs overland, before it enters a waterway or stormwater conveyance. Typical examples of impervious cover include roads, driveways, building rooftops and any areas of the ground that are impermeable to water. Imperviousness in the landscape causes water that would otherwise infiltrate in place to move across the landscape. Excessive imperviousness can lead to flooding in streams and roadways, increased transport of pollution into waterways, and a reduction in groundwater levels and stream baseflows.

The amount of imperviousness has an impact on stream and overall watershed health. Greater amounts of impervious cover, as occurs in more highly developed areas, can be an indicator of stress and impairment in a watershed. Watersheds with lower percentages of imperviousness generally lead to healthier aquatic habitats and cleaner and more available water, in streams and in the ground. The Center for Watershed Protection (CWP) has identified certain thresholds for imperviousness (as a percentage) which can indicate the health of a watershed or drainage area. Figure 36 shows the curve developed by CWP for typical watersheds and the associated level of impact based on percentage of impervious cover (Center for Watershed Protection, 2000). While local conditions and other factors influence how impacted a watershed is by development and the associated impervious surfaces, water quality and watershed health are worse in highly impervious areas, as the natural processes of infiltration, filtering and volume attenuation are hindered.

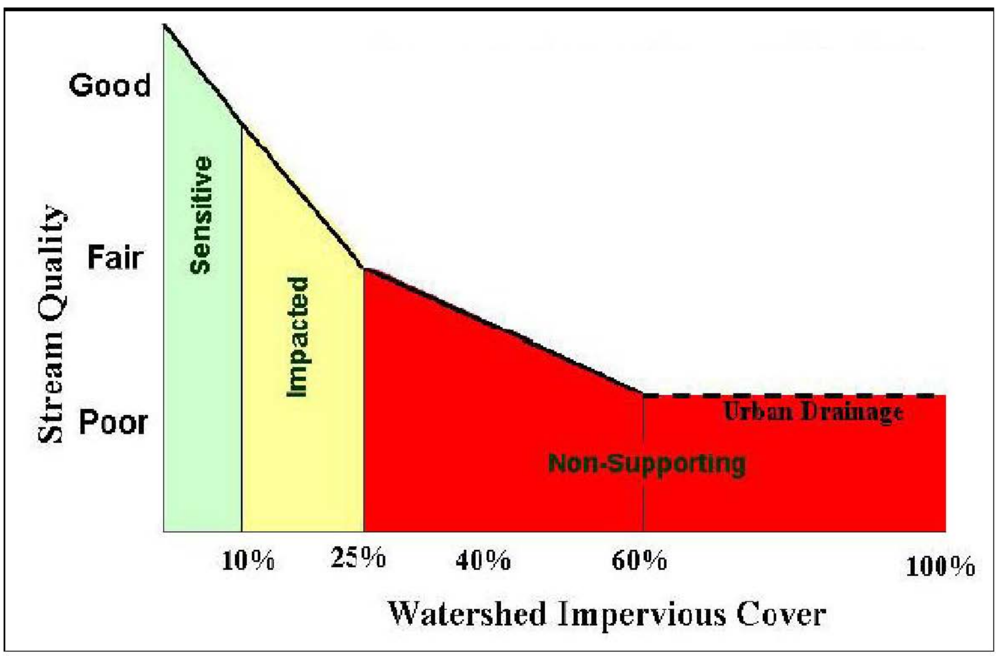


Figure 36. Impervious Cover Model

In this model, watersheds are considered “Impacted” if the percentage of imperviousness is above 10% of the total watershed area. Above 25% imperviousness, the watershed is considered “Non-supporting” for aquatic life (i.e., very negatively impacted).

The University of Massachusetts, Amherst has developed a Conservation Assessment and Prioritization System (CAPS) which characterizes landscapes based on a wide array of ecological features, including impervious cover. The OARS group, a local Massachusetts watershed nonprofit organization, has utilized the CAPS data and procedures to help assess the overall quality of their watersheds to produce a "report card" (including the Assabet, Sudbury and Concord Rivers). To assess the effects of imperviousness, CAPS has defined thresholds for watershed impacts based on local conditions. The OARS report card incorporated these thresholds and assessment methods, which are used here to grade imperviousness in the White Clay Creek watershed. Based on a 2011 study by the USGS, thresholds were identified for use in the OARS report card (Armstrong, D.S., T.A. Richards, and S.B. Levin, 2011. "Factors Influencing Riverine Fish Assemblages in Massachusetts." U.S. Geological Survey Scientific Investigations Report 2011-5193, 59 p.). Table 22 (adapted from OARS "Sudbury, Assabet and Concord River Report Card—Grade Calculation, Methods Report" 2019) shows the thresholds and related watershed score used in the OARS grading based on imperviousness. Figure 37 presents the grading curve based on the impervious metric.

Table 22. Threshold and Related Watershed Score (USGS)

USGS Description	% Impervious Metric	Score
Unaltered	0	100
Near-natural (<10%)	0.1	80
Least Altered (10%-20%)	0.2	60
Altered (20%-30%)	0.3	40
Highly Altered (30%-40%)	0.4	20
Extensively Altered (>50%)	0.5	0

Figure 37. Impervious Scoring

To assess the imperviousness in the White Clay Creek, the USGS National Land Cover Dataset Imperviousness layers were used (Dewitz, J. and U.S. Geological Survey, 2021). Using the data values expressed as a percentage of imperviousness within each 30-meter square ground pixel, the total area (in square meters) for each pixel was calculated. The total impervious cover area was then derived for each subwatershed (HUC 12) in the White Clay Creek watershed, for each year of analysis (2001, 2006, 2011, 2016 and 2019).

Figure 38 shows the imperviousness in the White Clay Creek watershed in 2019, as represented by the USGS NLCD Impervious Cover layer. Note the higher levels of imperviousness in the

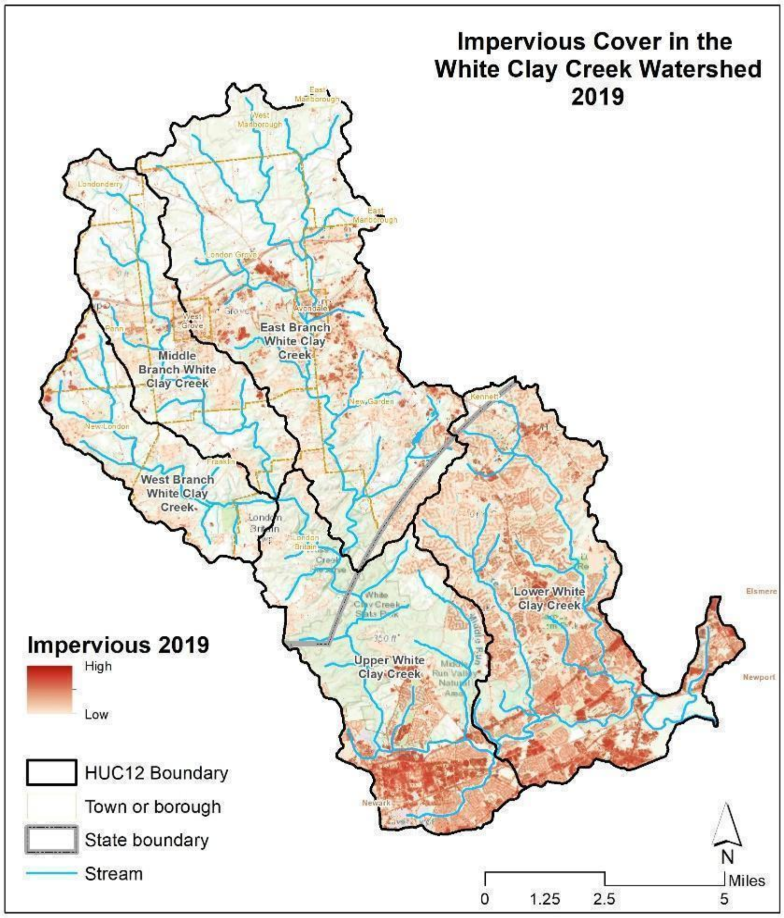


Figure 38. Imperviousness in the White Clay Creek watershed, 2019

Lower White Clay Creek (Mill Creek and Pike Creek watersheds), the City of Newark, and the central portion of the East Branch White Clay Creek, near Avondale, PA.

The maps in Figure 39 show the percentage of imperviousness for each of the five subwatersheds of the White Clay Creek watershed and the change in imperviousness between 2001 and 2019. While the percentage of imperviousness is lowest (3.9%) in the West Branch White Clay Creek and highest in the Lower White Clay Creek (22.6%), the change over the study period follows the opposite trend, with the highest increase (as a percentage of the 2001 impervious levels) in West Branch White Clay Creek (+26.6%) and lowest in the Lower White Clay Creek (+4.8%). The trend is not surprising, since areas with very low imperviousness can experience a large percentage increase while retaining a low overall percentage in terms of total watershed area. Nevertheless, increasing levels of imperviousness in areas with very low imperviousness can indicate that they will become an area of concern. Table 23 presents a summary of the total acreage and percentage, for each year of analysis.

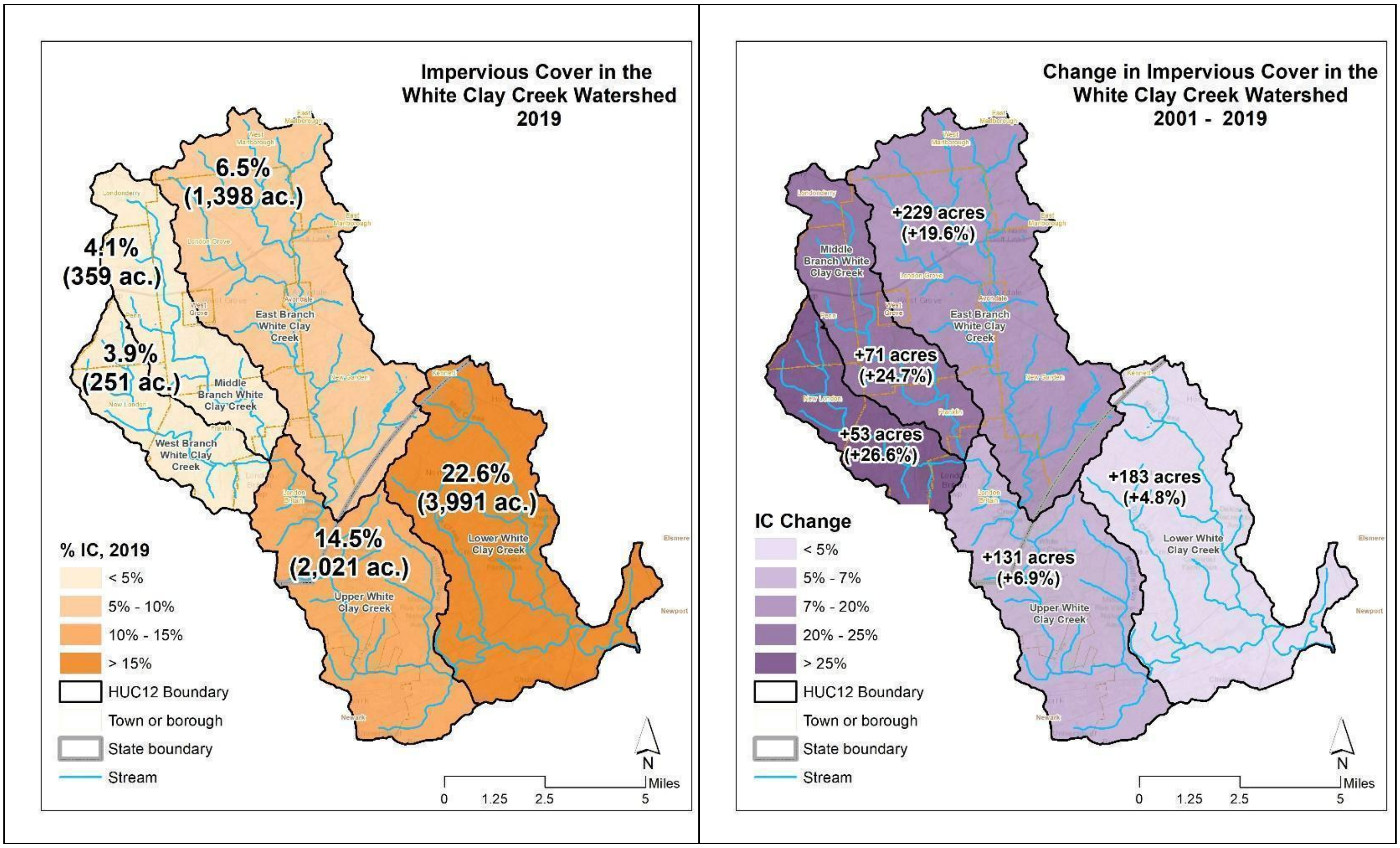


Figure 39. Percent Impervious in the White Clay Creek subwatersheds

Table 23. Total Acreage and Percentage of Impervious Cover in Each subwatershed

		2001		2006		2011		2016		2019	
HUC 12 Watershed	**Total Acres**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**	**Acres**	**%**
Lower White Clay Creek	17,652	3,808	21.6%	3,874	21.9%	3,925	22.2%	3,970	22.5%	3,991	22.6%
Upper White Clay Creek	13,972	1,890	13.5%	1,946	13.9%	1,992	14.3%	2,011	14.4%	2,021	14.5%
East Branch White Clay Creek	21,461	1,169	5.4%	1,210	5.6%	1,328	6.2%	1,378	6.4%	1,398	6.5%
Middle Branch White Clay Creek	8,723	288	3.3%	320	3.7%	338	3.9%	353	4.0%	359	4.1%
West Branch White Clay Creek	6,356	198	3.1%	216	3.4%	234	3.7%	247	3.9%	251	3.9%
White Clay Creek Total	**68,164**	**7,353**	**10.8%**	**7,566**	**11.1%**	**7,816**	**11.5%**	**7,958**	**11.7%**	**8,020**	**11.8%**

Figure 40 shows the percentage imperviousness for each HUC 12 subwatershed in the White Clay Creek watershed, by each year of analysis. Note that based on the USGS thresholds (see Table 22), only the Lower White Clay Creek is considered "Altered" (over 20% impervious), with the Upper White Clay Creek (along the main stem, comprising the City of Newark) is "Least Altered" (between 10% and 20% impervious). The upstream subwatersheds are all under 10% total imperviousness, and thus classified as "Near Natural." Note that over the nearly 20-year period of analysis, while all of the HUC 12 subwatersheds saw an increase in impervious cover, none crossed an imperviousness threshold to change classification.

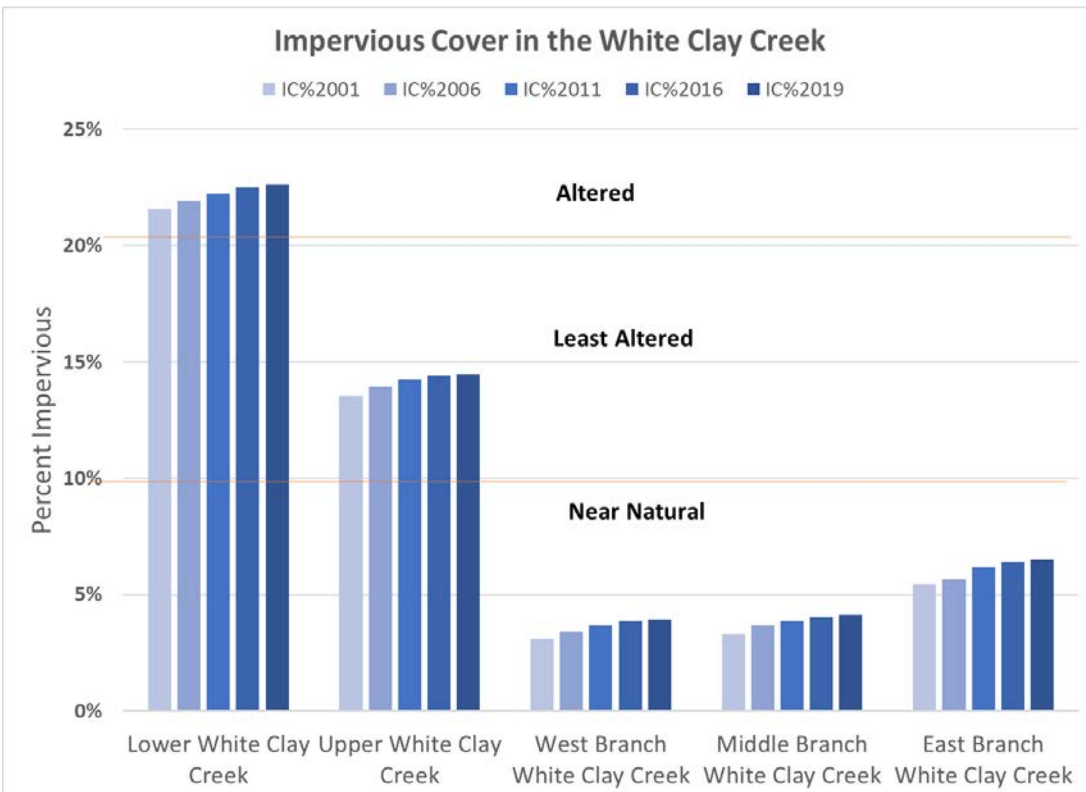


Figure 40. Percent Imperviousness in Each Subwatershed

Overall, the White Clay Creek watershed is highly variable in terms of imperviousness. The upper reaches are highly protected from development, with considerable amounts of public and private open space. The lower portions, however, are highly developed, with a high percentage of imperviousness. The following table (Table 24) summarizes the imperviousness scoring and grading for each HUC 12 subwatershed and the White Clay Creek as a whole, based on weighted averaging. Overall, the White Clay Creek watersheds receive a "C+" for imperviousness.

Table 24. Imperviousness Scoring and Grading for Each Subwatershed in the White Clay Creek

HU 12 NAME	Percent of WCC	IC Metric	Score	Weighted	Grade
Lower White Clay Creek	25.9%	22.6%	55	14	C+
Upper White Clay Creek	20.5%	14.5%	71	15	B
East Branch White Clay Creek	31.5%	6.5%	87	27	A-
Middle Branch White Clay Creek	12.8%	4.1%	92	12	A
West Branch White Clay Creek	9.3%	3.9%	92	9	A
WCC TOTAL	100.0%	11.8%	76	68	B+

Terrestrial Connectivity – Riparian Buffers

Forested riparian buffers perform several important functions to foster the health of a watershed. A forested corridor along streams and other water bodies can help filter pollutants such as sediment and nutrients, can cool the stream, providing healthy aquatic habitat, and provide terrestrial habitat for fauna that live in or pass through the buffers. The extent of forestation surrounding streams, rivers and waterbodies constitutes a measure of the overall expected health of those bodies and of the overall health of the watershed.

White Clay Creek, though comprising largely suburbanized landscapes, has many areas with robust forested riparian corridors, particularly in the White Clay Creek State Park (in Delaware) and Preserve (in Pennsylvania). In general, the wider the forested buffer along waterways the more benefit to the water resource, the aquatic and terrestrial fauna, and the overall health of the watershed. However, research has shown that different widths are required for various ecosystem services. For instance, filtering of nutrients requires less of a buffer than terrestrial wildlife support. Table 25 shows a range of recommended buffer widths for various ecosystem functions based on a review of the literature (Hawes and Smith, 2005, Fischer and Fischenich, 2000).

Table 25. Recommended Buffer Widths

Function		Recommended Width
Water Quality Protection	Buffers, especially dense grassy or herbaceous buffers on gradual slopes, intercept overland runoff, trap sediments, remove pollutants, and promote ground water recharge. For low to moderate slopes, most filtering occurs within the first 10 m, but greater widths are necessary for steeper slopes, buffers comprised of mainly shrubs and trees, where soils have low permeability, or where NPS loads are particularly high.	5 to 30 m
Stream Stabilization	Buffers, particularly diverse stands of shrubs and trees, provide food and shelter for a wide variety of riparian and aquatic wildlife	10 to 20 m
Riparian Habitat	Riparian vegetation moderates soil moisture conditions in stream banks, and roots provide tensile strength to the soil matrix, enhancing bank stability. Good erosion control may only require that the width of the bank be protected, unless there is active bank erosion, which will require a wider buffer. Excessive bank erosion may require additional bioengineering techniques.	30 to 500 m +
Flood Attenuation	Riparian buffers promote floodplain storage due to backwater effects, they intercept overland flow and increase travel time, resulting in reduced flood peaks.	20 to 150 m
Detrital Input	Leaves, twigs and branches that fall from riparian forest canopies into the stream are an important source of nutrients and habitat.	3 to 10 m

(Hawes and Smith, 2005)

Note that while effective protection of water quality requires buffers of up to 30 meters in width, buffers to support healthy riparian habitat for upland fauna should be much wider, even up to several hundred meters. For the purposes of this study a buffer width of 100 meters was selected to incorporate multiple functions, in particular terrestrial connectivity and habitat for upland fauna.

The metric used to assess and rank the amount of forested riparian buffer is the percentage of forest cover, relative to any other land cover type, within 100 meters from each waterbody (stream and pond) within the White Clay Creek watershed. A buffer of 100 meters from each stream and waterbody was created, based on the USGS's National Hydrography Dataset (NHD), which inventories all streams, rivers, ponds and other waterbodies of the United States (https://www.usgs.gov/national-hydrography/national-hydrography-dataset). The buffer included the areas within 100 meters of the edges of all rivers and lakes, or from the centerline of streams depicted in the NHD as a single line. Forested land was derived from the USGS National Land Cover Dataset (NLCD) from 2019. All land classified as "Deciduous Forest" (land cover code 41), “Evergreen Forest” (42) or “Mixed Forest” (43) was included as forest in the analysis.

A ranking system was developed through a comparison of the subwatersheds (HUC 12) of the White Clay Creek, relative to all HUC 12s within the Piedmont watersheds of PA within the Delaware Estuary, excluding the urbanized Philadelphia area. Figure 41 shows the extent of those watersheds, with the percentage of the 100-meter buffer that is forested indicated by color. Based on the amount of forested land within the stream buffers of the Estuary portions of Delaware and Pennsylvania (excluding urban Philadelphia), quartiles were generated, and a linear trend line fit to the plot (Figure 42). Table 26 shows the percentage riparian forest cover values (percent) and the corresponding ranking as a score on a scale of 1-100. Using this matrix, a grade can then be assigned to each HUC 12 watershed.

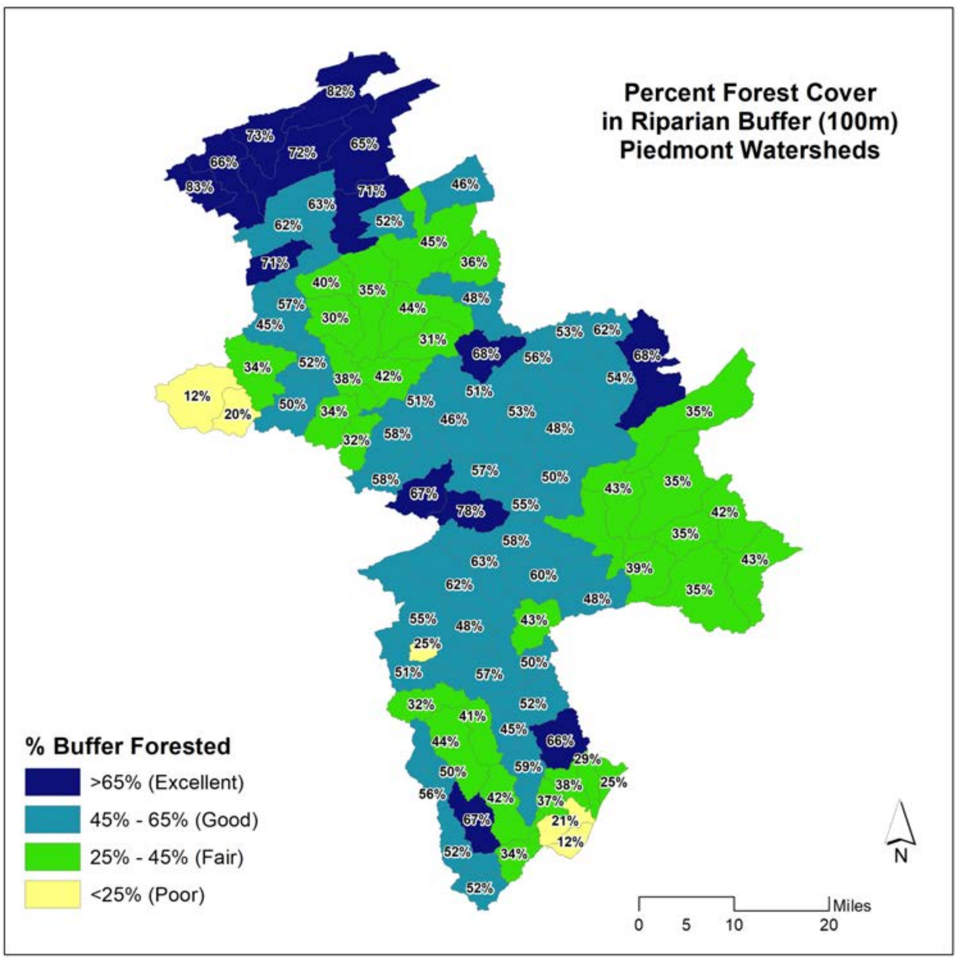


Figure 41. Percent Forest Cover in Riparian Buffer in the Piedmont Watersheds

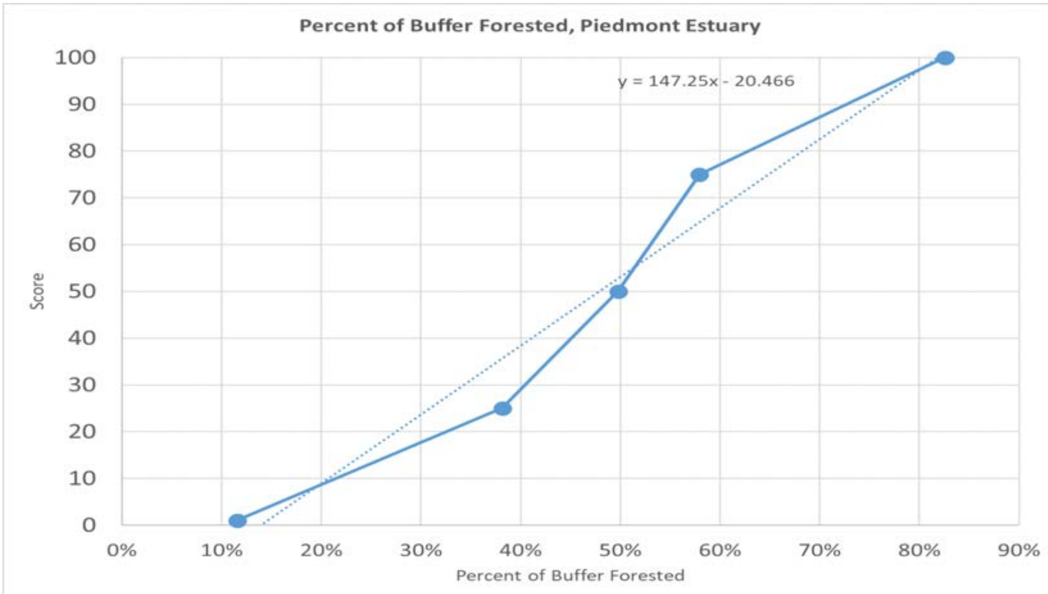


Figure 42. Percent of Buffer Forested in the Piedmont Estuary

Table 26. Forest Riparian Buffer Metrics in the Delaware Estuary

Forest Riparian Buffer Metrics, Delaware Estuary	% Forested	Score
Highest Value	83%	100
Upper Quartile	58%	75
Median	50%	50
Lower Quartile	38%	25
Lowest Value	12%	1

To assess the amount of forested buffer within the White Clay Creek subwatersheds, the trend line for the Piedmont portion of the Estuary was used to generate a score for each of the five HUC 12 watersheds in the White Clay Creek Watershed, which are then ranked against all watersheds in the region. Figure 43 shows the riparian buffer areas within the White Clay Creek watershed (light green), and the portion of the buffer that is forested (dark green). Figure 44 shows the percentage of the buffer in each HUC 12 watershed that is forested.

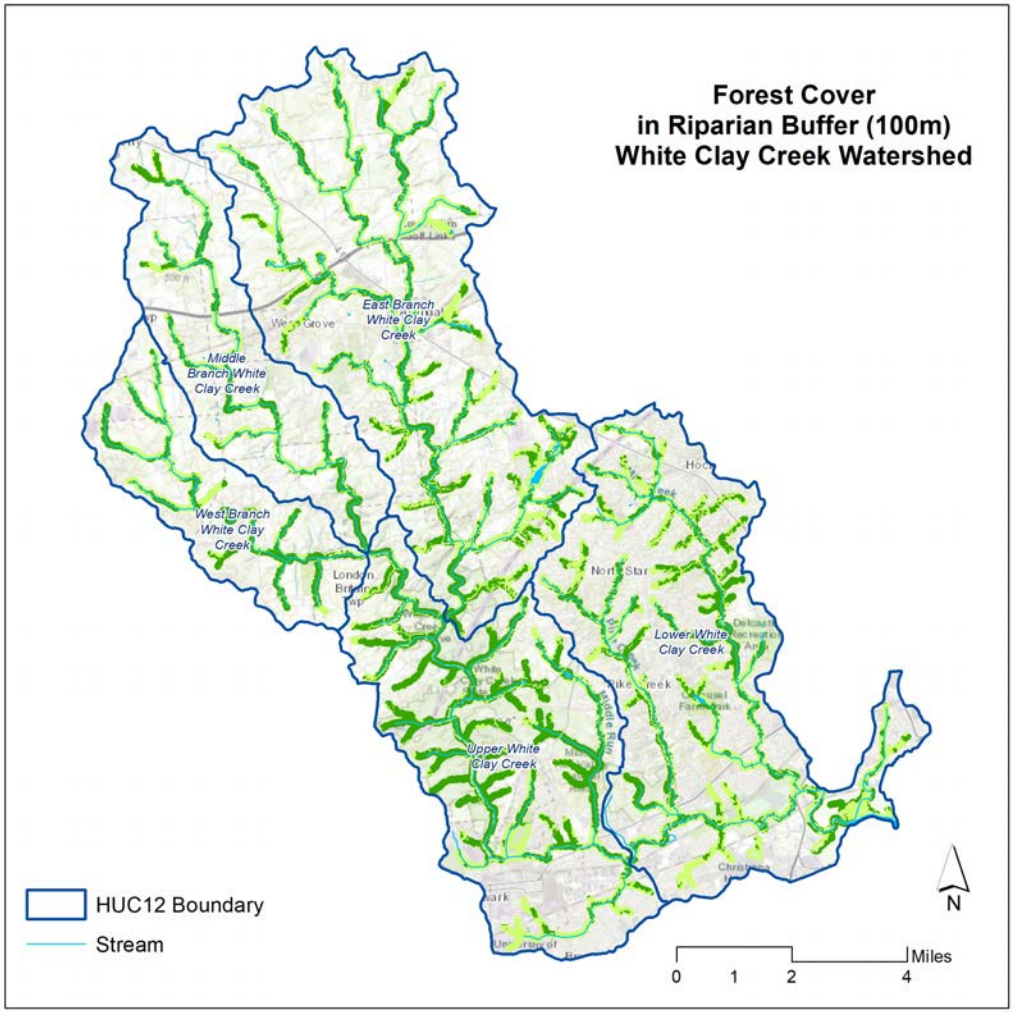


Figure 43. Forest Cover in the Riparian Buffer in the White Clay Creek Watershed

The highest percentage of stream buffer that is forested is in the Upper White Clay Creek (main stem), with 67% of the buffer in forest cover. The Lower White Clay and the East Branch have the lowest percentage of forested buffer cover, and the Middle and East Branches have forest cover in the riparian buffer in the “Good” range (45%-65%). Using an area weighted average of all the HUC 12 watersheds, the White Clay Creek watershed has a score of 55, or a total forested buffer of 51%.

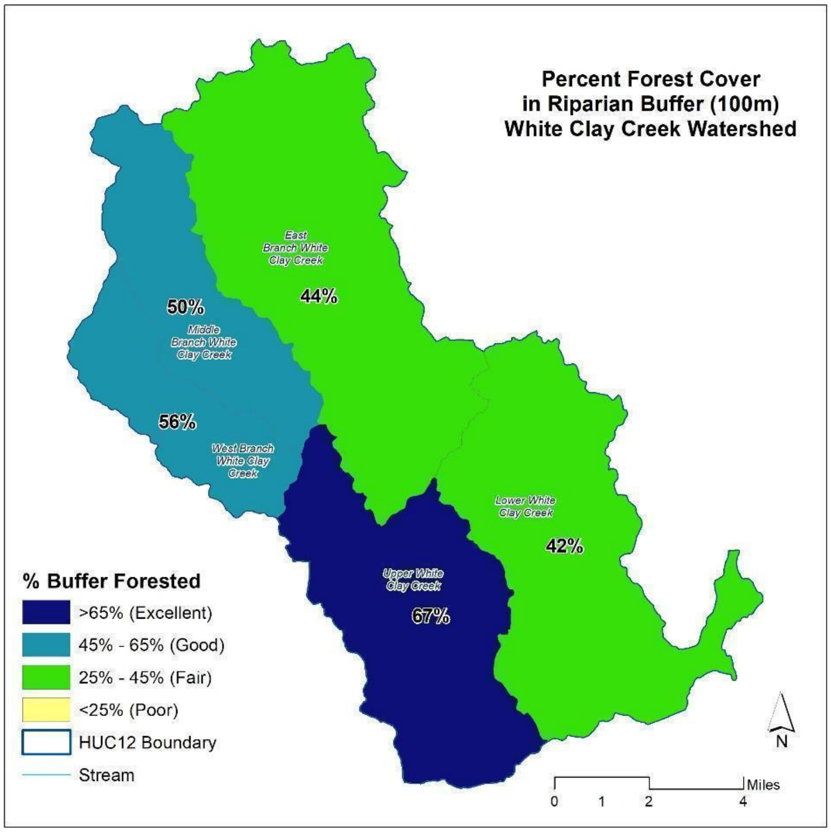


Figure 44. Percent Forest Cover in Riparian Buffer in the White Clay Creek Watershed

Table 27 summarizes the percentage of stream buffers that are forested within each of the five HUC 12 watersheds in White Clay Creek, and shows the scores and grades for each subwatershed and the White Clay Creek as a whole.

Table 27. Percent Forested Stream Buffers in the White Clay Creek Watershed, with watershed grade

Name	Total Buffer Area	Forest Buffer	% Forested in Buffer	SCORE	Grade
Lower White Clay Creek	4,560	1,921	42%	43	C-
Upper White Clay Creek	3,959	2,670	67%	79	A-
East Branch White Clay Creek	4,861	2,140	44%	46	C
Middle Branch White Clay Creek	1,414	711	50%	55	C+
West Branch White Clay Creek	1,308	737	56%	63	B-
Total	**16,101**	**8,180**	**51%**	**55**	**C+**

Terrestrial Connectivity – Forest Fragmentation

An important factor in determining the health of a watershed in terms of its ability to provide high-quality habitat for a wide variety of fauna is the degree to which natural land cover types are connected and cohesive. Many organisms require a certain minimum area of natural land (e.g., forest and wetlands) to survive and thrive. The ability to move about the landscape is often also very dependent on connection among natural areas (or "patches" of natural landscapes). In order to quantify these landscape features, many computer-based tools and techniques have been developed. One of the most popular of these methods is implemented in the Fragstats software package. Fragstats is a "spatial pattern analysis program for quantifying landscape structure," developed in the mid-1990s by researchers at Oregon State University, in partnership with the U.S. Forest Service (McGarigal 1995). Since then, it has been widely used to characterize natural landscapes based on an organism's ability to navigate through that landscape.

Fragstats can generate a variety of landscape metrics to characterize a habitat's suitability for biota. To determine the relative suitability of the White Clay Creek watersheds the cohesion index was used. Cohesion describes the degree of connectedness in a particular landscape cover type (for instance, a specific habitat type), as well as its shape characteristics (e.g., the relationship between area and perimeter of a given patch). Using a raster representation of a given land cover type, the degree of connectedness and cohesion, and thus suitability for sustaining an organism within a designated geographic, can be determined.

The Fragstats software package requires raster-based input to generate statistics. The 2019 NLCD dataset of land cover for the nation, compiled at a 30-meter pixel resolution, was subset for each of the HUC 12 watersheds in the Pennsylvania and Delaware portions of the Delaware Estuary, excluding the Philadelphia metropolitan area. Land cover representing deciduous forest (NLCD code 41), evergreen forest (42) and mixed forest (43) were extracted from the NLCD and combined for use as input to Fragstats to determine landscape characteristics including the cohesion index.

By analyzing the forest cohesion index for each of the 89 HUC 12 watersheds within the Estuary, and comparing those with the White Clay Creek, a relative determination of natural landscape cohesion could be determined. The map in Figure 45 shows the forested cover in the watersheds of the Delaware Estuary used for this analysis. By plotting the quartiles of the index for the 89 HUC 12 watersheds, a curve was created against which the results for the five HUC 12 watersheds of the White Clay Creek could be compared. A score on a scale of 0-100 was calculated from the quartiles of the cohesion indices. Figure 46 shows the Fragstats cohesion score, based on the amount and pattern of forest cover, within the HUC 12 watersheds of the Piedmont portion of the Delaware Estuary in Delaware and Pennsylvania. The high degree of forest cover in the northern portions of the estuary are evident; the more southerly portions show a more fragmented distribution of forest cover.

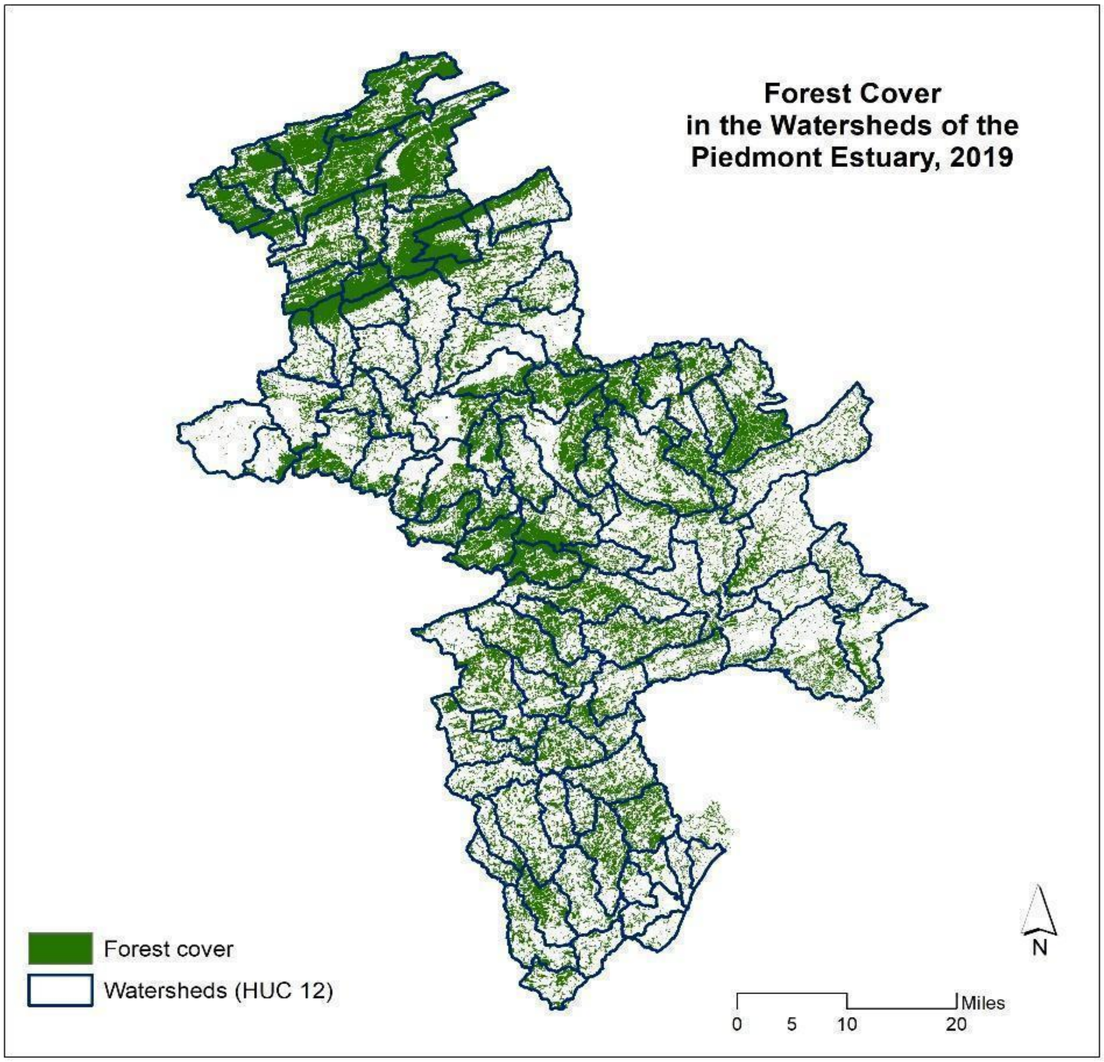


Figure 45. Forest cover in the watersheds of the Piedmont estuary, 2019

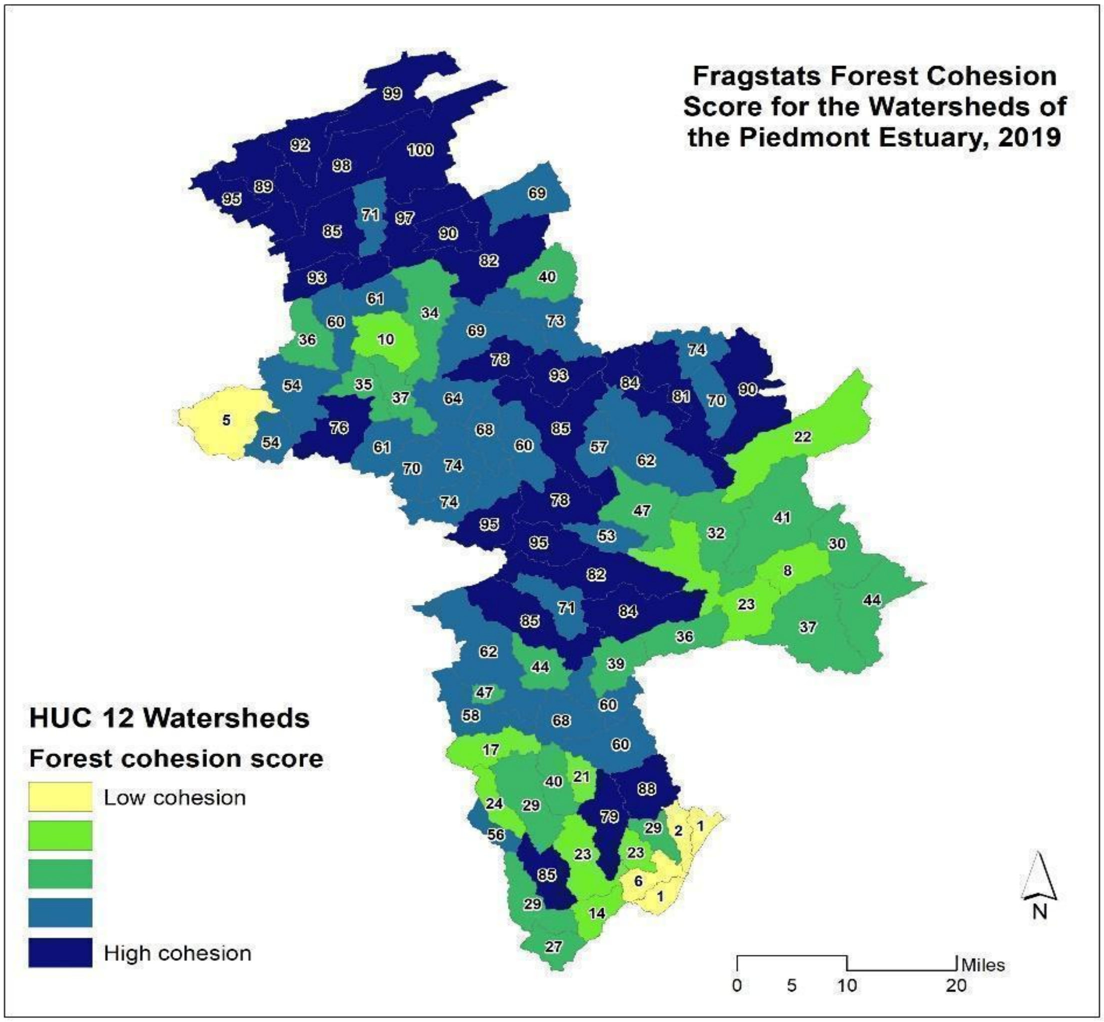


Figure 46. Forest cohesion scores, watersheds of the Piedmont estuary, 2019

Figure 47 shows the curve based on the cohesion indices for the Delaware Estuary, plotted against the 0 to 100 scale, representing the cohesion score. This score is used to determine the relative cohesion of forests within the White Clay Creek watershed and arrive at a grade.

The maps in Figure 48 shows forest cover (left) and Fragstats cohesion index (right) for the HUC 12 watersheds within the White Clay Creek watershed.

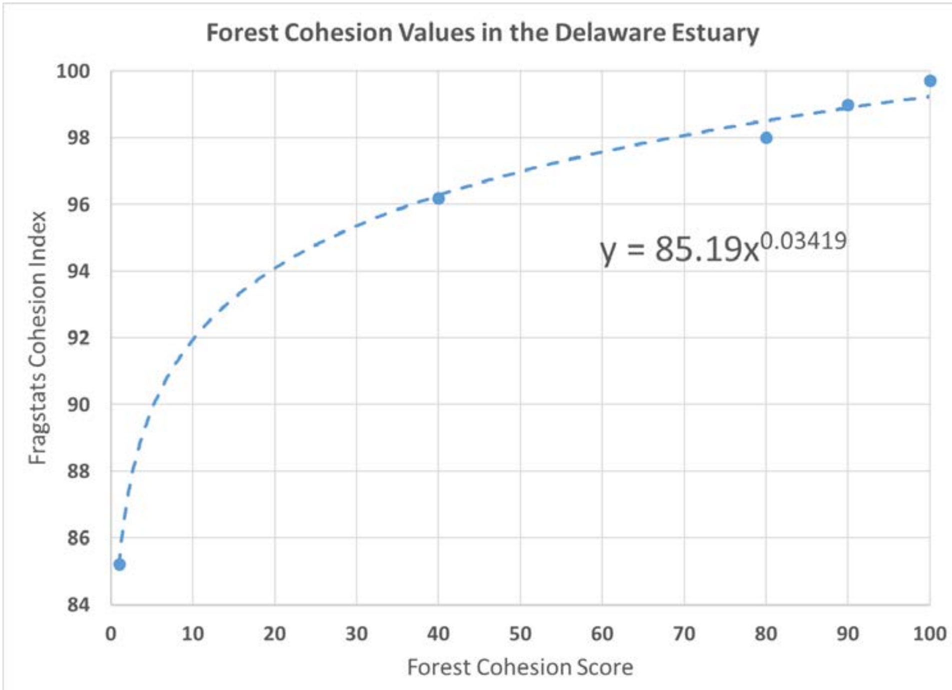


Figure 47. Forest cohesion scores

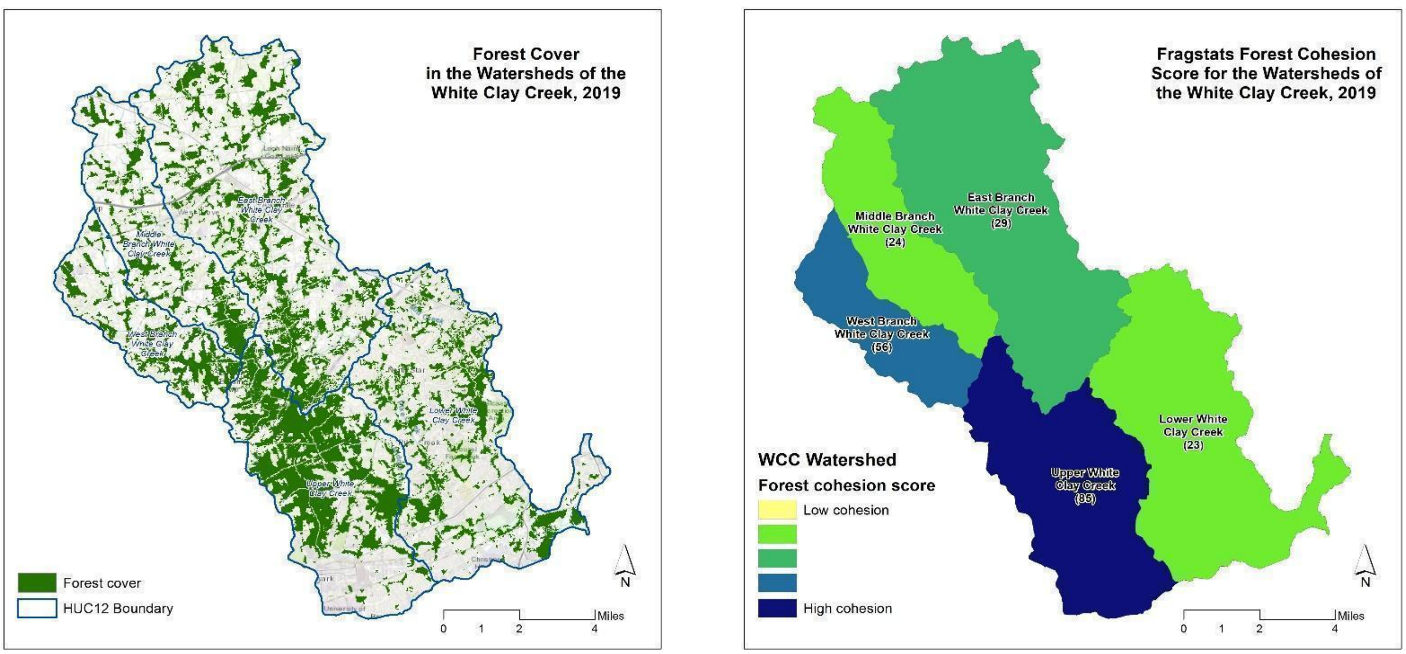


Figure 48. Forest Cover (left) and Fragstats Cohesion Index (right) in the White Clay Creek Watershed

Based on the curve numbers derived from the graph, the following table (Table 28) summarizes the forest cohesion scores of the watersheds of the White Clay Creek, both individually, and as an area weighted composite.

Table 28. Forest cohesion scores of the watersheds in the White Clay Creek

Watershed	Cohesion Index	Area Weighted Index	Cohesion Score	Grade
Lower White Clay Creek	94.8	24.56	22.94	D-
Upper White Clay Creek	99.2	20.32	84.64	A-
East Branch White Clay Creek	95.6	30.09	28.81	D+
Middle Branch White Clay Creek	95.0	12.15	23.97	D-
West Branch White Clay Creek	97.8	9.12	56.40	C+
	Composite	**96.24**	**35.38**	**D+**

The Lower Main Stem, as well as the East and Middle Branches have relatively low scores in the 20s (out of 100), while the West Branch is intermediate at just over 50. The highest score, nearly 85, occurs in the Upper Main Stem, due to the extensive forest cover within the White Clay Creek State Park (in Delaware) and the White Clay Creek Preserve (in Pennsylvania). Overall, the White Clay Creek watershed has a score of approximately 35, which puts the watershed in the lowest quartile of scores within the Piedmont portion of the Delaware Estuary.

While there is much variability in forest fragmentation, with many portions of the watershed highly forested, overall, the suburban, and in some areas agricultural, nature of much of the watershed leads to a relatively low score of "D+."

Aquatic Connectivity – Culverts and Pipes

Culverts are structures that channelize water past or underneath an obstacle such as a roadway. Culverts may vary considerably in terms of material, construction and configuration. Often they consist of pipes or other conveyance that pass under a road and allow a stream or other waterway to flow longitudinally under the road berm. Culverts have a negative impact on the overall health of streams, since they interrupt the natural hydrologic flow, and disturb the natural stream habitat, including natural buffer areas and stream substrate. The presence of a culvert along a stream impedes the passage of aquatic wildlife, including fish and macroinvertebrates. A stream with many road crossings that result in construction of culverts can have a significant negative effect on the health of that stream.

The number of culverts in a stream channel increases in more developed areas, where there is a higher density of roads. The presence of culverts can be an indicator of stream health and overall impairment. Culverts on their own do not necessarily directly affect water quality, but they do represent a disruption to habitats and to natural hydrologic conditions. Streams with few or no culverts tend to have healthier and more cohesive habitats.

The initiative called Designing Sustainable Landscapes (DSL), a program of the Landscape Ecology Lab at the University of Massachusetts, has assessed the aquatic connectedness in the streams of New England and the mid-Atlantic coast, developing metrics for those areas based on data provided by the North Atlantic Aquatic Connectivity Collaborative (NAACC). The NAACC data for determining passability to aquatic fauna (fish, macroinvertebrates, etc.) were developed through a comprehensive inventory of road crossings (i.e., culverts), as well as run-of-stream dams in the northern portion of the Atlantic coast, between Maine and Virginia. The dataset includes over 35,000 point features corresponding to road culverts in the region. Figure 49 presents the culvert density (number of culverts per square kilometer), within HUC 12 watersheds of the Piedmont Estuary.

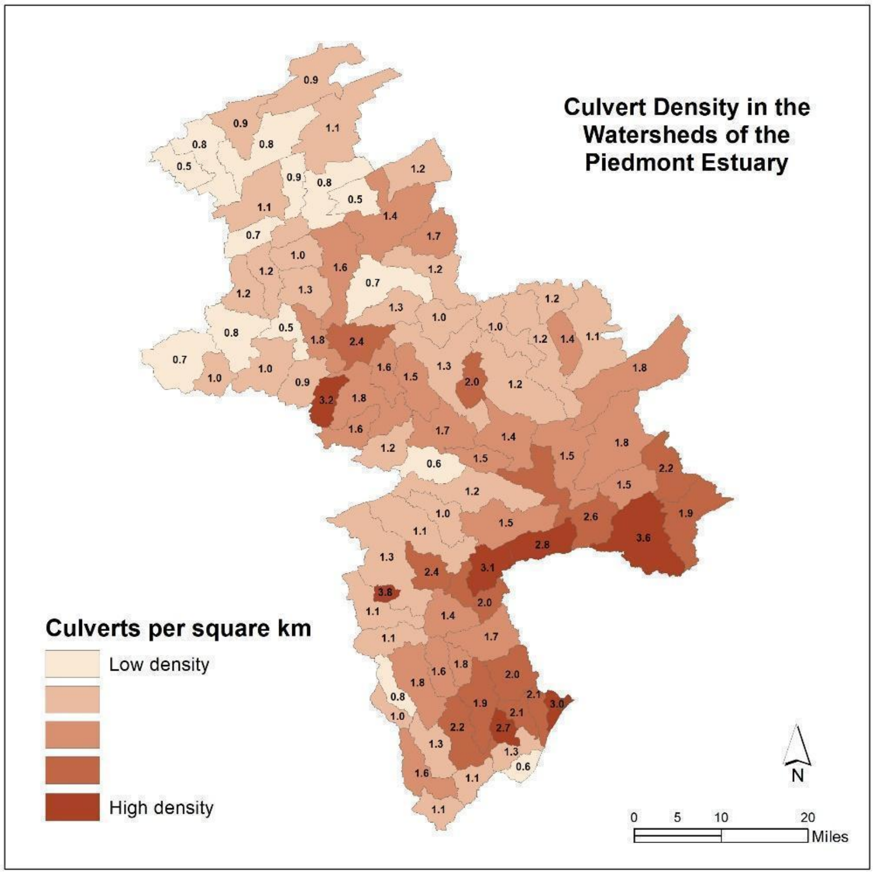


Figure 49. Culvert density in the watersheds of the Piedmont estuary

A variety of metrics was developed for each road crossing based on factors such as stream channel configuration and road size, among others. For each culvert (and dam) inventoried, a series of scores was developed to predict the resistance to an organism's ability to pass the aquatic barrier. One key metric is the aquatic passability score (the variable "aquatic" in the culvert dataset); this measures the resistance to an organism's ability to pass through the culvert, ranging from 0 (no passability) to 1 (fully passable).

To assess the relative passability due to the presence of culverts in the watersheds in the White Clay Creek, a reference score for each HUC 12 in the Piedmont Estuary (89 watersheds) was assessed based on the "aquatic" score, and the scores for the watersheds in the White Clay Creek were compared with the overall range of scores for the Piedmont Estuary.

To derive the score, the total value of the variable "aquatic" for all culverts was summarized for each HUC 12. The total was then normalized by the total length of streams within each HUC 12 to arrive at the total aquatic score per stream mile. Figure 50 shows the overall "aquatic" index (normalized by stream miles), and the corresponding passability score (on a scale of 0 to 100).

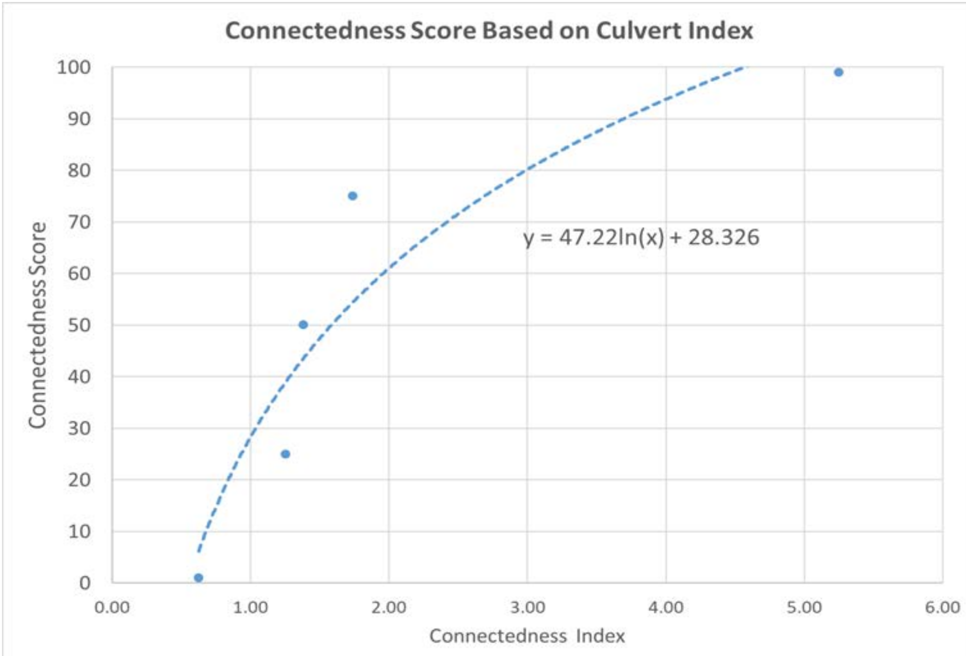


Figure 50. Connectedness score

Table 29 presents the quartiles and corresponding ranking of passability based on the score.

Table 29. Culvert Aquatic Index/Passability Score

Culvert Passability Score		
	Aquatic Index	Score
Highest Value	5.25	99
Upper Quartile	1.74	75
Median	1.38	50
Lower Quartile	1.26	25
Lowest Value	0.63	1

The watersheds of the White Clay Creek were ranked based on their relative passability scores within the Piedmont Estuary as a whole. Figure 51 shows the White Clay Creek, with the locations of all culverts (road stream crossings).

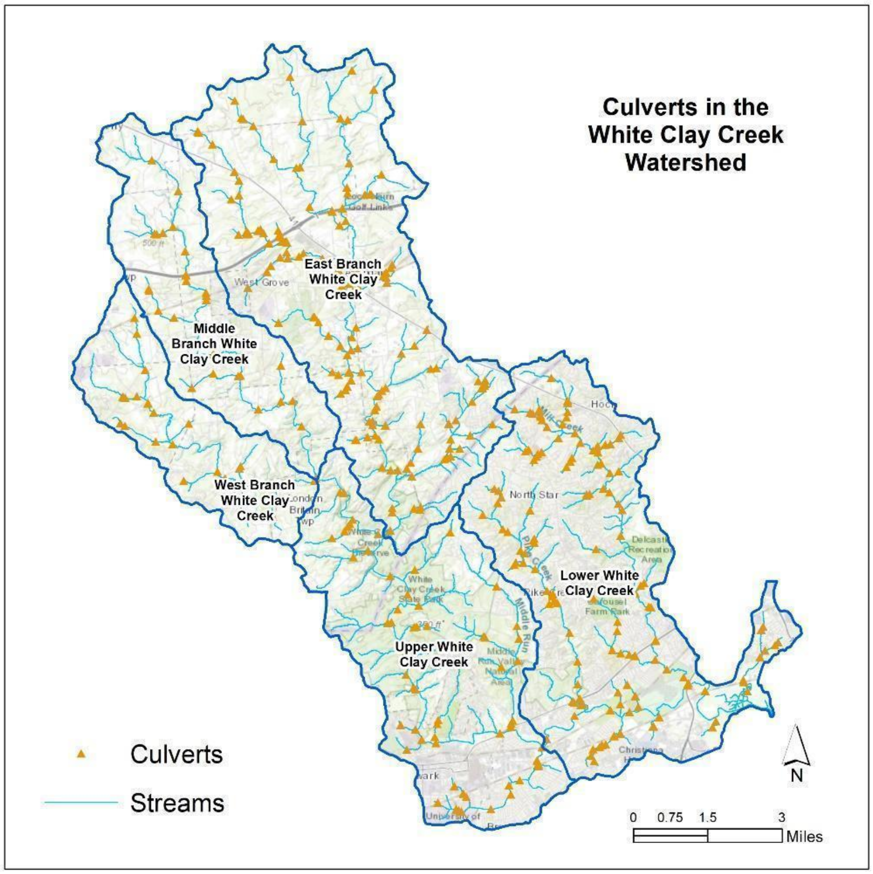


Figure 51. Culverts in the White Clay Creek watershed

Table 30 presents the final index (total “aquatic” score, normalized by stream mileage), and then weighted by area, to give an overall index value for the White Clay Creek as a whole. Note that the number of culverts is only one factor in determining the passability score; culvert design and number of culverts per stream mile has a large influence on passability and therefore final score. Based on the area weighted index for all HUC 12s in the White Clay Creek watershed, 1.39, the overall (composite) score for the White Clay Creek is 43.7, which equates to a grade of “C-.”

Table 30. Overall Culvert Passability Index Value for the White Clay Creek

Watershed	Index	Area Weighted Index	Passability Score	Grade
Lower White Clay Creek	1.652	0.43	**52.0**	**C**
Upper White Clay Creek	0.92	0.19	**24.6**	**D-**
East Branch White Clay Creek	1.647	0.52	**51.9**	**C**
Middle Branch White Clay Creek	1.216	0.16	**37.6**	**D+**
West Branch White Clay Creek	1.017	0.09	**29.1**	**D**
WCC Total		1.39	**43.7**	**C-**

Aquatic Connectivity – Dams/Fish Passage

Dams are in-stream structures designed to restrict the flow of water for various purposes, including flood control, recreation, hydropower and to run mills. Most of the dams in the White Clay Creek were built for water power, and many date to the colonial period.

Today, there are many efforts around the nation involved with removing dams, in order to restore natural hydrologic flows, foster healthy natural habitats, increase recreational safety, and enable the passage of migratory fish species. Examples on the White Clay include the removal of the most downstream dam, a historic mill dam[6] that had been deteriorating in recent years. In the Delaware portion of the White Clay Creek main stem there were seven dams (now six, since the first dam was taken out in 2014), which affect hydrology and impede fish passage to some degree. Table 31 lists the dams in the Delaware portion of the main stem.

In the White Clay Creek watershed, fish passage research and dam removal design and implementation, with a focus on restoring American shad migration, has been undertaken by

[6] The historic Byrnes Mill Dam, also known as White Clay Creek Dam No. 1, was removed in early December 2014. The removal connects 3.5 miles of the White Clay Creek National Wild and Scenic River to the tidal Christina and Delaware Rivers opening 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, the White Clay Wild and Scenic Management Committee and multiple partner organizations. These groups, in partnership with numerous stakeholders, have compiled key information on the dam landscape in the Delaware portion of the White Clay Creek watershed. There were originally seven dams located on the Delaware section of White Clay Creek that have the potential to block fish passage and prevent fish migration throughout the entire 107-sq.-mi. watershed (Table 31). The historic Byrnes Mill Dam, also known as White Clay Creek Dam No. 1, was removed in early December 2014. The removal connects 3.5 miles of the White Clay Creek National Wild and Scenic River to the tidal Christina and Delaware Rivers opening 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.

Table 31. Dams on the White Clay Creek main stem in Delaware

Dam	Historic Name	Common Name	River Mile
TCS*	n/a	Tidal Capture Structure	0.6
1**	Byrnes Mill Dam	Delaware Park Dam	4.1
2	England/Red Mill Dam	Red Mill Dam	7.6
3	n/a	Karpinski Park Dam	9.5
4	Dean Woolen Mill Dam	Paper Mill Dam	10.1
5	Curtis Paper Mill Dam	Newark Intake Dam	11.1
6	Unknown	Creek Road Dam	11.6
7	Tweeds Mill Dam	Deerfield Dam	12.7

*Does not impede fish passage.
**Dam removed.

Funding has been secured from the National Fish and Wildlife Foundation Delaware River Conservation Fund to remove Dams 2, 4 and 7. Dam 3 encases a sewer main for the City of Newark, which will be relocated underground upon removal of the dam. There is no time frame for this replacement. Dam 5 is the intake for the Newark Reservoir. Providing fish passage at this location may require a different strategy than full or partial removal and this still needs to be studied. Dam 6 is largely broken up rock, and fish passage may already be possible. It is also worth noting that Dam 8 (which is the next dam upstream located in the Pennsylvania Preserve) is on a list of low head dams slated for potential removal by PA DCNR. Continuing to work with partners to remove dams along the White Clay Creek and restore it to a free-flowing stream will continue to improve the habitat and natural resources of the watershed. Figure 52 shows the location of all of the dams in the White Clay Creek watershed.

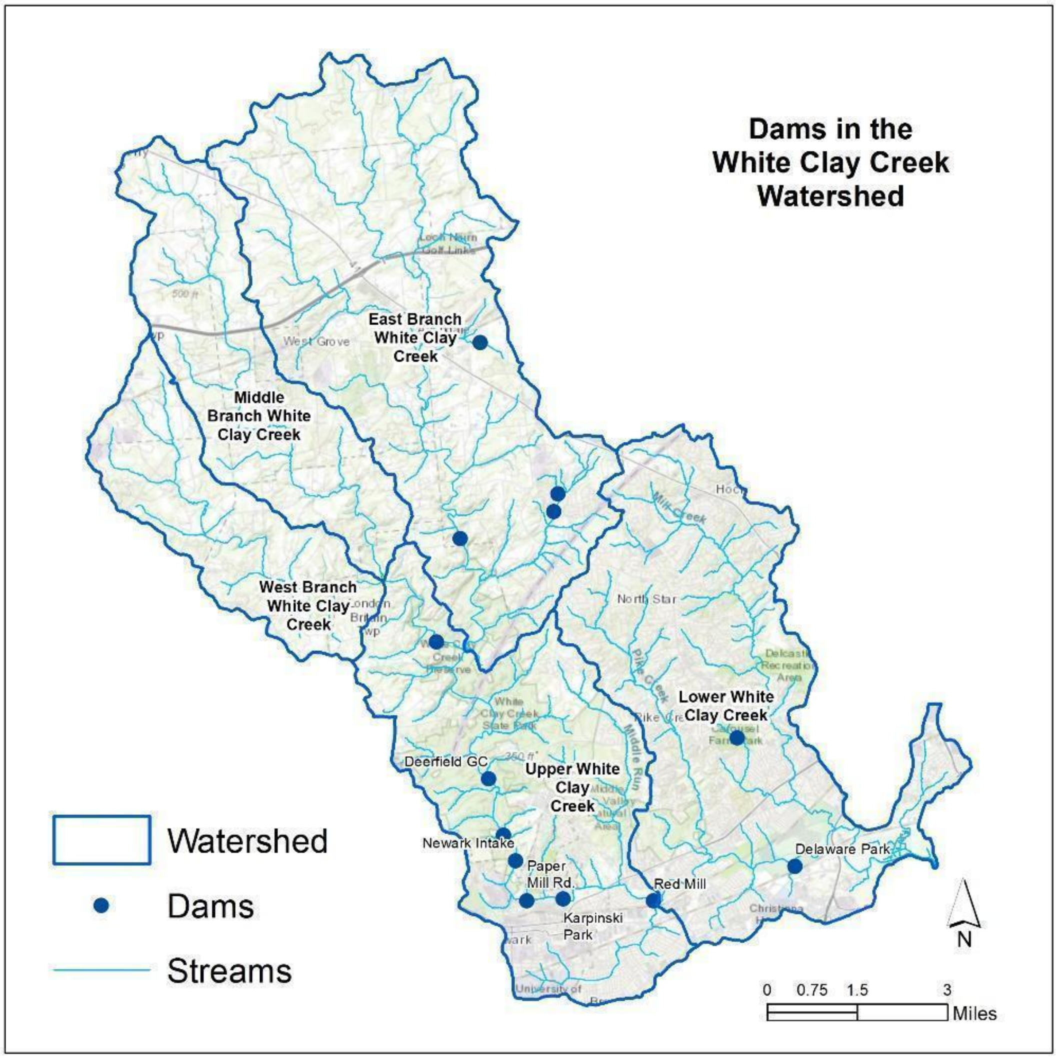


Figure 52. Location of dams in the White Clay Creek watershed

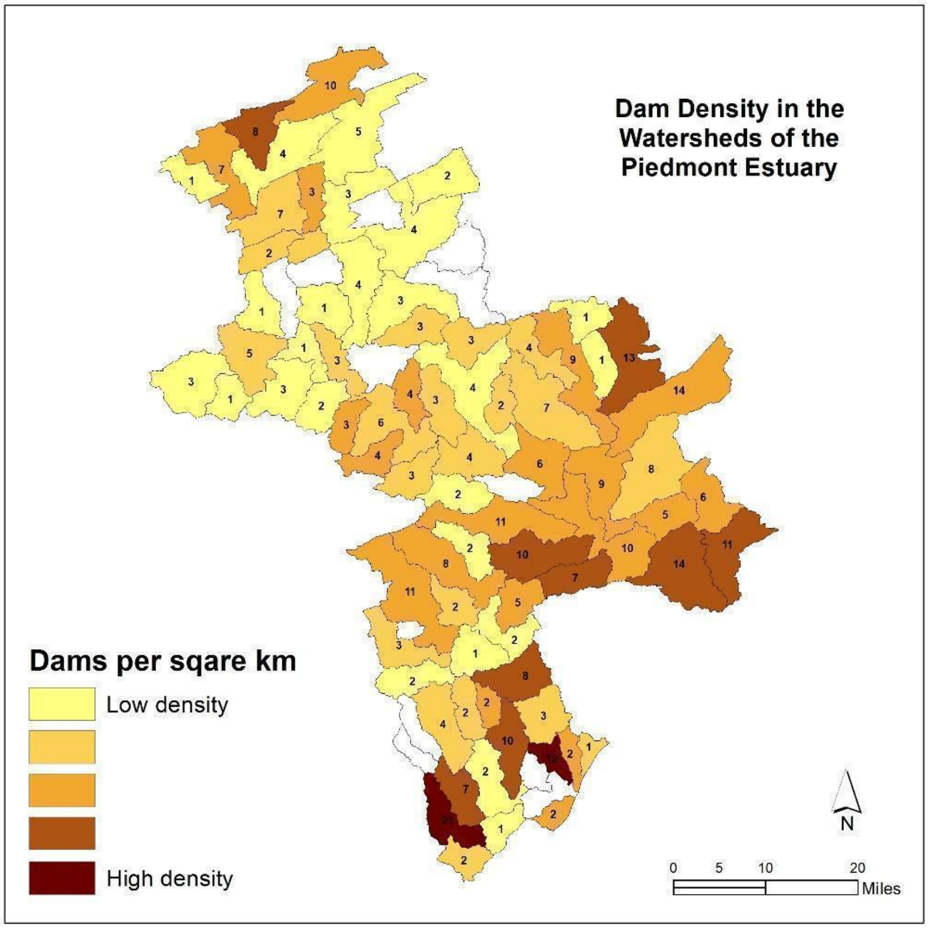


Figure 53. Dam density in the White Clay Creek watershed

Data from the DSL (see previous section) was used to assess the passability scores based on presence of run-of-river dams. The dataset includes over 2,000 point features corresponding to dams in the region. Figure 53 presents the dam density (number of dams per square kilometer), within HUC 12 watersheds of the Piedmont Estuary. The number of dams in a particular HUC 12 watershed is indicated by the corresponding label. Watersheds with no dams are depicted in white.

A variety of metrics was developed for each road crossing based on factors such as stream channel configuration and road size, among others. For each culvert (and dam) inventoried, a series of scores was developed to predict the resistance to an organism's ability to pass the aquatic barrier.

To determine the effect of dams, the DSL developed a series of metrics to determine the effect on aquatic habitats from dams (or their removal).

The variable “delta” was created to measure the difference between aquatic connectedness in an unaltered stream versus the same stream with the dam. This helps indicate the relative impact of a given dam on the health of a stream, and in particular its connectedness, which equates to its passability by aquatic organisms, including anadromous fish. See McGonigal (2021) for a fuller explanation; here the variable “delta” is defined as: “The difference between the altered and base aquatic connectedness, multiplied by 1000 to make the numbers more tractable. This represents the potential improvement in aquatic connectedness from removing the dam.”

To develop a framework for comparison of the relative effects of dams in the White Clay Creek watershed, a reference score for each HUC 12 in the Piedmont Estuary (89 watersheds) was generated using the index (i.e., the “delta” metric). The scores for the watersheds in White Clay Creek were then compared with the overall range of scores.

To derive the score, each HUC 12 in the Piedmont Estuary was assigned an index value, normalized by the number of stream miles in each watershed. Figure 54 shows the overall “delta” index (normalized by stream miles and stretched between 0 and 1), and the corresponding connectedness score (on a scale of 0 to 100).

Table 32 presents the quartiles and corresponding ranking of connectedness based on the score. Note that in this case, lower index values indicate less of an impact by dams, so that lower index numbers and resultant scores, indicate less impacted watersheds.

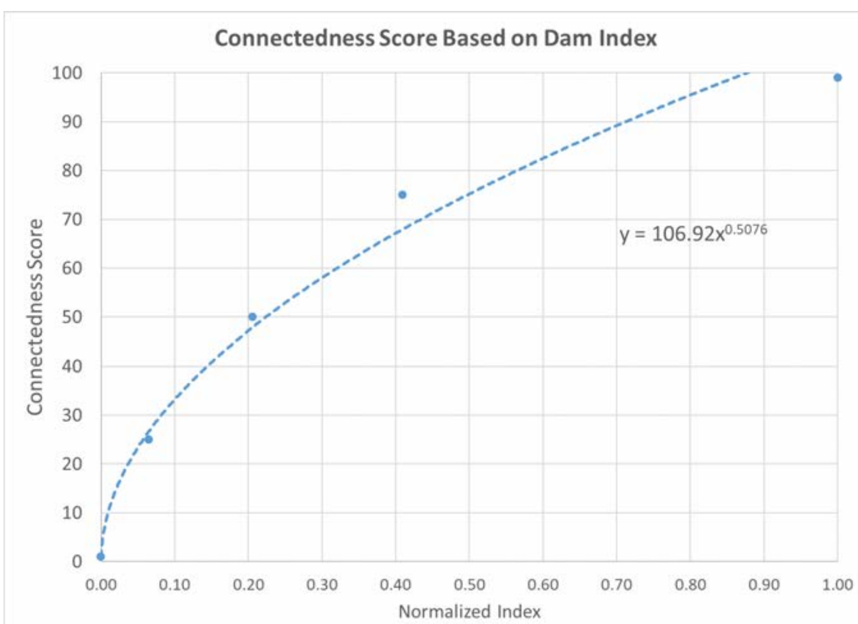


Figure 54. Connectedness score based on dams

Table 32. Dam Connectedness Score

Connectedness Score		
	Index	Score
Highest Value	1.00	99
Upper Quartile	0.41	75
Median	0.21	50
Lower Quartile	0.07	25
Lowest Value	0.00	1

Using the scoring within the Piedmont Estuary as a whole, the watersheds of the White Clay Creek were ranked based on their relative connectedness scores. Figure 55 shows the connectedness ("delta") score for dams in each of the HUC 12 watersheds of the White Clay Creek watershed. The scores shown are derived from the summation of the "delta" index values in a watershed (scaled between 0 and 1), and calculated using the curve in Figure 54.

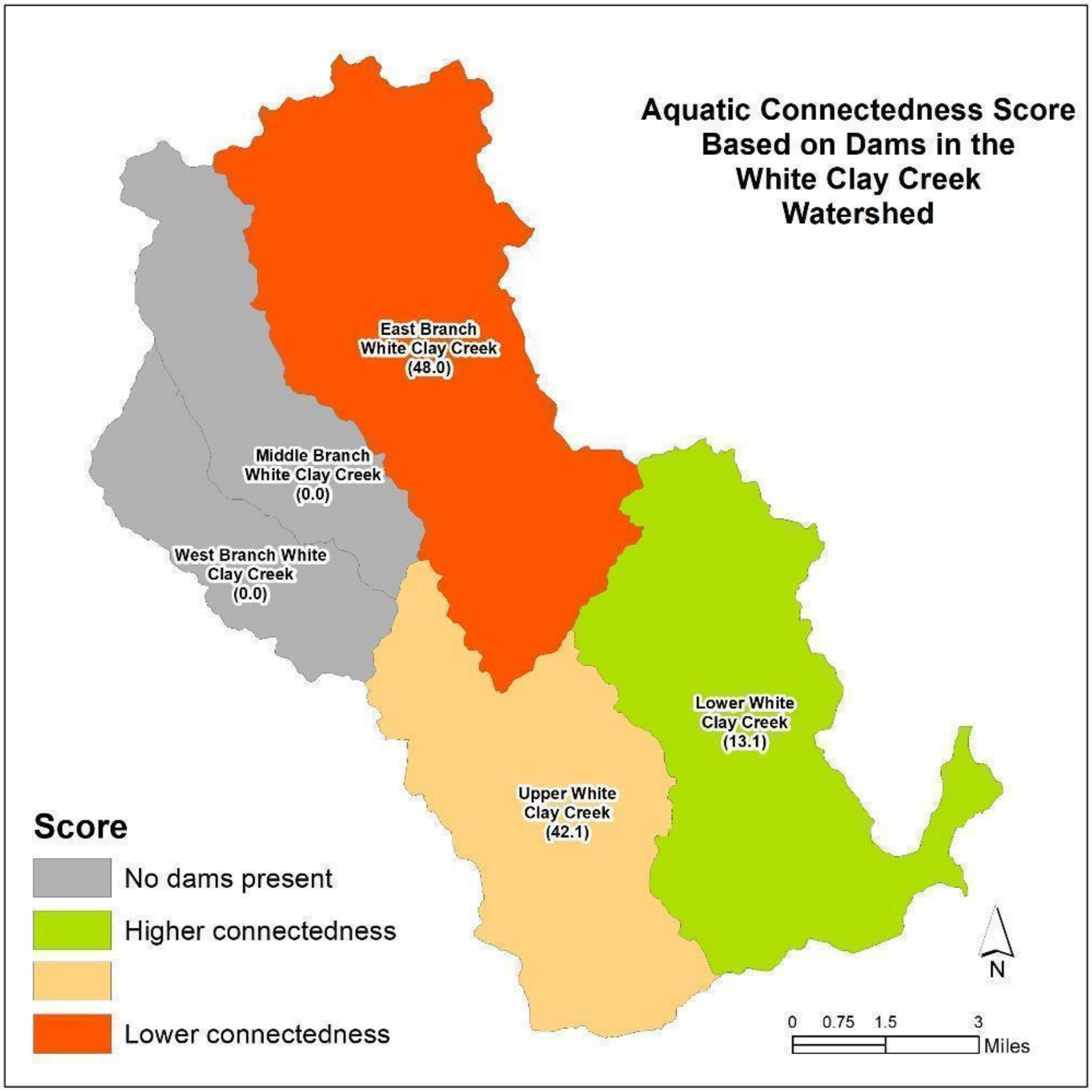


Figure 55. Aquatic Connectedness Score in the White Clay Creek Subwatersheds

Table 33 presents the final index (total "delta" score, normalized by stream mileage), and then weighted by area, to give an overall index value for the White Clay Creek as a whole.

Table 33. Overall Dam Passage Index Value for the White Creek Subwatersheds

Watershed	Index	Area Weighted Index	Passability Score	Grade
Lower White Clay Creek	0.016	0.004	**86.94**	**A**
Upper White Clay Creek	0.159	0.033	**57.92**	**C+**
East Branch White Clay Creek	0.206	0.065	**52.02**	**C+**
Middle Branch White Clay Creek	0	-	**100.00**	**A+**
West Branch White Clay Creek	0	-	**100.00**	**A+**
WCC Total		**0.102**	**66.49**	**B**

Based on the area weighted index for all HUC 12s in the White Clay Creek watershed (0.102), the overall (composite) score for the White Clay Creek is 66.5, which equates to a grade of "B."

2.4 Category 3: Water Quality

The location and extent of potential contaminant sources are identified by examining stream water quality data collected by the U.S. Geological Survey, states of Delaware and Pennsylvania, Delaware Nature Society Stream Watch Program, White Clay Wild and Scenic Management Committee, and Stroud Water Research Center. The following table (Table 34) summarizes the grading for the seven Water Quality category indicators for the White Clay Creek watershed and subwatersheds:

Table 34. White Clay Creek, overall grades for Water Quality

	Lower Main Stem	Upper Main Stem	East Branch	Middle Branch	West Branch	Watershed
Water Quality	C+	C+	C+	C	B	C+
Water Temperature	B	B-	C	D	B	C+
Dissolved Oxygen (DO)	A-	A	A	A	A	A
Phosphorus (TP)	A	A-	B+	C+	A+	A-
Nitrogen (NO3-N)	D+	F	F	F	F	F
Chloride (Cl)	A-	A+	A	A+	A+	A
Total Suspended Sediment (TSS)	D	D	C	N/A	N/A	C
Macroinvertebrates	F	D-	D	D	D+	D-

Water Quality Indicators – Methodology

The Water Quality Scores used here for the White Clay Creek were calculated following the approach used for the OARS' Water Quality Index (OARS River Report Card – Grade Calculation. Prepared by S. Flint, June 2019, Updated by B. Wetherill). Water quality indicators (aka parameters) were selected based on the availability of field data, which reflects in part their general importance in the assessment of stream condition. For the selected chemical/physical parameters, the Water Quality Indicator Score (WQIS) calculation can be divided into a three-part approach: (1) develop the best-fit sub-index score curves for each parameter; (2) temporally average available water-quality data at each site to arrive at annual mean values and then use the best-fit equations from step one to estimate sub-index scores for each parameter/site pair; (3) spatially average the site-specific sub-index scores within each of the five HUC 12s, as well as for the entire watershed, followed by converting these final watershed-specific WQIS values into water-quality letter grades. Macroinvertebrate data methodology does not involve step one.

Developing best-fit scoring curves.

Scoring curve data needed for establishing the sub-index score prediction equations were either pulled directly from the OARS River Report Card reference (temperature and dissolved oxygen) or were extracted from data appendices for a USGS report on water-quality temporal trends in the Delaware River basin (Shoda and Murphy 2022; trend analysis methodology and associated data are from Murphy et al., 2020). The five water-quality parameters worked up using USGS data were total phosphorus (TP), nitrate (NO_3N), specific conductance (SC), chloride (Cl) and total suspended solids (TSS).

Water Temperature

In this State-of-the-Watershed, temperature was interpreted relative to the fisheries standards associated with specific reaches (i.e., designated as coldwater versus warmwater fisheries). Temperature threshold data are from Table 5 (Tables 35 and 36; Figure 56 here) and Figure 3 (not shown) in the OARS River Report Card Grade Calculation document (Nov. 2021). Separate relationships were defined for coldwater, warmwater and aquatic life designated fisheries.

Table 35. Water Temperature scoring curve for warmwater resources

Temperature (°C)	Reference	Sub-Index Score
20	Mass WQS cold (Mass WQS, 1993)	100
27	Maximum for growth in black crappie (EPA, 1986)	60
28.6	Mass WQS for warmwater fisheries (Mass WQS, 1993)	50
32	Maximum for growth of largemouth bass (EPA, 1986)	20
34	Maximum for survival of largemouth bass (EPA, 1986)	1

Table 36. Temperature scoring curve for warmwater aquatic life resources

Temperature (°C)	Reference	Sub-Index Score
20	Mass WQS cold (Mass WQS, 1993)	100
27	Maximum for growth in black crappie (EPA, 1986)	60
29.4	Mass WQS for warmwater fisheries (Mass WQS, 1993)	50
32	Maximum for growth of largemouth bass (EPA, 1986)	20
34	Maximum for survival of largemouth bass (EPA, 1986)	1

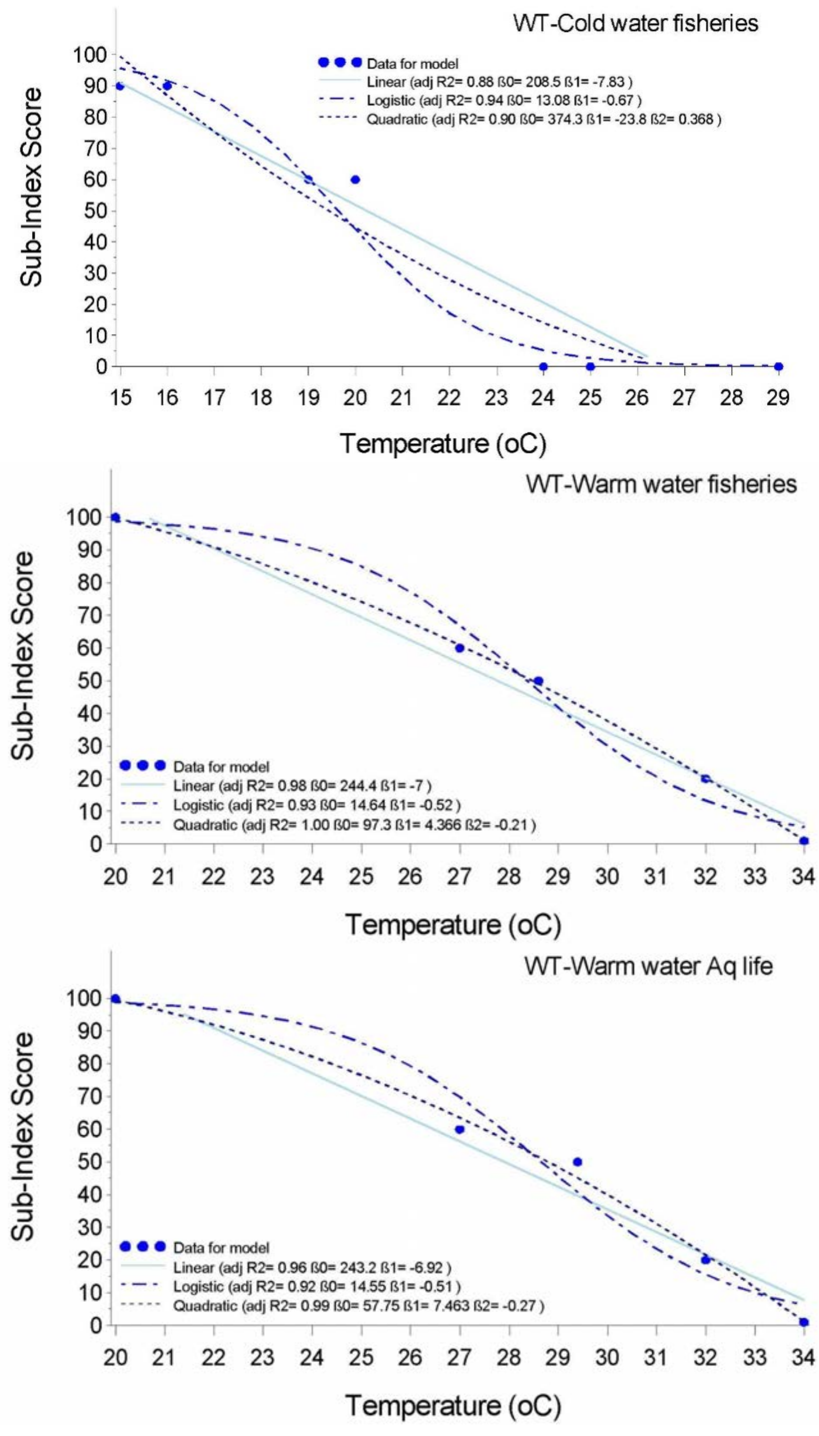


Figure 56. Water temperature (WT) equations for predicting sub-index score (thresholds) from average temperature values for sites included in assessing the water temperature contribution to the Water Quality Index score (WQIS).

Dissolved Oxygen

In similar fashion to temperature, dissolved oxygen threshold data are from Table 4 (Tables 37 and 38; Figure 57 here) and Figure 2 (not shown) in the OARS River Report Card Grade Calculation document (Nov. 2021). Separate relationships were defined for coldwater and warmwater fisheries, plus aquatic life designated fisheries.

Table 37. Dissolved oxygen scoring curve for warmwater fisheries with DO < 100% saturation.

DO (mg/L)	Description & Citation	Score
1.0	Acute mortality for crappie (Oregon DEQ, 1994)	1
3.0	Acute mortality (EPA, 1986), critical oxygen tension for largemouth bass (Oregon DEQ, 1994)	10
3.5	Severe impairment (EPA, 1986)	20
4.0	Moderate impairment (EPA, 1986)	40
4.5	Swimming performance reduced in largemouth bass (Oregon DEQ, 1994)	50
5.0	Slight impairment (EPA, 1986)	60
5.0	Massachusetts Water Quality Standards for warmwater fisheries	60
6.0	No impairment (EPA, 1986), reduced growth rates in bass (Oregon DEQ, 1994)	70
7.7	25th percentile calculated from Ecoregion XIV subregion 59 data (June - Sept)	80
8.0	Onset of O2-dependent metabolism in brown bullhead (Oregon DEQ, 1994)	80
9.4	75th percentile calculated from Ecoregion XIV subregion 59 data (June - Sept)	100

Table 38. Dissolved oxygen scoring curve for warmwater "Aquatic Life" streams with DO < 100% saturation

DO (mg/L)	Description & Citation	Score
1.0	Acute mortality for crappie (Oregon DEQ, 1994)	1
3.0	Acute mortality (EPA, 1986), critical oxygen tension for largemouth bass (Oregon DEQ, 1994)	30
3.0	MA Water Quality Standard for Class B "Aquatic Life" (not less than 3.0mg/L any time)	30
3.5	Severe impairment (EPA, 1986)	40
4.0	Moderate impairment (EPA, 1986)	45
4.5	Swimming performance reduced in largemouth bass (Oregon DEQ, 1994)	50
5.0	MA WQS "Aquatic Life" not less than 5.0mg/L at least 16 hrs/day	60
5.0	Slight impairment (EPA, 1986)	70
7.7	25th percentile calculated from EPA Ecoregion XIV subregion 59 data (Jun - Sept)	80
8.0	Onset of O2-dependent metabolism in brown bullhead (Oregon DEQ, 1994)	90
9.4	75th percentile calculated from EPA Ecoregion XIV subregion 59 data (Jun - Sept)	100

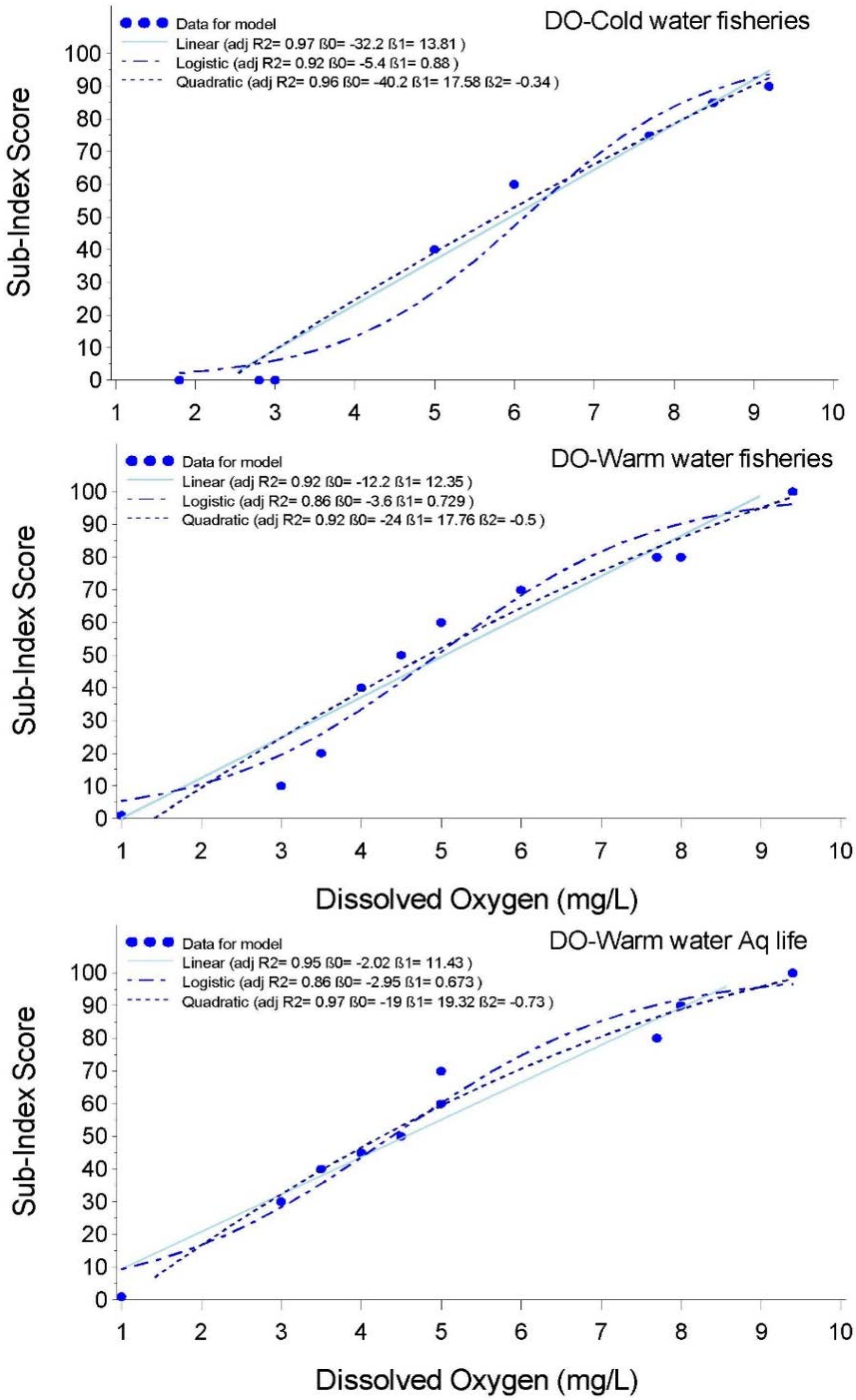


Figure 57. Dissolved oxygen (DO) equations for predicting sub-index score (thresholds) from average DO values for sites included in assessing the DO contribution to the Water Quality Index score (WQIS).

Phosphorus (TP), Nitrate (NO3-N), Conductivity (SC), Chloride (Cl) and Total Suspended Solids (TSS)

The specific USGS sampling sites providing the scoring-curve data for the five chemical parameters (TP, NO_3N, SC, Cl and TSS) are listed in Table 39; summary statistics of these data for the five parameters can be found in Table 40.

Table 39. United States Geological Survey (USGS) stream monitoring stations used in developing the sub-index score prediction equations (aka scoring curves). Showing the number of individual sample values for each water-quality parameter used in generating the initial percentiles (aka sub-index scores). These percentiles are plotted against concentration values (natural-log transformed) in each of the parameter-specific plots showing the different prediction equations. Water quality parameters include: TP – Total Phosphorus; NO3N – Nitrate; SC – Specific Conductance; Cl – Chloride; TSS – Total Suspended Solids. Sample collection agency acronyms: PA DEP = PA Department of Environmental Protection; DE DNREC – DE Department of Natural Resources and Environmental Control; DRBC – Delaware River Basin Commission; USGS WSC – United States Geological Survey (state-specific) Water Science Center.

Station Name	COMID	Total Drainage Area (km^2)	Latitude/ Longitude	Sample Collection Agency	Number of Samples included in developing the sub-index score prediction equations				
					TP	NO_3N	SC	Cl	TSS
Brandywine Creek at Chadds Ford, PA	4652052	757	39.86940/ -75.59310	PA DEP	64	152	870	234	91
Brandywine Creek at Wilmington, DE	4655440	825	39.76983/ -75.57884	DE DNREC, USGS MD WSC		240	347	131	242
Christina River at Coochs Bridge, DE	4651956	63	39.63746/ -75.72848	DE DNREC		147	175	133	148
Red Clay Creek at Wooddale, DE	4651912	125	39.76288/ -75.63658	USGS MD WSC, DE DNREC		145	205	140	150
Red Clay Creek near Kennett Square, PA	4651090	77	39.81610/ -75.69140	PA DEP, USGS PA WCS	61	61			
Red Clay Creek near Stanton, DE	4651930	136	39.71632/-75.64038	DE DNREC		84	143	85	91
White Clay Creek at Newark, DE	4651394	178	39.68997/ -75.73759	DE DNREC		83	114	82	87
White Clay Creek near Newark, DE	4651938	235	39.69896/ -75.67544	DE DNREC, USGS MD WSC, DRBC		146	210	145	151
White Clay Creek near Strickersville, PA	4651254	154	39.74750/ -75.77083	USGS PA WSC		85	145	87	92
				Total:	**125**	**1143**	**2209**	**1037**	**1052**

Table 40. Summary statistics for the water quality parameters included in the Water Quality Index Score calculation. Parameter values summarized here were used to generate the sub-index scores (percentiles) needed to generate the scoring-curve equations used to predict the sub-index scores for the WCC-specific stream monitoring sites. The values were collected at the USGS stations provided in Table 39.

Parameter	**Min sample date**	**Max sample date**	**Mean**	**Median**	**Min**	**Max**	**N obs**
Total phosphorus (mg/L as P)	13Feb08	14Aug18	0.12	0.09	0.01	0.65	125
Nitrate (mg/L as N)	7Jan08	14Aug18	2.75	2.79	0.48	6.2	1143
Specific conductance (µS/cm)	9Mar93	5Sep18	330	323	87	1520	2209
Chloride (mg/L)	7Jan08	7Aug18	52.2	46	10	406	1037
Total suspended solids (mg/L)	7Jan08	7Aug18	12.6	3	1	509	1052

Scoring curve development for the five parameters using USGS data began with calculating percentiles in 5% increments from 5 to 95 based on sample data collected from 2008 to 2018. The percentiles, or sub-index scores (y) were regressed against corresponding concentration value (x, natural log transformed) for a given percentile using three separate equations: simple linear regression [$y = \beta_o + \beta_1 * \ln(x)$], logistic regression [$\log(y/100 = \beta_o + \beta_1 * \ln(x)$], and quadratic regression [$y = \beta_o + \beta_1 * \ln(x) + \beta_2 * (\ln(x)^2)$]. The adjusted R^2 value (adjusted for the number of independent terms in the prediction equation) was used to determine best fit. In all cases, the quadratic regression had the highest adjusted R^2 value. Plots of the sub-index score data v. natural log-transformed concentration data and including all three prediction equations are provided below (Figures 58 – 61). Sub-index scores were predicted for available data from sampling sites found across the White Clay Creek watershed as detailed in the following section.

TP:

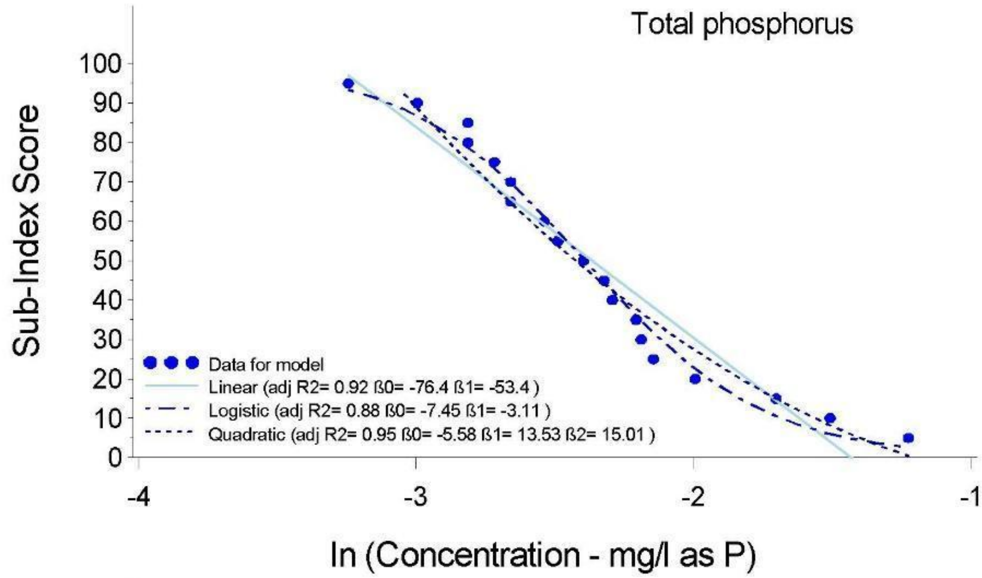


Figure 58. Total phosphorus (TP) equations for predicting sub-index score (thresholds) from average TP values for sites included in assessing the TP contribution to the WQIS.

NO_3-N:

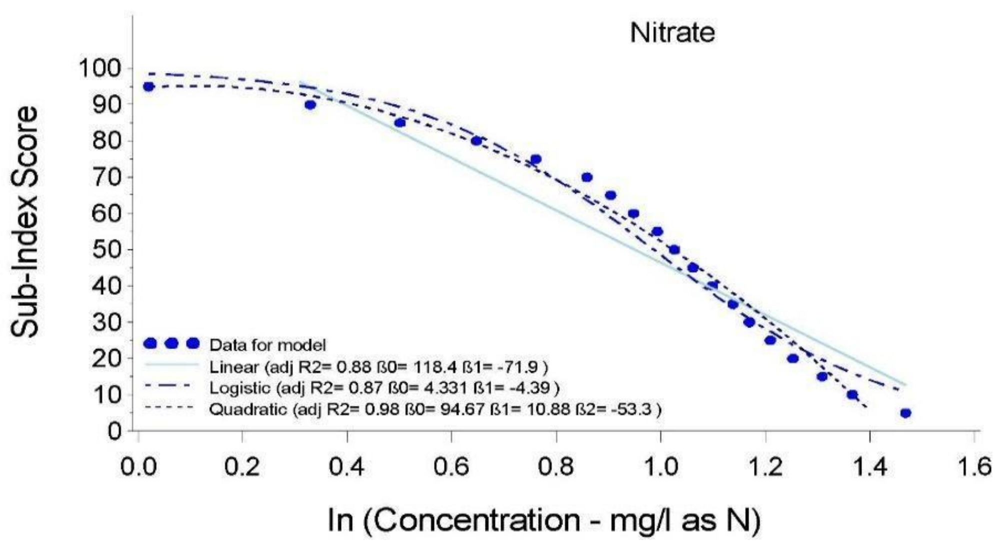


Figure 59. Nitrate equation for predicting sub-index score from average nitrate values for sites included in assessing the nitrate contribution to the WQIS.

SC/Cl:

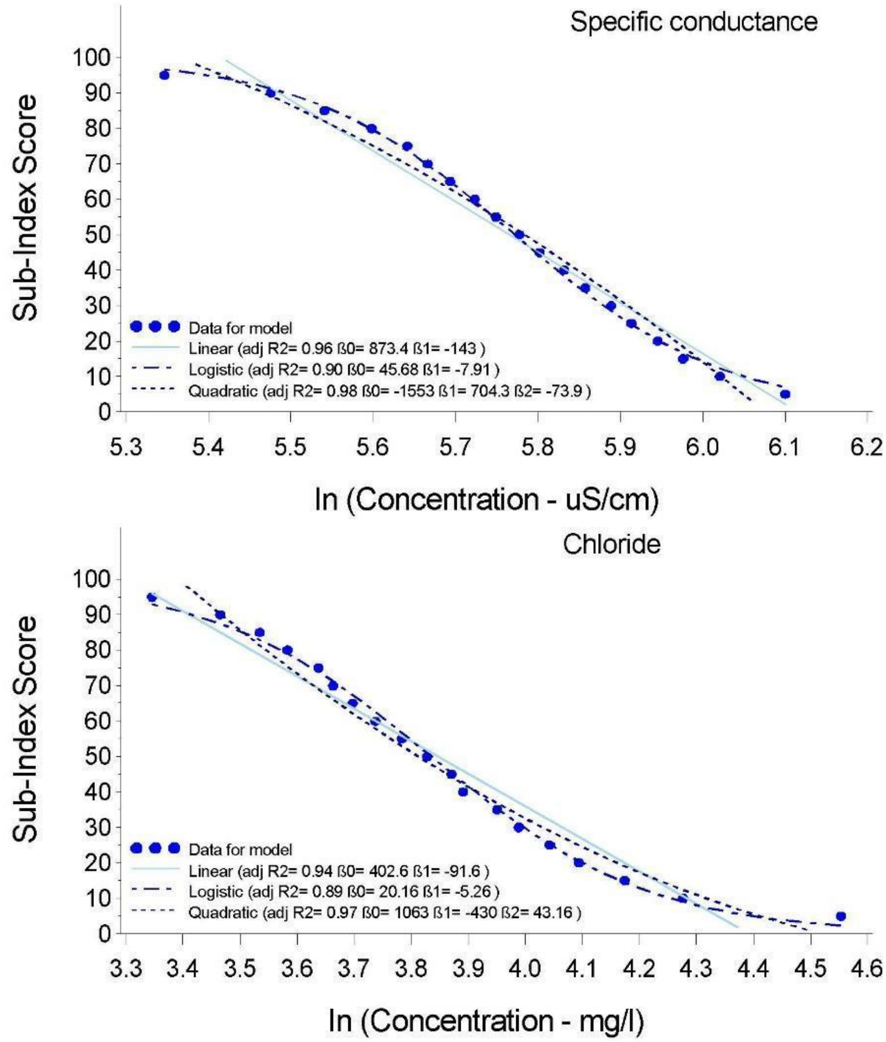


Figure 60. Specific conductance (SC) and chloride (Cl) equations for predicting sub-index score from average SC and Cl values for sites included in assessing Cl contribution to the WQIS. SC was not included in the final WQIS calculation; SC equation and resulting

TSS:

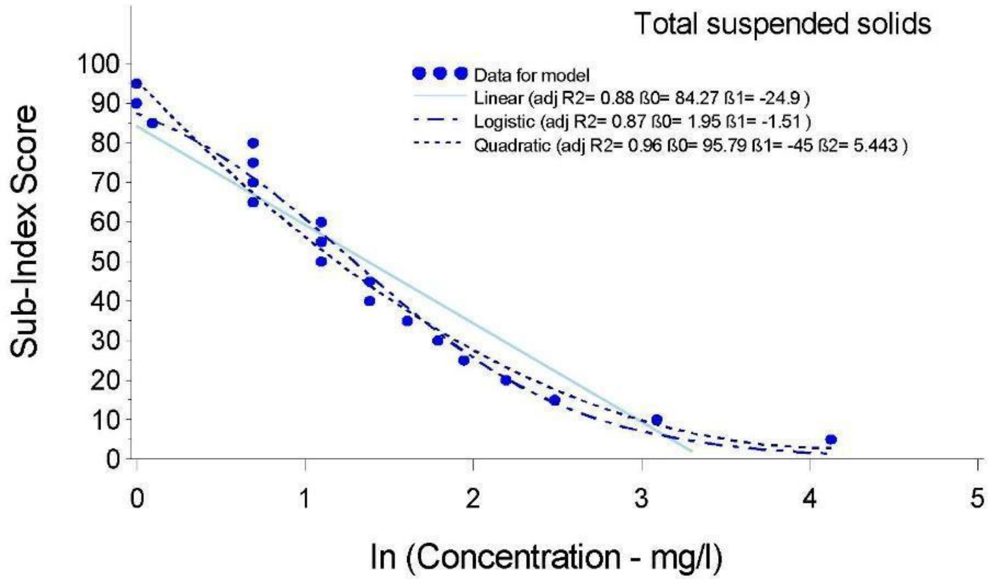


Figure 61. Total suspended solids (TSS) equation for predicting sub-index score from average TSS values for sites included in assessing the TSS contribution to the WQIS

Calculating sub-index scores for each parameter/site pair.

White Clay Creek water quality data were obtained from numerous sources (see Figure 62): Delaware Fish and Wildlife (DEF&W), Delaware Nature Society (DNS SW), Delaware Natural Resource and Environmental Control (DNREC), Delaware River Watershed Initiative (DRWI; Stroud Water Research Center, Academy of Natural Sciences of Drexel University), Stroud Water Research Center (LTREB, SWRC SW), United States Geological Survey (USGS QW Sites), and White Clay Wild & Scenic (WCWS WQ). The number of sites averaged varied greatly, from a high of 85 sites (Specific Conductance) to a low of 12 sites (Total Suspended Sediment; TSS). At least one site was located in each HUC for every Water Quality Indicator except TSS. TSS was not measured at any sampling site in the Middle or West Branches of the White Clay Creek. Specifics on the water quality, including sampling period, sites having available data and specific summary statistics will be covered in the results section for each individual parameter.

Average annual values were initially calculated for all White Clay Creek water-quality data prior to predicting sub-index scores. Due to the wide temporal range in available data this averaging of the water quality data was accomplished using the following hierarchy: (1) monthly means of available raw data; (2) seasonal means using the monthly means where winter = October-March and summer = April-September; (3) final annual means using the seasonal means. The site annual means were used to predict a sub-index score for each parameter at each site where a given parameter was measured. Predicted scores of <0 or >100 were rounded to 0 or 100 respectively. As the last step, the predicted sub-index scores for each site were averaged (arithmetically) across all available annual means to arrive at a site-specific sub-index score for each parameter measured at a given site.

Calculating final, watershed-specific, WQIS values for each parameter and assigning a water-quality letter grade.

A weighted average of the site mean values was calculated for each HUC 12 watershed as well as for the entire White Clay Creek watershed. As previously noted, final WQIS values for the entire White Clay Creek watershed are not based on averaging the HUC 12 values; rather the entire watershed is treated as simply another HUC watershed in this process. The weights were calculated as the ratio of the watershed area for a given site relative to the sum of watershed areas for all sites having data for the given parameter and located within a specific HUC 12/entire White Clay Creek watershed. These HUC 12/White Clay Creek watershed weighted-average sub-index scores are the final WQIS values which in turn were converted to final water-quality letter grades as shown in Table 41. Note that this letter grade scheme does not follow the typical academic system (e.g. <60 is a "D"). The map in Figure 62 shows the locations in the White Clay Creek watershed of all sample sites used in this analysis for all parameters, including water quality indicators, macroinvertebrates and bacteria.

Table 41. Letter Grade Scores for Water Quality Indicators

Grade	Points (from final WQIS value)	Grade	Points (from final WQIS value)
A+	95-100	C+	55-59
A	85-94	C	45-54
A-	80-84	C-	40-44
B+	75-79	D+	35-39
B	65-74	D	25-34
B-	60-64	D-	20-24
		F	0-19

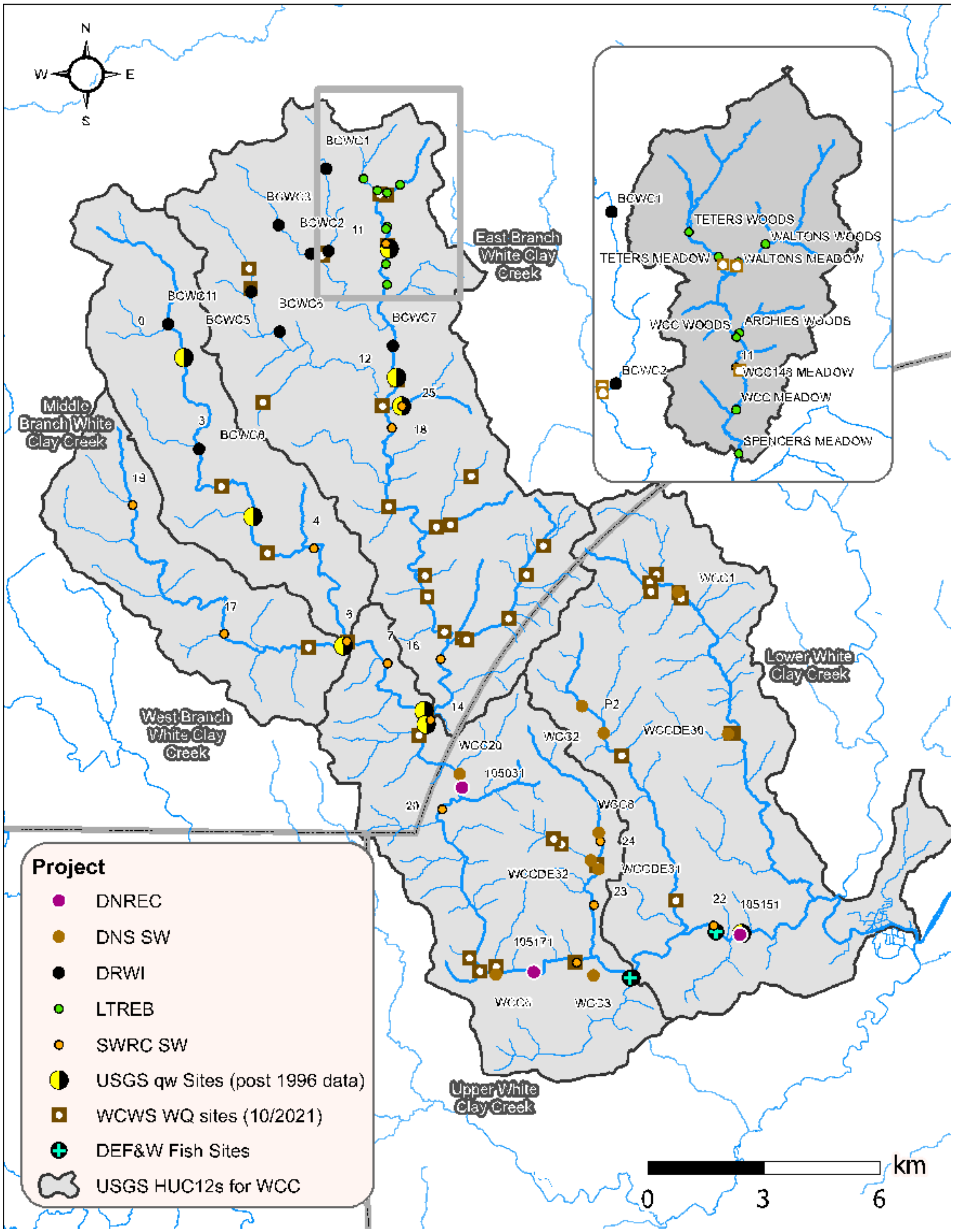


Figure 62. Map of White Clay Creek sites included in the analyses of water quality, macroinvertebrate, and bacterial data. Data came from the Delaware Fish and Wildlife (DEF&W), Delaware Nature Society (DNS SW), Delaware Natural Resource and Environmental Control

Macroinvertebrates

Macroinvertebrate data for this report came from different sources that had different levels of taxonomic resolution. Some were identified to genus/species, some to family, some to family/order or higher. We converted all data to family-level metrics. The family-level metric we used was the multimetric Macroinvertebrate Aggregated Index for Streams or MAIS Score. Rather than relying only on one or a few individual metrics, multimetric indices have been developed that integrate various types of information into a single number that can be used to compare streams. The MAIS Score was developed by Smith and Voshell (1997) based on benthic macroinvertebrate data from streams in the Mid-Atlantic Highlands of Maryland (51 sites), Pennsylvania (53 sites), Virginia (126 sites) and West Virginia (200 sites). The MAIS summarizes the values of 10 metrics:

- Ephemeroptera Richness,
- EPT Richness
- Intolerant Taxa Richness
- % Ephemeroptera
- % EPT
- % 5 Dominant Taxa
- Simpson Diversity
- Hilsenhof Biotic Index (HBI)
- % Scrapers
- % Haptobenthos

Values for the individual metrics are transformed into a score of 0, 1 and 2, and then combined into a MAIS Score. MAIS Scores are predicted to decrease in response to a decrease in water/habitat quality. Streams are classified based on MAIS Scores as follows:

- 13.1-20 classify a site as Good
- 6.1-13 classify a site as Fair
- 0-6 classify a site as Poor

The difference between Good and Poor sites is dramatic. For example, EPT Richness (the number of mayfly, stonefly and caddisfly families, which are generally considered pollution sensitive) might be 11-12 at the highest scoring Good sites, but only 1-3 at the Poor sites.

Given the labor-intensive nature of macroinvertebrate sampling and sample processing, only a single annual value was available at any given site, negating the need for any temporal averaging as was the case with the chemical/physical water quality parameters. The annual MAIS Scores were relativized by dividing values by 20, or the maximum achievable MAIS score, and then multiplying by 100 to express relativized values as percentages. The final WQIS and corresponding water-quality letter grades were calculated from the annual, site-specific 'sub-index scores' using the same weighted-averaging as was done for the other water-quality parameters and following the same letter grade scheme provided in Table 41.

Water Quality Indicators – Results

Table 42. Final WQIS parameter values, associated water-quality letter grades, mean concentrations/values, number of sites and year range for the five WCC HUC 12 watersheds and the entire WCC watershed.

Parameter	Type	E Br White Clay Cr	Middle Br White Clay Cr	W Br White Clay Cr	Upper White Clay Cr	Lower White Clay Cr	White Clay Cr
Temp (^oC)	Grade	C	D	B	B-	B	C+
	Score	50.5	28.5	65.9	60.8	69	55.9
	Mean	18.4	21.3	17.2	19.3	21.1	19.4
	n sites	29	6	2	17	13	67
	Yr range	2000-21	2014-21	2014-21	2000-21	2011-21	2000-21
DO (mg/L)	Grade	A	A	A	A	A-	A
	Score	88.3	88	95.1	90.5	81.3	89.6
	Mean	8.9	8.9	9.6	9.6	8.1	8.9
	n sites	23	6	2	7	7	45
	Yr range	2000-21	2014-21	2014-21	2000-21	2011-16	2000-21
TP (mg/L)	Grade	B+	C+	A+	A-	A	A-
	Score	79.4	57.5	100	84.4	87.9	82.2
	Mean	0.058	0.098	0.019	0.039	0.034	0.056
	n sites	14	4	2	6	1	27
	Yr range	1995-21	2003-08	2003-08	2002-21	2003-05	1995-21
NO_3N (mg/L)	Grade	F	F	F	F	D+	F
	Score	4.4	1.8	0	17.9	35.6	17
	Mean	4.7	5.4	6.2	3.1	4.2	4.4
	n sites	19	4	2	11	5	41
	Yr range	1990-21	2003-08	2003-08	2000-21	2003-21	1990-21

SC (µS/cm)	Grade	N/A-	N/A-	N/A-	N/A-	N/A-	N/A-
	Score	21.3	65.4	87.6	52.8	52	48
	Mean	401	285	238	272	360	341
	n sites	36	10	4	21	14	85
	Yr range	1992-21	2003-21	2003-21	2000-21	2003-21	1992-21
Cl (mg/L)	Grade	A	A+	A+	A+	A-	A
	Score	87.2	97.9	98.9	96.2	85	91.5
	Mean	30.5	21.1	18.2	19.9	24.7	25.8
	n sites	15	4	2	6	2	29
	Yr range	2002-21	2003-08	2003-08	2003-21	2003-21	2002-21
TSS (mg/L)	Grade	C			D	D	C
	Score	50.1			30.3	28	46.6
	Mean	8.1			7.2	10.5	8.2
	n sites	9			2	1	12
	Yr range	2013-20			2018-21	2018-20	2013-21
MAIS	Grade	D	D	D+	D-	F	D-
	Score	32.9	33.2	37.9	21.8	13.6	24.5
	Mean	9.7	7.2	8.5	5.3	2.7	8.5
	n sites	20	6	2	4	1	33
	Yr range	2003-21	2003-21	2003-08	2003-05	2003-05	2003-21
Overall Water Quality Score	Grade	C+	C	B	C+	C+	C+
	Score	56.1	51.5	66.3	57.4	57.2	58.2

Water Temperature

Water temperature is an important water quality variable to be measured because it varies temporally (e.g., day versus night, winter versus summer) and spatially (e.g., tropical versus arctic, sea level versus mountaintop, in the shade versus in the open), and it has a major influence on chemical and biological activity. Temperature affects chemical characteristics such as oxygen (see below) or salt solubility; physiological processes such as photosynthesis, growth, metabolism and respiration; and life history parameters such as body size, fecundity and development/generation time. Responses have been studied for fish, insects, zooplankton, algae and other aquatic species, but is probably best known for fish (i.e., coldwater versus warmwater fisheries). Anthropogenic influences that modify natural thermal regimes are well known, especially for warm-thermal pollution associated with deforestation and heated effluents (e.g., from power plants, factories or surface water released from reservoirs, ponds or stormwater basins). Cold-thermal pollution most commonly associated with deep water released from reservoirs. Some cases of thermal pollution have been addressed over the last 50 years, but many others (e.g., deforestation and releases from ponds or stormwater basins) are still common.

The best way to characterize the thermal regime of a freshwater ecosystem would be with a continuous recorder over many years. However, that represents a significant investment of time than many are not able to commit. Rather, most temperature values are instantaneous or single-point measures, representing temperature at that moment with no information about preceding or succeeding conditions. While not as thorough as a continuous record, the single-point measure can help identify potential thermal stress if measured temperature is unusually high, or compare sites if temporal differences among values can be addressed.

Temperature was measured at 67 sites in the White Clay Creek watershed, 29 sites in East Branch White Clay, six sites in Middle Branch White Clay, two sites in West Branch White Clay, 17 sites in Upper White Clay, and 13 sites in Lower White Clay. Based on available data, sites averaged 10.6 to 23.8°C (Table 42; Figure 63). These data summarize single-point measurements (no data from continuous temperature sensors were included here), so the data must be interpreted with caution because both low or high temperature might reflect extremes (e.g., a low in early morning in winter or high in later afternoon in summer) versus mean temperature for a site. Temperature at 45 sites equaled or exceeded 20°C, a common threshold for defining cold- and warmwater fisheries. Temperature at 31 sites equaled or exceeded 21°C, a common threshold for defining the thermal limit for brook-trout habitat. These data suggest that temperature at some sites may be stressful for coldwater species, at least at some times. However, based on known occurrences of year-around trout, and designated uses in PA, there are some locations in White Clay Creek that are able to support trout year around. Scores and Grades for each HUC 12 and overall are shown on Table 42.

When summarized by HUC 12, water temperature averaged 18.4°C across East Branch sites (area weighted score = 51 or “C”), 21.3°C across Middle Branch sites (area weighted score = 29 or “D”), 17.2°C across West Branch sites (area weighted score = 66 or “B”), 19.3°C across the Upper White Clay sites (area weighted score = 61 or “B-“), and 21.1°C across the Lower White Clay sites (area weighted score = 69 or “B”). It is important to remember that temperature criteria are colder for Coldwater Fisheries (e.g., all of East Branch) or Trout Stocking Fisheries (e.g., all of Middle Branch and West Branch) than for Warmwater Fisheries (e.g., portions of the

Upper and Lower White Clay). Thus, a temperature such as 20°C would score higher for a Warmwater Fisheries site than a Coldwater Fisheries site.

Across all sites in the five HUC 12s, the area weighted score for water temperature = 56 or "C+."

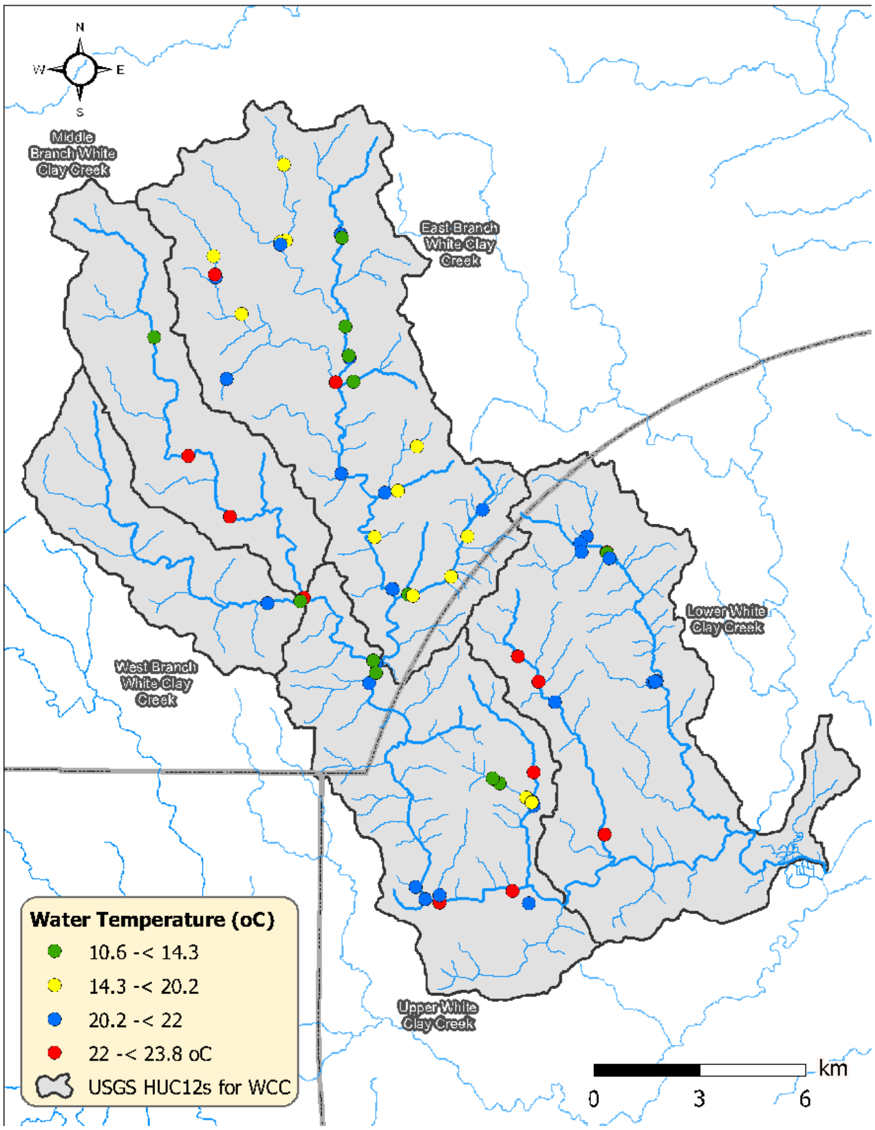


Figure 63. Map of average temperature measured at White Clay Creek sites

Dissolved Oxygen

As for animals on land, oxygen is essential to life in water, and most aquatic animals depend on dissolved oxygen to support their metabolic processes. Unfortunately, oxygen does not easily dissolve into water, and aquatic animals can be stressed when oxygen concentration is low.

Both physical and biological processes contribute to dissolved oxygen. Rapidly moving water and turbulence in the form of waves or water crashing over and around rocks increases the amount of dissolved oxygen as does oxygen produced by photosynthesis. Oxygen concentration decreases when oxygen consumption (e.g., metabolic activities of plants and animals, especially microbes associated with decomposition) exceeds oxygen production (i.e., photosynthesis) or reaeration/reintroduction (i.e., physical turbulence). Temperature also influences dissolved oxygen—oxygen is more soluble, and concentrations are higher when water temperature is cold versus warm.

Historically low oxygen was often a concern downstream of waste water treatment facilities and factories, where nutrients and organic waste resulted in excessive oxygen consumption by microbes, or downstream of reservoirs releasing deep water that had low oxygen (again due to microbial consumption). Both of these cases are much less common today as permitting associated with the Clean Water Act has addressed these problems over the last 50 years. Low oxygen concentration is less commonly measured, but still occurs, especially if there is an accidental spill such as a break in a sewage line, an accidental release from a manure or wastewater storage container, or excess algal production and elevated oxygen demand associated with eutrophic conditions (see phosphorus below).

Oxygen was measured at 45 sites in the White Clay Creek watershed, 23 sites in East Branch White Clay, six sites in Middle Branch White Clay, two sites in West Branch White Clay, seven sites in Upper White Clay, and seven sites in Lower White Clay. As noted above for temperature, these data summarize single-point measurements. No data from continuous oxygen sensors were included here. Based on available data, sites averaged 5.5 to >12 mg/L (Table 42; Figure 64). All but one site exceeded 7 mg/L and oxygen would not have been considered stressful. The site where oxygen was 5.5 mg/L might benefit from additional investigation as this equals the DO standard applied by PA to warmwater fisheries (i.e., <5.5 mg/L would be of concern for some warmwater fishes). Scores and Grades for each HUC 12 and overall are shown on Table 42.

When summarized by HUC 12, DO averaged 8.9 mg/L across East Branch sites (area weighted score = 88 or “A”), 8.9 mg/L across Middle Branch sites (area weighted score = 88 or “A”), 9.6 mg/L across West Branch sites (area weighted score = 95 or “A+”), 9.6 mg/L across the Upper White Clay sites (area weighted score = 91 or “A”), and 8.1 mg/L across the Lower White Clay sites (area weighted score = 81 or “A-“). As with temperature, it is important to remember that DO criteria are higher for Coldwater Fisheries (e.g., all of East Branch) or Trout Stocking Fisheries (e.g., all of Middle Branch and West Branch) than for Warmwater Fisheries (e.g., portions of the Upper and Lower White Clay). Thus, a temperature such as 7 mg/L would score higher for a Warmwater Fisheries site than a Coldwater Fisheries site because it would be considered higher than usual.

Across all sites in the five HUC 12s, the area weighted score for dissolved oxygen = 90 or “A.”

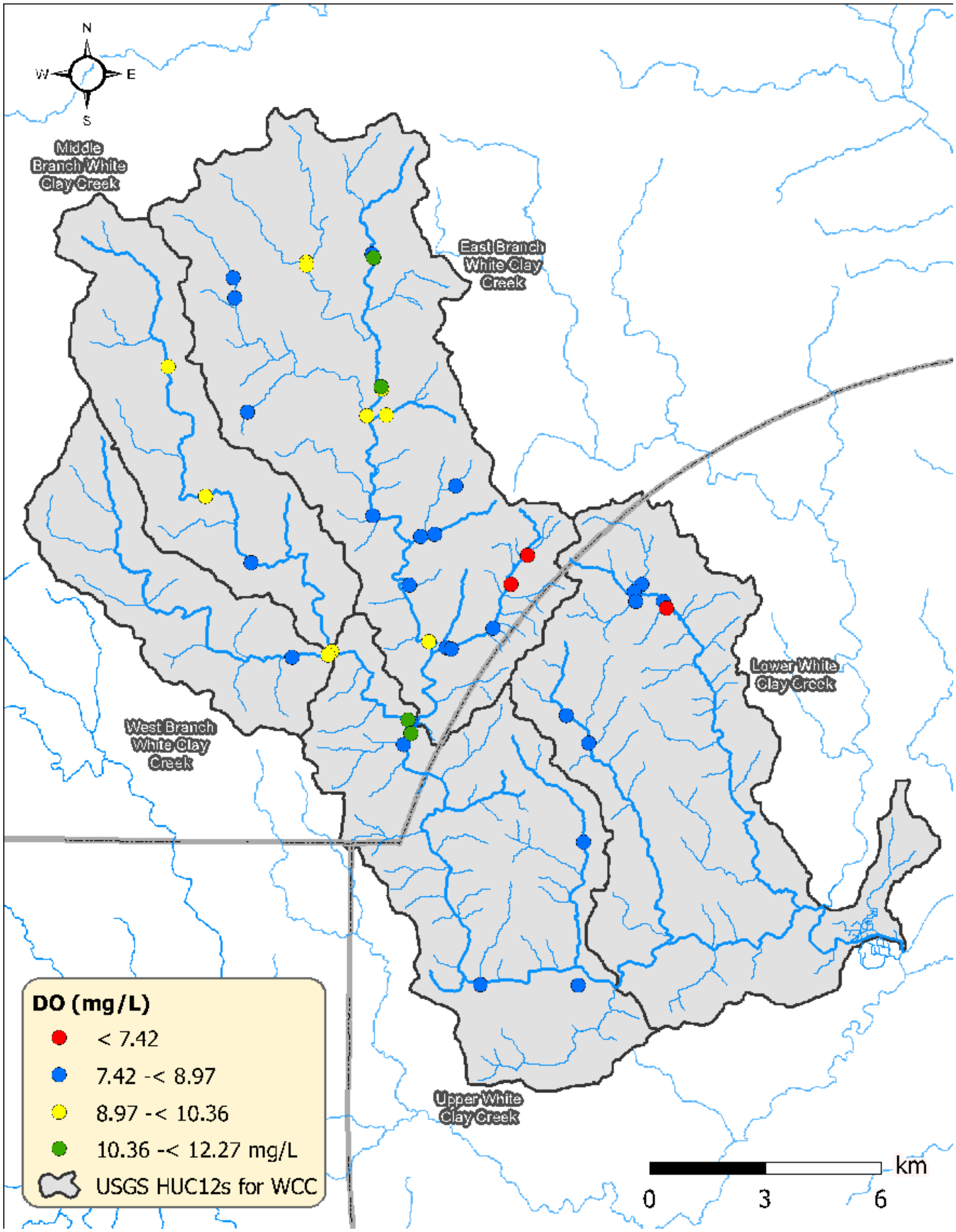


Figure 64. Map of dissolved oxygen (mg/L) measured at White Clay Creek sites. Note that conditions improve as dissolved oxygen increases.

Phosphorus

Phosphorus is critical to plant and animal life, playing key roles in physical structure (e.g., DNA, cell membranes and even bones) and cellular physiology/function. While not an uncommon element, most phosphorus on land is tied up geologically and not readily available for biological use. As a result, phosphorus is often considered an element that limits life in fresh water draining from that land. Because phosphorus is often a, or the, factor limiting plant and microbial growth in fresh water in the mid-Atlantic region, added phosphorus can increase plant and microbial growth. Phosphorus is considered a pollutant when it contributes to eutrophication (i.e., excess algal and microbial growth), which can be associated with harmful algal blooms, nuisance algal and aquatic plant growth, and even low dissolved oxygen levels (i.e., anoxia or hypoxia) and fish kills. People add phosphorus to fresh water through point sources (i.e., effluents from wastewater treatment plants) as well as nonpoint sources (i.e., agricultural and urban runoff). Since the 1970s, reducing the phosphorus added to aquatic ecosystems has been a priority for pollution reduction plans. These included efforts to reduce phosphorus use such as the nationwide voluntary ban of phosphorus in laundry detergent in 1994, and some bans of phosphorus in automatic dishwasher detergent in 2010. There have been more targeted bans of phosphorus use such as in lawn fertilizers in the Chesapeake Bay watershed. Phosphorus-reduction efforts also included major upgrades to wastewater treatment facilities to increase biological/chemical removal of phosphorus (i.e., a component of nutrient removal in tertiary treatment of wastewater).

There are a variety of ways to express the amount of phosphorus in water. Total Phosphorus is a measurement that accounts for all of the dissolved and particulate forms of phosphorus, including the orthophosphates, polyphosphates and organophosphates. These can also be referred to as soluble reactive phosphorus (SRP), soluble unreactive or soluble organic phosphorus (SUP) and particulate phosphorus (PP). The sum of SRP and SUP is called soluble phosphorus (SP), and the sum of all phosphorus components is termed total phosphorus (TP). Soluble and particulate phosphorus are differentiated by whether or not they pass through a 0.45-micron membrane filter.

In wastewater, most of the particulate/insoluble phosphorus is removed through sedimentation during primary treatment; the remaining phosphorus forms are converted in secondary treatment to orthophosphates. Therefore, the majority of phosphorus found within treated-wastewater effluent is in the form of orthophosphates, such as SRP; this form is the most bioavailable to plants and microbes and is of the greatest concern for reducing eutrophication.

Total Phosphorus (TP) was measured at 27 sites in the White Clay Creek watershed, 14 sites in East Branch White Clay, four sites in Middle Branch White Clay, two sites in West Branch White Clay, six sites in Upper White Clay, and one site in Lower White Clay. Based on available data, sites averaged 0.014 to 0.270 mg/L for TP (Table 42; Figure 65). All of these averages summarize single-point measurements.

SRP (PO_4-P) was measured at 16 sites in the White Clay Creek watershed, six sites in East Branch White Clay, zero sites in Middle Branch White Clay, zero sites in West Branch White Clay, six sites in Upper White Clay, and one site in Lower White Clay. Based on available data, sites averaged 0.007 to 0.853 mg/L for PO_4-P. All of these averages summarize single-point measurements.

For the State of the White Clay report, we addressed phosphorus based only on the TP data because data were available from more sites (27 vs 16 sites). Scores and Grades for each HUC 12 and overall are shown on Table 42.

When summarized by HUC 12, TP averaged 0.058 mg/L across East Branch sites (area weighted score = 79 or “B+”), 0.098 mg/L across Middle Branch sites (area weighted score = 58 or “C+”), 0.019 mg/L across West Branch sites (area weighted score = 100 or A+), 0.040 mg/L across the Upper White Clay sites (area weighted score = 84 or “A-"), and 0.034 mg/L across the Lower White Clay sites (area weighted score = 88 or “A”).

Across all sites in the five HUC 12s, and the area weighted score for TP = 82 or “A-.”

The high grades for phosphorus (i.e., low concentrations), accompanied by high dissolved oxygen, show that these watersheds are probably phosphorus limited, and not eutrophic (impaired by excess nutrients).

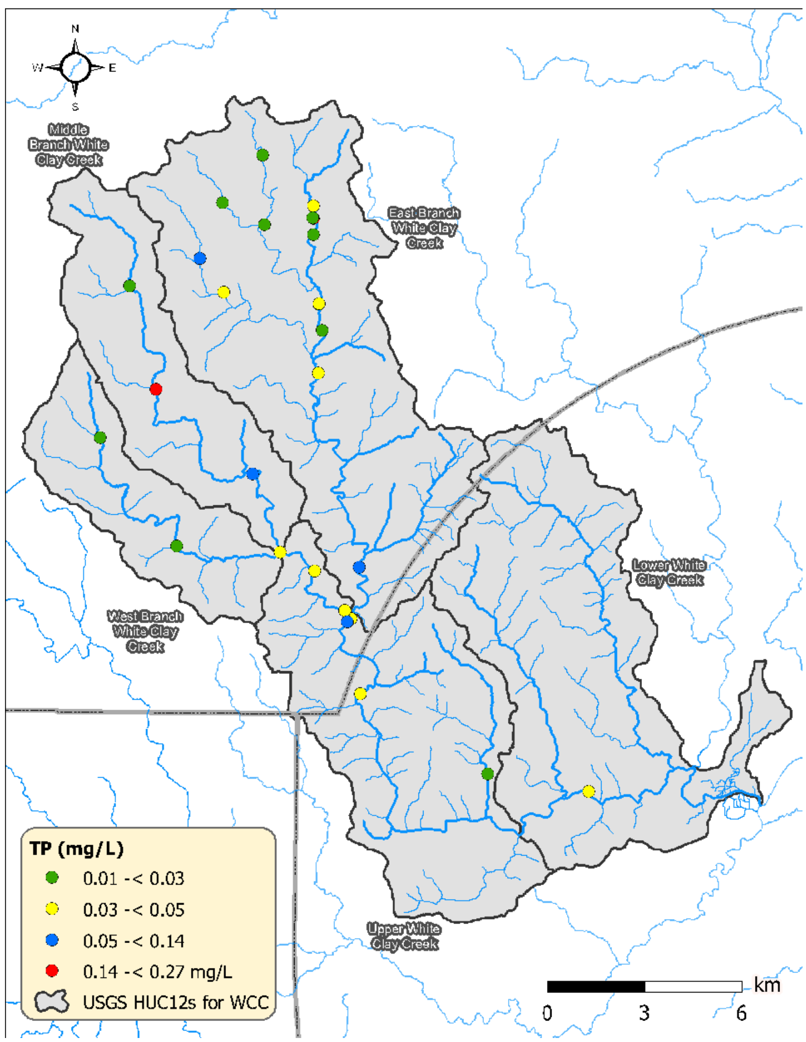


Figure 65. Map of average total phosphorus (mg/L) measured at White Clay Creek sites.

Nitrogen

Nitrogen, like phosphorus, is critical to plant and animal life, playing key roles as core components of amino acids, which are the building blocks of proteins, and of nucleic acids, which are the building blocks of genetic material (RNA and DNA). Nitrogen is generally more abundant in fresh water than phosphorus and is therefore generally not considered the factor limiting plant and microbial growth in fresh water in the mid-Atlantic region. However, when there is excess phosphorus, nitrogen can become the factor limiting plant and microbial growth. Under those conditions, added nitrogen can also contribute to eutrophication (i.e., excess algal and microbial growth) of our aquatic ecosystems. Evidence of eutrophication include harmful algal blooms, nuisance algal and aquatic plant growth, and even low dissolved oxygen levels (i.e., anoxia or hypoxia) and fish kills. Dead zones at the mouths of rivers such as the Mississippi River or in the Chesapeake Bay often reflect the combined effects of abundant phosphorus (from marine waters) and nitrogen (from the river). People add nitrogen to freshwater ecosystems primarily through agricultural activities—fertilizer for crops and liquid and solid waste from livestock—and through point sources associated with wastewater treatment plants and urban runoff. A third source of nitrogen to a watershed is atmospheric deposition in the form of dissolved and particulate nitrogen.

The map in Figure 66 shows the status of impairment for nutrients (both nitrogen and phosphorous) in the streams of the White Clay Creek watershed in Delaware and Pennsylvania, based on the integrated reports on impairments produced by the Pennsylvania Department of Environmental Protection (PA DEP) and Delaware Department of Natural Resources and Environmental Control (DNREC).

The amount of nitrogen in water is expressed in several ways. Total Nitrogen (TN) is the sum of nitrate-nitrogen (NO3-N), nitrite-nitrogen (NO2-N), ammonia-nitrogen (NH3-N) and organically bonded nitrogen. Total Nitrogen and nitrate are most commonly measured. Ammonia can be a concern if abundant because it can be toxic to fish and other organisms, and because it can contribute to low oxygen conditions as it is converted (i.e., oxidized) to nitrate.

Nitrate-N (NO3-N) was measured at 41 sites in the White Clay Creek watershed, 19 sites in East Branch White Clay, four sites in Middle Branch White Clay, two sites in West Branch White Clay, 11 sites in Upper White Clay, and five sites in Lower White Clay (Table 42; Figure 67). Based on available data, sites averaged 0.7 to 10.3 mg/L for NO3-N.

Total Nitrogen (TN) was measured at 11 sites in the White Clay Creek watershed, nine sites in East Branch White Clay, zero sites in Middle Branch White Clay, zero sites in West Branch White Clay, two sites in Upper White Clay, and zero sites in Lower White Clay. Based on available data, sites averaged 2.9 to 6.2 mg/L for TN (Figure 66).

For the State of the White Clay report, we addressed nitrogen based on nitrate (NO3-N) data because data were available from more sites (41 sites vs 11 sites for Total Nitrogen). All of these averages summarize single-point measurements. Scores and Grades for each HUC 12 and overall are shown on Table 42.

When summarized by HUC 12, NO3-N averaged 4.7 mg/L across East Branch sites (area weighted score = 4 or “F”), 5.4 mg/L across Middle Branch sites (area weighted score = 2 or “F”), 6.2 mg/L across West Branch sites (area weighted score = 0 or “F”), 3.1 mg/L across the Upper White Clay sites (area weighted score = 18 or “F”), and 4.2 mg/L across the Lower White Clay sites (area weighted score = 36 or “D+”).

Across all sites in the five HUC 12s, the area weighted score for nitrate = 17 or “F.”

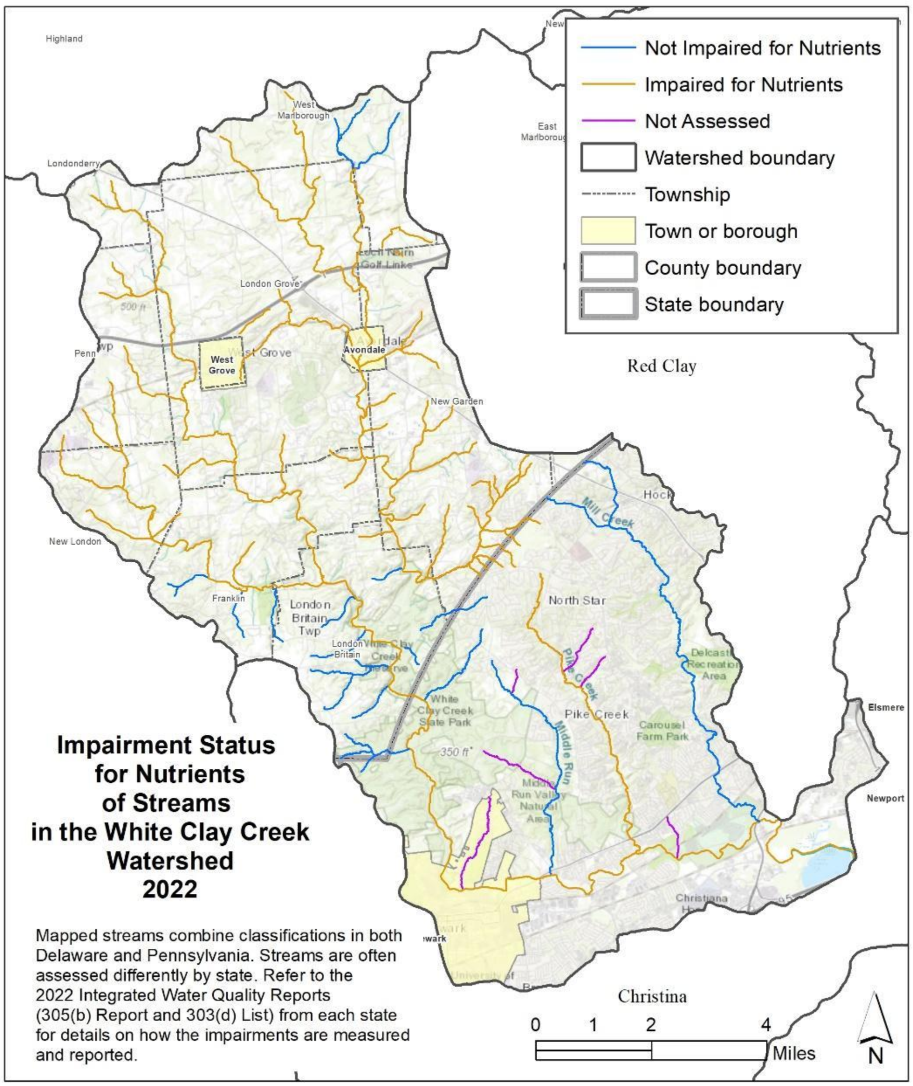


Figure 66. Streams impaired for nutrients in the White Clay Creek watershed, 2022

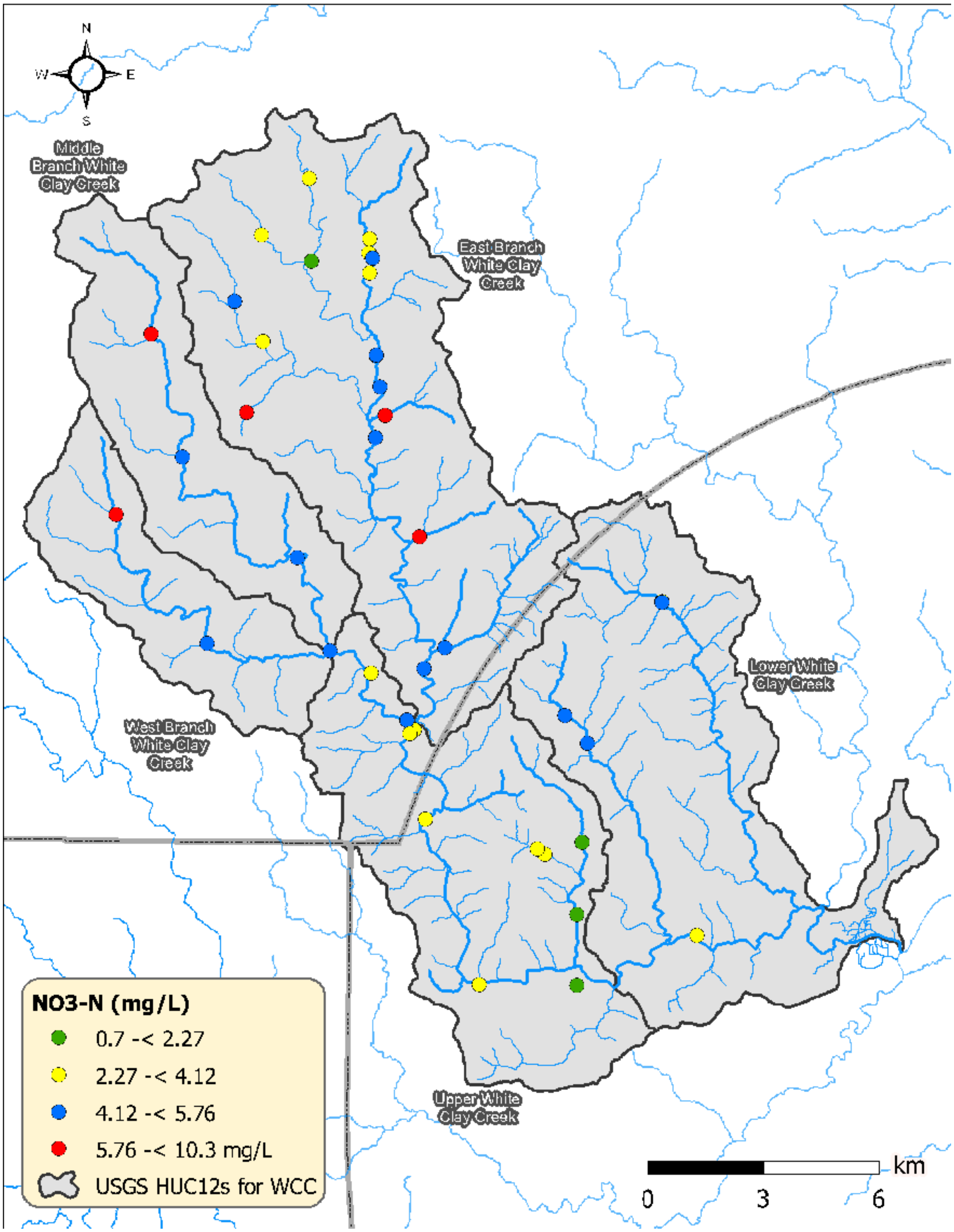


Figure 67. Map of average nitrate (mg/L) measured at White Clay Creek sites.

Specific Conductance/Chloride

The amount of salt (e.g., NaCl, CaCO2, MgCO2) dissolved in water is commonly measured and expressed as Specific Conductance (i.e., conductivity corrected to 25°C), as Total Dissolved Solids (TDS), as hardness (combination of calcium and magnesium concentrations), or as individual cations (e.g., calcium, magnesium, sodium, potassium concentrations), and/or anions (e.g., carbonate, sulfate, chloride concentrations). Under natural conditions, the concentration of dissolved salts in stream water reflects the solubility of salts in the groundwater and soils. A wide variety of anthropogenic activities can add salts to fresh water. Two of the most common sources of additional salt would be road salt applied for winter deicing, and effluent from wastewater treatment facilities. Wastewater can have elevated salts due to our salty diets and lifestyles, and due to brines from water softeners. In most cases, it appears that freshwater animals are relatively tolerant of some added salt relative to known toxins such as insecticides. However elevated salts often present water balance challenges that impact physiological processes for aquatic animals, and at times can be lethal.

We addressed dissolved salts by looking at both specific conductance and chloride. Conductivity is probably the most commonly used measure of salt concentration. Conductivity (expressed as µS/cm) is a measure of the ability for electricity to pass through water. This ability reflects the concentration of soluble salts or ions—water with low ion concentration has low conductivity (e.g., rainwater <50 µS/cm); water with high ion concentration has high conductivity (e.g., limestone streams = 500 to >1000 µS/cm, seawater ~ 55,000 µS/cm). Because water conductivity increases as water temperature increases, the standardized method of reporting conductivity is to correct to 25° C, which is reported as Specific Conductance. Most conductivity sensors make this correction automatically and thus users are not aware of adjustment. However, it is essential that the data recorded be correctly labeled as either conductivity or specific conductance to ensure comparability. In addition to specific conductance, the amount of salt in fresh water is also being expressed as chloride concentration because of its connection to table salt or rock salt (i.e., primarily NaCl). Estimates of chloride concentration are relatively easy and inexpensive to obtain.

Specific conductance was measured at 85 sites in the White Clay Creek watershed, 36 sites in East Branch White Clay, 10 sites in Middle Branch White Clay, four sites in West Branch White Clay, 21 sites in Upper White Clay, and 14 sites in Lower White Clay. Based on available data, sites averaged 112 to 700 µS/cm (Table 42; Figure 68). All of these averages summarize single-point measurements. No data from continuous conductivity sensors were included here. Scores and Grades for each HUC 12 and overall are shown on Table 42.

Chloride was measured at 29 sites in the White Clay Creek watershed, 15 sites in East Branch White Clay, four sites in Middle Branch White Clay, two sites in West Branch White Clay, six sites in Upper White Clay, and two sites in Lower White Clay. Based on available data, sites averaged 8 to 88 mg/L (Figure 69). All of these averages summarize single-point measurements. Scores and Grades for each HUC 12 and overall are shown on Table 42.

When summarized by HUC 12, specific conductance averaged 401 µS/cm across East Branch sites (area weighted score = 21 or “D-"), 284 µS/cm across Middle Branch sites (area weighted score = 65 or “B”), 238 µS/cm across West Branch sites (area weighted score = 88 or “A”), 272 µS/cm across the Upper White Clay sites (area weighted score = 53 or “C”), and 341 µS/cm across the Lower White Clay sites (area weighted score = 52 or “C”).

Across all sites in the five HUC 12s, the area weighted score for specific conductance = 48 or “C.”

When summarized by HUC 12, chloride averaged 31 mg/L across East Branch sites (area weighted score = 87 or “A”), 21 mg/L across Middle Branch sites (area weighted score = 98 or “A+”), 18 mg/L across West Branch sites (area weighted score = 99 or “A+”), 25 mg/L across the Upper White Clay sites (area weighted score = 96 or “A+”), and 26 mg/L across the Lower White Clay sites (area weighted score = 85 or “A”).

Across all sites in the five HUC 12s, the area weighted score for chloride = 92 or “A.”

For the State of the White Clay report, the overall water quality score used chloride to evaluate degree of environmental degradation associated with dissolved salts. Specific Conductance was influenced by natural variation in underlying geology (i.e., presence or absence of limestone/carbonate bedrock and derived soils) within the White Clay watershed, making it impossible to separate differences in conductivity due to geology versus other salt sources such as road salt, water softeners, wastewater and agricultural field treatments. The low chloride concentrations and high grades in the more urbanized areas (i.e., Upper and Lower White Clay sites) were unexpected as chlorides are generally elevated in urbanized areas due to winter deicing programs that use salt brines and road salts. However, the absence of elevated chlorides in these areas may merely reflect the limited number of sites where chloride was measured. More urbanized sites, including small watersheds with extensive parking lots and roads/highways, need to be sampled to understand stream responses to past and present winter deicing programs in the White Clay watershed.

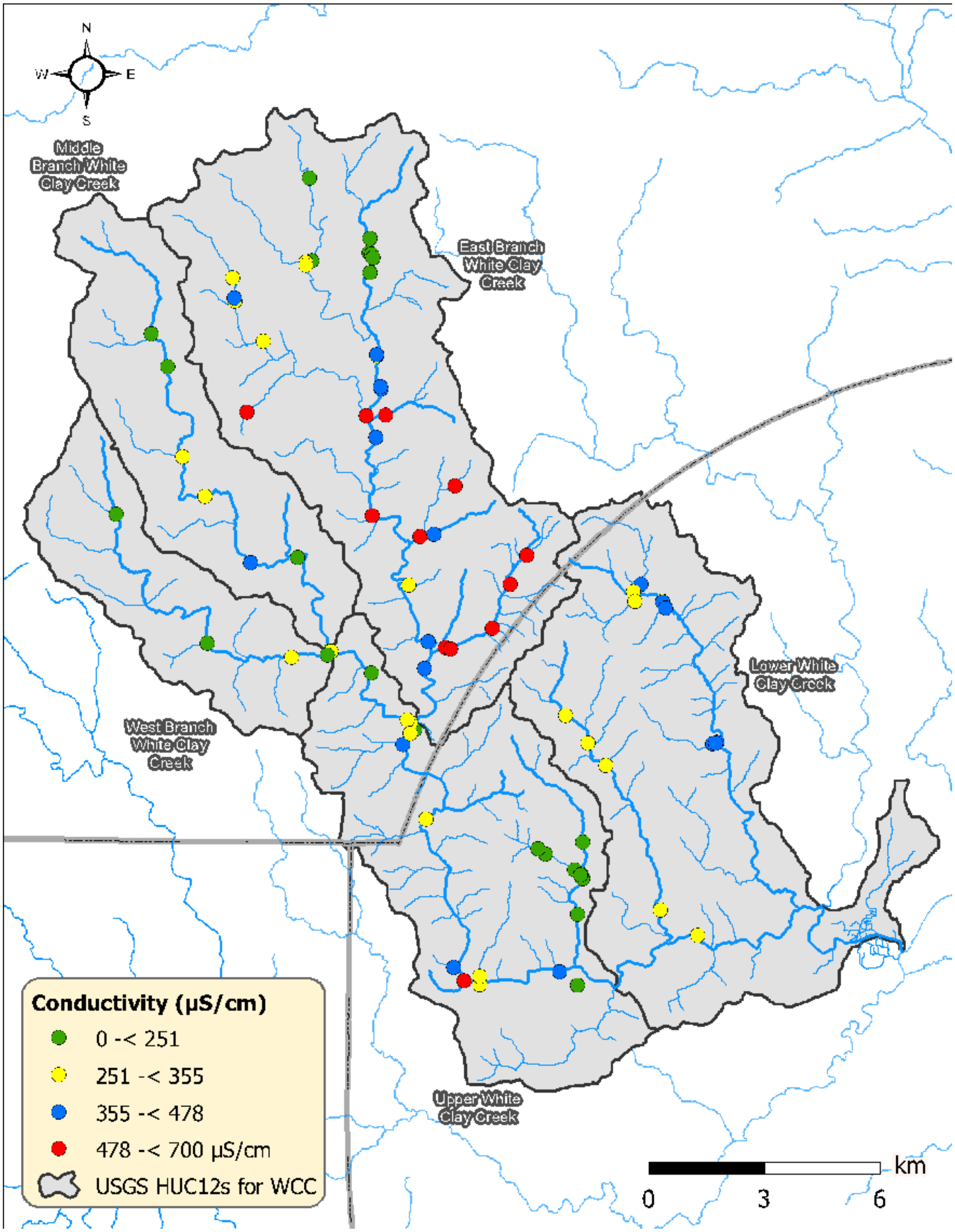


Figure 68. Map of average specific conductance (µS/cm) measured at White Clay Creek sites.

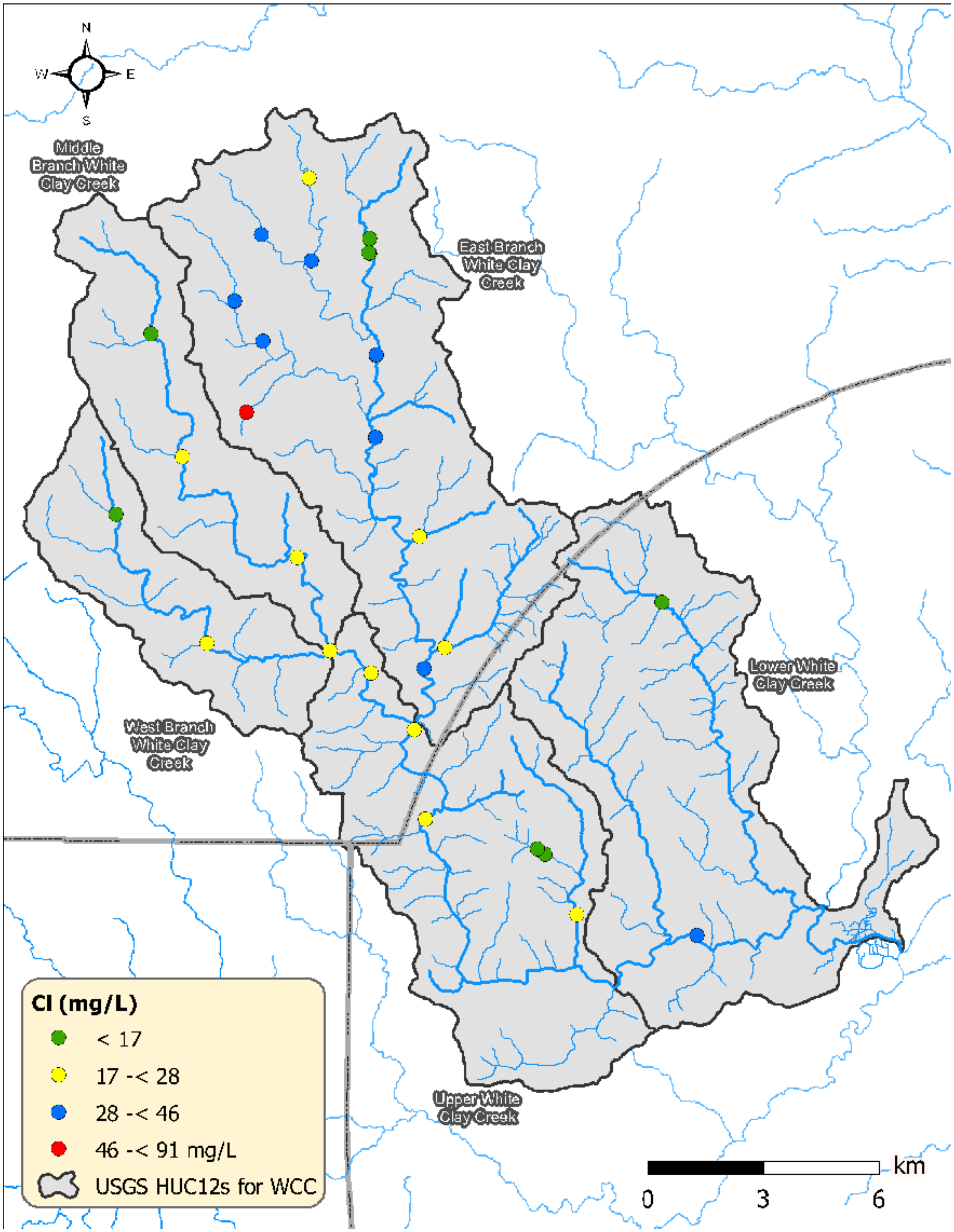


Figure 69. Map of average chloride (mg/L) measured at White Clay Creek sites.

Total Suspended Sediment

Total suspended solids or sediments (TSS) are inorganic (sediment, silt and sand) and organic (algae, bacteria, fine plant or animal tissue) particles that are found in the water column. Most suspended solids are made up of inorganic materials, but the suspended organic particles are important food for filter-feeding invertebrates, and collector/gatherers that feed on the organic particles once they settle along stream edges or in slow, depositional areas. As TSS increases, measured turbidity increases and the water is less clear. TSS at a site can vary with discharge; TSS might be low and the water clear at baseflow whereas TSS might be high and the water turbid during a flood event. Many solids suspended during a flood event can settle out into the streambed as velocities and turbulence decrease, and this can have a negative impact on aquatic life (plants and animals) that depends on clean/clear substrates or open spaces between rocks and gravel. Thus, while TSS is natural in streams and rivers, suspended particles that settle into the streambed can become a pollutant when they are excessive. TSS can also act as a pollutant when it contains high levels of organic particles, such as those associated with intensive farming activity (e.g., cows in streams), industrial processes (e.g., paper mills) or sewage wastes. These abundant organic particles can contribute to low dissolved oxygen conditions that result from decomposition.

Total Suspended Solids (TSS) was measured at 12 sites in the White Clay Creek watershed, nine sites in East Branch White Clay, zero sites in Middle Branch White Clay, zero sites in West Branch White Clay, two sites in Upper White Clay, and one site in Lower White Clay. Based on available data, sites averaged 1.8 to 26 mg/L (Table 42; Figure 70). All of these averages summarize single-point measurements. Scores and Grades for each HUC 12 and overall are shown on Table 42.

When summarized by HUC 12, TSS averaged 8.1 mg/L across East Branch sites (area weighted score = 50 or “C”), 7.1 mg/L across the Upper White Clay sites (area weighted score = 30 or “D”), and 10.5 mg/L across the Lower White Clay sites (area weighted score = 28 or “D”). There were no TSS data for Middle Branch or West Branch sites

Across all sites in the five HUC 12s, the area weighted score for TSS = 47 or “C.”

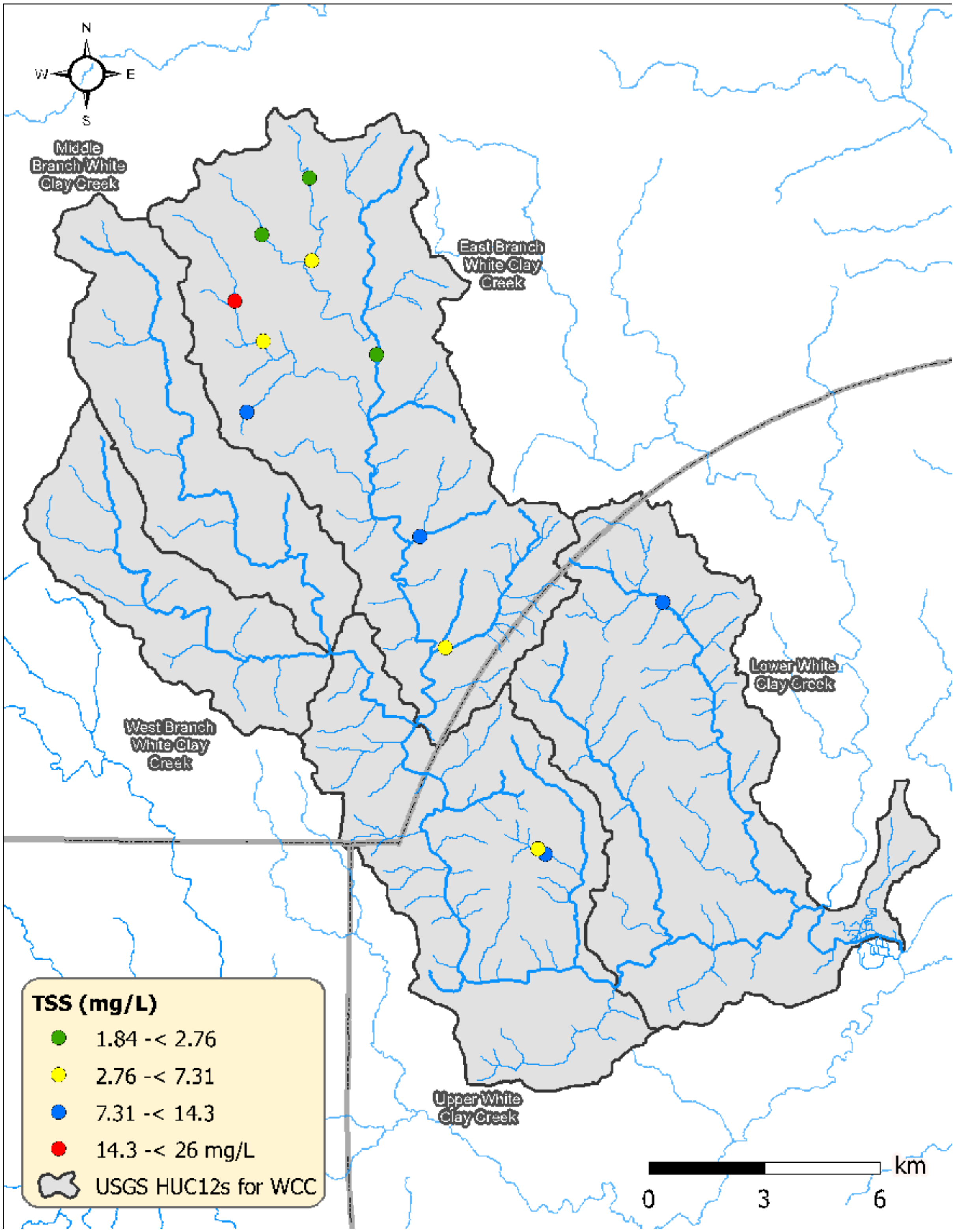


Figure 70. Map of average total suspended sediment (mg/L) measured at White Clay Creek sites.

Macroinvertebrates

Aquatic macroinvertebrates (i.e., aquatic insects as well as other aquatic invertebrates such as worms, crayfish, snails and mussels) are the most common group of aquatic organisms included in water quality assessment programs (Weber 1973, Hellawell 1978, Hawkes 1979, Rosenberg and Resh 1993, Resh 2008, Hauer and Resh 2017) and have provided water quality assessment programs with valuable insight for more than 100 years (Cairns and Pratt 1993). They are the most cost-effective, commonly used and widely accepted tools in water quality monitoring programs for a number of reasons:

1.) Most river and stream ecosystems have relatively diverse aquatic insect assemblages (100-200 species), with species from several different orders [e.g., Ephemeroptera (mayflies), Trichoptera (caddisflies), Coleoptera (beetles), Diptera (true flies)]. Each of these species is to some degree evolutionarily unique; as a result, each potentially possesses different tolerances to changes in environmental conditions. Thus, together, the aquatic macroinvertebrates are a sensitive measure of environmental change and stress.
2.) Their limited mobility and relatively long lifespans (a few months to at least a year) in the water make the presence or conspicuous absence of a species at a site a meaningful record of environmental quality during the recent past, including short-term and/or infrequent pollution events that might be missed by periodic water samples.
3.) Macroinvertebrates are an important link in the food web, functioning as primary consumers (herbivores and detritivores) of plant and microbial matter that are then available to secondary consumers such as fish.
4.) Their abundance lends itself to statistical analysis, which can play an integral role in water quality assessment programs. The presence or conspicuous absence of certain macroinvertebrate species at a site is a meaningful record of environmental conditions during the recent past, including ephemeral events that might be missed by assessment programs that rely on periodic water chemistry samples (Weber 1973, Barbour et al. 1999).

Aquatic macroinvertebrates were sampled at 33 sites in the White Clay Creek watershed, 20 sites in East Branch White Clay, six sites in Middle Branch White Clay, two sites in West Branch White Clay, four sites in Upper White Clay, and one site in Lower White Clay. Based on available data, MAIS Scores averaged 1.1 to 13.9 (Table 42; Figure 71). Of the 33 sites, five sites were classified as Good, 19 sites were classified as Fair, nine sites were classified as Poor. All of the Good sites were located in the headwaters of the East Branch. Scores and Grades for each HUC 12 and overall are shown on Table 42.

When summarized by HUC 12, MAIS Scores averaged 9.7 across East Branch sites (area weighted score = 33 or “D”), 7.2 across Middle Branch sites (area weighted score = 33 or “D”), 8.5 across West Branch sites (area weighted score = 38 or “D+”), 5.3 across the Upper White

Clay sites (area weighted score = 22 or “D-"), and 2.7 across the Lower White Clay sites (area weighted score = 14 or “F”).

Across all sites in the five HUC 12s, the area weighted score for MAIS Scores = 25 or “D.”

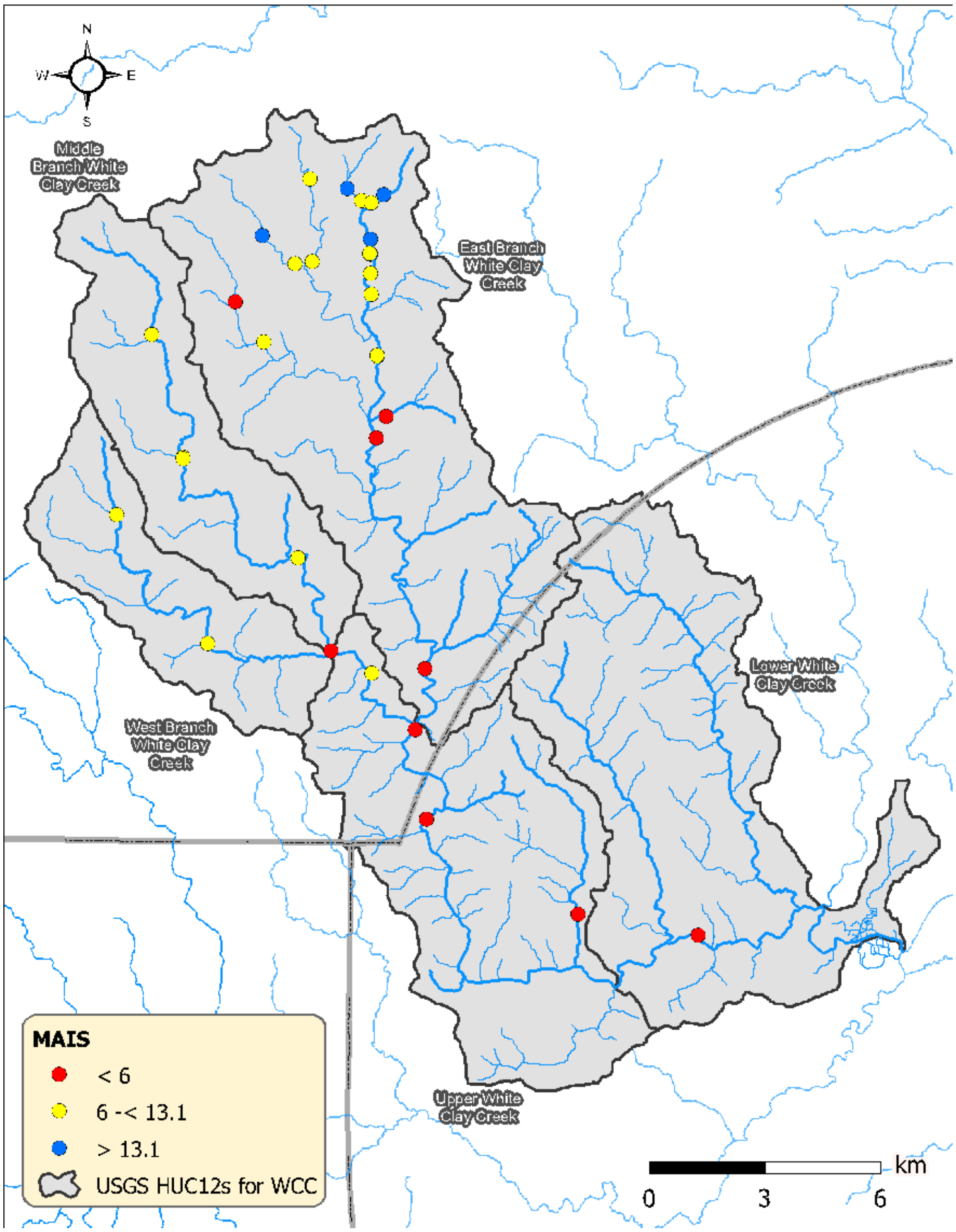


Figure 71. Map of average Macroinvertebrate Score (MAIS, Macroinvertebrate Aggregated Index for Streams) measured at White Clay Creek sites. Note that conditions improve as MAIS Score increases.

The map in Figure 72 shows the status of impairment for macroinvertebrates (aquatic life) in the streams of the White Clay Creek watershed in Delaware and Pennsylvania, based on the integrated reports on impairments produced by PA DEP and DNREC.

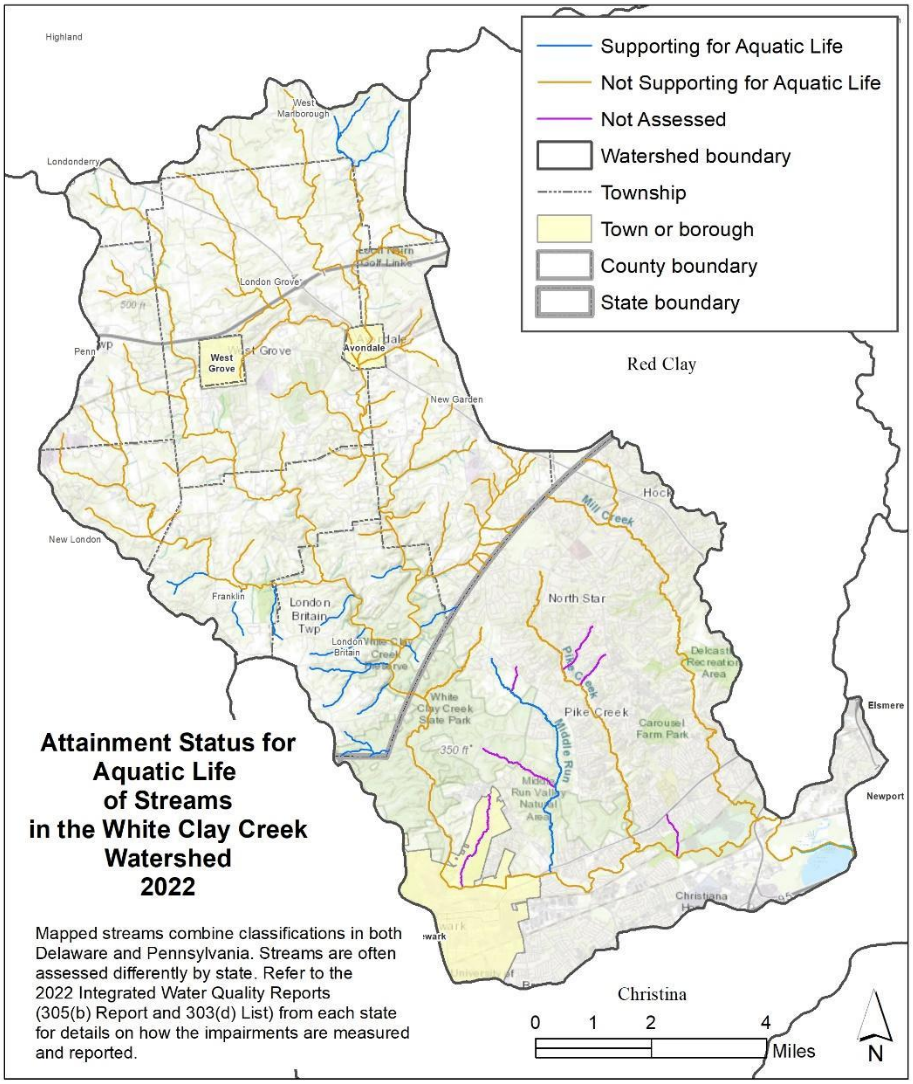


Figure 72. Streams not supporting for aquatic life in the White Clay Creek watershed, 2022

Summary of Water Quality Indicators for White Clay Creek

Based on seven measures of water quality, the overall grade for White Clay Creek was a “C+.” As with most watersheds in the region, this reflects a wide range of conditions, from Good to Poor. Based on HUC 12 averages, the West Branch received the highest grade (“B”) while the Middle Branch received the lowest grade (“C”). The East Branch, Upper White Clay and Lower White Clay all received grades of “C+.” While these averages of averages are nothing spectacular, there are many positives across the many sites summarized there. Dissolved oxygen and chloride averaged “A” across the watershed, while total phosphate averaged “A” and “B” at four of five HUC 12s, and “A-" overall. In contrast, nitrate was elevated in all HUC 12s and was given a grade of “F” in four of five HUCs. The upper reaches of the East Branch had some of the best grades among all sites, even compared with other portions of the East Branch HUC 12. Temperature tended to be cool, dissolved oxygen was high, total phosphorus and chloride were low, and macroinvertebrates were Good or Good/Fair. This was not unexpected as this portion of the watershed is designated as Exceptional Value and has been good for decades (it received this Special Protection status in 1984).

Macroinvertebrates summarize overall environmental health as their response integrates many environmental stressors (physical, chemical and biological) at a site (measured and unmeasured; constant and ephemeral). In the case of White Clay Creek, all five HUC 12s were given grades of “D” or “F,” and the overall grade for macroinvertebrates in White Clay Creek was “D-.” These low grades mean that a wide variety of macroinvertebrate species are unable to tolerate conditions at numerous sites throughout the watershed. These results match the “impaired or failing to sustain aquatic life” designations by Pennsylvania Department of Environmental Protection and Delaware Natural Resources and Environmental Control (DNREC). Unfortunately, these macroinvertebrate grades only indicate that there is excess stress, but does not identify the stressor(s).

Based on high grades for each HUC 12 and watershed wide, it appears that this stress is not related to dissolved oxygen, chloride or total phosphate. In contrast, temperature and nitrate give some clues to potential stressors. Elevated temperature (and land cover analyses) indicates that stream degradation may be related, in part, to riparian forest removal. Streamside areas that are deforested contribute to thermal stress in the stream and are not fully contributing to the buffering/protection of these streams from land and water uses that drain to the stream. Nitrate is high in both agricultural and urbanized areas and is evidence that intensive agricultural and urban activities are defining, in part, water quality in the stream and groundwater. This might reflect extensive use or improper storage of manures, other soil amendments, and/or chemical fertilizers in agricultural lands, and lawn fertilizer use and the dominance of wastewater effluents (which is often treated to remove phosphorus, but not nitrogen) in urban areas. The widespread and continuous nature of elevated nitrogen conditions suggest that these agricultural and urbanized watersheds have been producing excess “fertilizers” that show up as degradation of stream water and groundwater quality across years, and even decades.

Nitrate itself does not appear to be a significant stressor as it was not at levels known to be toxic, and it is not accompanied by high phosphate that might contribute to anoxia/hypoxia associated with eutrophication (of the high dissolved oxygen frequently measured). In addition, nitrate is elevated even at the best sites in the White Clay watershed. However, elevated nitrate is evidence that agricultural and urban land and water uses are intensive enough to change water quality in the stream and groundwater, and therefore may be contributing to the degradation of stream condition. Nitrate may be an indicator of the presence of other chemical stressors associated with agricultural and urban land and water uses, but these other stressors were not measured and therefore could not be included in our analyses. This could involve toxins (agricultural or urban) reaching these waterways as nonpoint-source pollutants (i.e., through runoff and groundwater), and/or as part of permitted point-source effluents coming from wastewater treatment facilities. It will be a challenge to identify and prioritize these other stressors as their influence might be diffuse (i.e., widely variable across the landscape, and over time). Better conditions in the Exceptional Value portion of the East Branch suggest that more complete forested buffer coverage, and better farmland practices, may help address some of these other stressors and contribute positively to improved conditions in other agricultural portions of the White Clay watershed.

2.5 Category 4: Scenery

Scenic quality and view importance are the key indicators used in ranking Scenic Value. The *scenic quality rating* identifies and describes visible elements of the viewed landscape and rates the scenic quality of the view. The *view importance rating* identifies and describes key scenic, cultural and/or historic attributes of the viewpoint in addition to rating the importance of the view to NPS (or the local land manager) and the visitor experience. The following table (Table 43) summarizes the grading for the two scenery indicators for the White Clay Creek watershed and subwatersheds:

Table 43. White Clay Creek, overall grades for Scenery

	Lower Main Stem	Upper Main Stem	East Branch	Middle Branch	West Branch	Watershed
Scenery	**N/A**	**B+**	**B**	**B**	**N/A**	**B**
Scenic Quality	N/A	A-	A-	A	N/A	A
View Importance	N/A	B	B-	C	N/A	B-

Scenic Quality and View Importance

The scenic quality and view importance of 10 locations in the watershed were rated using the National Park Service (NPS) Visual Resource Inventory methodology (VRI). The VRI is a systematic process to identify scenic values and importance to NPS visitor experience and interpretive goals, for views within and extending beyond NPS units. The NPS VRI includes two primary processes that lead to ratings for scenic quality and view importance: the scenic quality assessment and the view importance assessment. The scenic quality and view importance data were collected in 2021. A NPS representative provided training (in the form of two online and recorded webinars) to the White Clay Wild and Scenic Program Director and 10 volunteers prior to going out in the field. The views (and data) within the White Clay Wild and Scenic watershed will be added to the White Clay watershed interactive map. A full description of the Visual Resources Inventory methodology is available online at http://blmwyomingvisual.anl.gov/vr-inventory/nps/.

Views in the White Clay Creek watershed were selected to be representative of those within the most visited sections of the watershed (accessible by trail and on public land). Views in the following HUCs were selected and assessed to be representative within the White Clay Creek watershed:

- East Branch
- Middle Branch
- Upper White Clay Creek

Views were identified, mapped, described and evaluated in a way that seeks to represent the visitor's experience. Each view is mapped and described from the viewers' perspective and is evaluated to capture two distinct facets of a view: what is its scenic quality and how important is it to the visitor experience?

The following table (Table 44) summarizes the views were assessed within the East Branch, Middle Branch and Upper White Clay Creek subbasins.

Table 44. Views assessed in the subwatersheds of the White Clay Creek

East Branch White Clay Creek
View of the East Branch along the PennDel Trail between parking lot 1 and the pedestrian bridge across the East branch in White Clay Creek Preserve, London Britain Township, PA.
View from Wendel Cassel Farm Trail near Yeatmans Station Road in White Clay Creek Preserve, London Britain Township, PA
Middle Branch White Clay Creek
View of the Middle Branch in Banffshire Preserve, Franklin Township, PA.
View from the farm overlook in Banffshire Preserve, Franklin Township, PA.
Upper White Clay Creek
View of the Welsh Baptist Church (also known as the London Tract Meeting House) in the White Clay Creek Preserve, London Britain Township, PA.
View of the Shirley Russel bridge from upstream along the main branch White Clay Creek, White Clay Creek State Park, Newark, DE.
View of the Dean Woolen Mill from the Newark Reservoir, Newark, DE.
View looking towards the White Clay Creek Preserve from the Tristate Marker, London Britain Township, PA/Newark, DE/Cecil County, MD.
View of White Clay Creek State Park (main branch) from Robinson House, White Clay Creek State Park, Newark, DE.
View of the Arc Corner Monument, White Clay Creek State Park, Newark, DE.

Data were not collected or reported for the West Branch and Lower White Clay Creek. These two subwatersheds are therefore not included in the overall watershed scores.

The NPS Scenic Inventory Value (SIV) comprises two parts, the Scenic Quality Rating and the View Importance Rating. A SIV for each site assessed was generated and the raw scores for scenic and view importance are shown in Table 45. Raw scores for scenic quality and view importance from each site were weighted by subbasin and converted to percent for calculation. It is important to note that the maximum scores in each category unweighted is 45, the maximum scores were also weighted by subbasin. Area-weighted scores were calculated for each river section and for the watershed. Grades reported for the entire watershed are based on the area-weighted average scores across the three subbasins that were assessed (Table 45). Letter grades were assigned using a 100-point scale with 20-point breaks (Table 46).

Table 45. Unweighted Scenic Inventory Values (NPS Scoring Protocol)

View ID #	View Name	Sub-watershed name	Visual Quality (Scenery Score)	Cultural Importance Score	Total Numerical Score	Scenic Rating	Importance Rating	Scenic Inventory Value
V14	Penn Del Trail from pedestrian bridge - PennDel Stony Beach	East	43.5	32.5	76	A	2	VH
V09	Yeatman's Mill - Wendel Cassel Trail Farm Overlook	East	32.5	21.5	54	B	4	M
V16	Banfftshire Preserve 1	Middle	43	25.5	68.5	A	3	VH
V17	Banfftshire Preserve 2	Middle	36	22	58	B	4	M
V08	Welsch Baptist Church	Upper WCC	41	40.5	81.5	A	1	VH
V05	Shirley Russell Bridge (Wedegewood Bridge)	Upper WCC	41	36	77	A	2	VH

V03	Dean Woolen Mill	Upper WCC	33.5	39.5	73	**B**	1	VH
V24	Tristate Marker	Upper WCC	38	26	64	**B**	3	H
V04	Robinson House	Upper WCC	36.5	22	58.5	**B**	4	M
V26	Arc Corner	Upper WCC	29.5	22	51.5	**C**	4	L

Table 46. Weighted Scenic Quality and View Importance Scores

Subwatershed	**Visual Quality**	**Weighted Score**	**Visual Quality Grade**	**Cultural Importance**	**Weighted Score**	**Cultural Importance Grade**	**Sub-watershed Scores**	**Sub-watershed Numerical Grade**	**Sub-watershed Letter Grade**
East Branch (30%)	**38**	**11.4**	**84%**	27	8.1	**60%**	19.5	72%	**B**
Middle Branch (13%)	**39.5**	**5.14**	**88%**	23.75	3.0875	**53%**	8.2225	70%	**B**
Upper WCC (21%)	**36.58**	**7.68**	**81%**	31	6.51	**69%**	14.1925	75%	**B+**
Subtotal			85%			61%		73%	
Watershed Overall Subtotals			**A**			**B-**		**B**	

2.6 Category 5: Recreation

The following table (Table 47) summarizes the grading for the three Recreation category indicators for the White Clay Creek watershed and subwatersheds:

Table 47. White Clay Creek, overall grades for Recreation

	Lower Main Stem	Upper Main Stem	East Branch	Middle Branch	West Branch	Watershed
Recreation	C+	A-	B-	B-	C	B
Trails	C	A	B	B	D	B
Fish Consumption Advisories	N/A	N/A	N/A	N/A	N/A	N/A
Bacteria (*E. coli*)	B	B+	B	A-	B	B+
Bacteria (*Enterococcus*)	C	B	C	D+	C	C+

Trails

Recreational access to the waters of the White Clay Creek watershed is an important indicator of the degree to which those waters constitute a benefit to the population. Activities such as hiking, biking, horseback riding, nature observation and others provide opportunities for people to pursue healthful and restorative activities. Many trails that provide access to these activities are associated with the water resources of the White Clay Creek watershed.

The White Clay Creek is nationally designated Wild & Scenic River system, so providing access to the natural assets which make the watershed so valuable is an important part of the priorities of the Park and Preserve system. Other entities, such as counties, towns, townships and boroughs, also have an interest in providing access to their citizens to the natural areas which enhance their quality of life.

In order to quantify the status and effects of trail-based access to the water resources in the White Clay Creek watershed, an inventory of trails was mapped, and the mileage of trails within the riparian zone (100 meters for the purposes of this study) were calculated. Subwatersheds (i.e., HUC 12s) with higher amounts of trail access to water resources were scored higher, while areas with less public access to riparian areas received lower scores.

The sources of trails data included those from the Delaware Natural Resources and Environmental Control (DNREC) Department of Parks and Recreation, Chester and New Castle County databases, the Pennsylvania Department of Conservation and Natural Resources (DCNR), local municipalities and the White Clay Creek Wild & Scenic River program. While effort was taken to compile a complete inventory of trails, there are necessary gaps, including potentially smaller local parks and unmapped trails. There are also many privately preserved conservation areas which may have trail systems not included in this inventory.

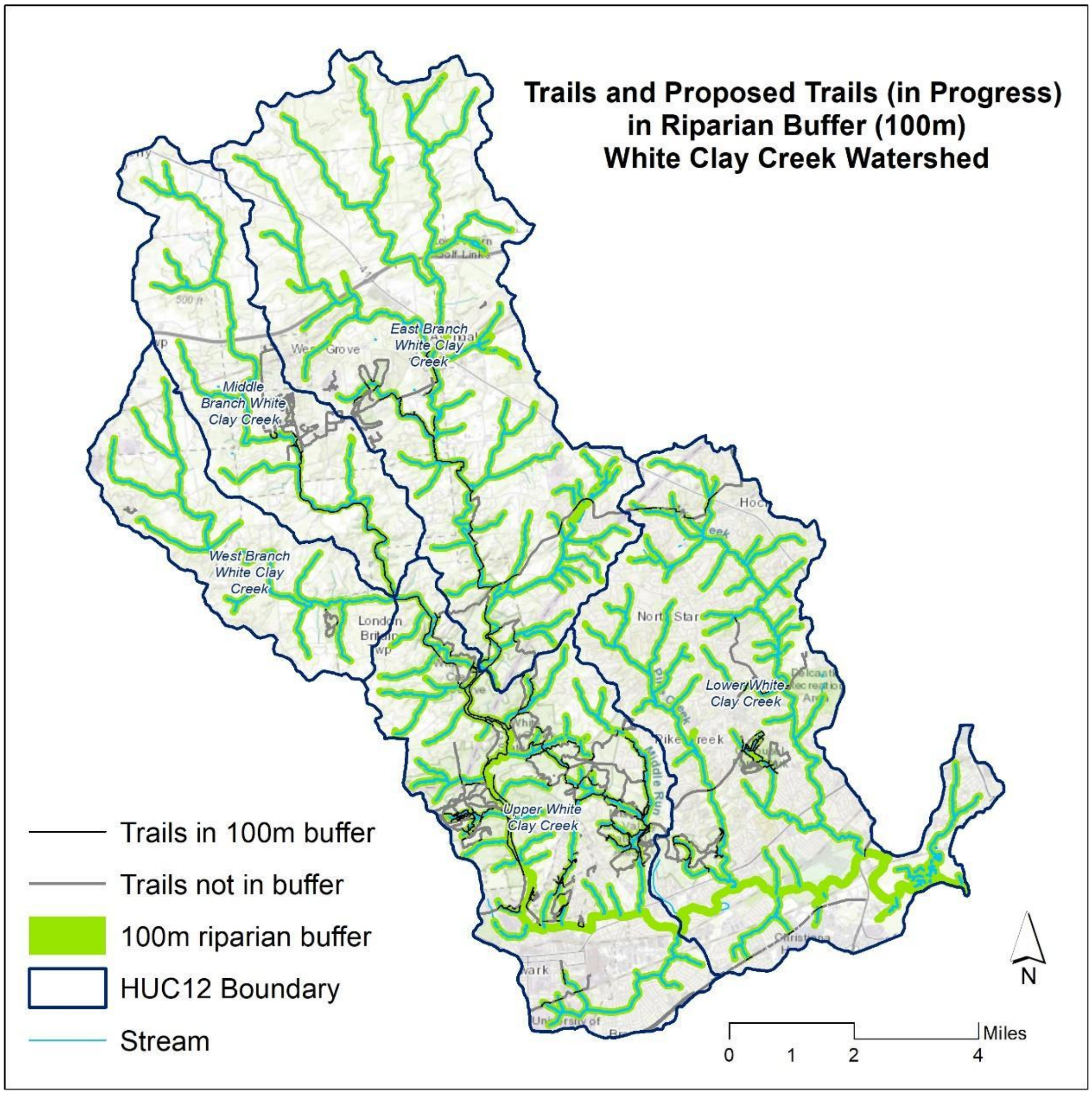


Figure 73. Trails in the riparian zone of the streams of the White Clay Creek watershed

Figure 73 presents the White Clay Creek watershed, showing the 100-meter-wide riparian buffer (100 meters from the edge of streams and waterbodies), along with the mapped trails within the riparian zone.

While the density of trails can enhance the value of riparian habitats for human recreation, increasing use can also have negative impacts on the resource. The building of trails, particularly paved trails, causes initial disruptions, and depending on the use and number of visitors, effects including erosion, pollution, habitat disruption, among others can harm the resource as it provides access. The type of use may vary widely in its effect—for instance, motorized vehicles, mountain bikes and horses may have a greater impact than hikers. Wildlife is often driven from areas of high usage, particularly if dogs are present, and damage to trees and other vegetation can be problematic.[7] It is therefore important that trails be designed with appropriate uses in mind, and with rules to protect the resources. With such proper design, impacts can be minimized while recreational value is maximized.[8]

To assess the relative trail prevalence in the riparian zone (100-meter buffer) of the waters of the White Clay Creek, the GIS inventory of trails compiled for the watershed was overlaid with the 100-meter buffer around the waters of the White Clay Creek watershed to determine total mileage of trails within the riparian zone. To determine the relative prevalence of trail access to water resources, the total trail mileage was divided by the total riparian buffer area (in square miles) for each HUC 12 in the White Clay Creek watershed, to derive a value for the density, in miles per square mile, of trails. Additionally, the Z-score for each of the five HUC 12s in the White Clay Creek was calculated based on the trail density. This score indicates the number of standard deviations above or below the mean is the density value for each HUC 12.

To determine the relative prevalence of trails in the riparian zone, and the resulting impact on recreation, comparison among the five HUC 12s was performed, specifically using the Z-Scores to rank the watersheds relative to each other. An overall ranking or score for the White Clay Creek watershed is produced by comparing the total stream mile density compared to the average for each of the subwatersheds.

Table 48 presents the total number of trail miles within the riparian zone (100-meter buffer around streams and other water bodies), the total buffer area (square miles), stream mileage, and total trail mile density, in miles per square mile.

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[7] Thompson B. Recreational trails reduce the density of ground-dwelling birds in protected areas. Environ Manage. 2015 May;55(5):1181-90. doi: 10.1007/s00267-015-0458-4. Epub 2015 Mar 27. PMID: 25813628.

[8] https://swcr.ca/trail-density/#:~:text=The%20initial%20trail%20construction%20stage,deplete%20oxygen%20in%20the%20water.

Table 48. Key Data for Relative Prevalence of Trails in the Riparian Zone

HUC 12 Name	Trail Miles in Riparian Buffer	Riparian Buffer, Square Miles	Total Stream Miles	Trail Miles per Sq. Mile in Buffer
Lower White Clay Creek	7.6	7.1	63.7	1.07
Upper White Clay Creek	32.3	6.2	53.2	5.23
East Branch White Clay Creek	9.5	7.6	65.2	1.25
Middle Branch White Clay Creek	5.0	2.2	18.4	2.24
West Branch White Clay Creek	0.1	2.0	17.1	0.03
TOTAL	54.4	25	217.5	2.16

The density ranges from a high of over five miles per square mile in the Upper White Clay Creek (location of the Delaware portion of the White Clay Creek Park and Preserve), to less than a tenth of a mile per square mile in the West Branch White Clay Creek.

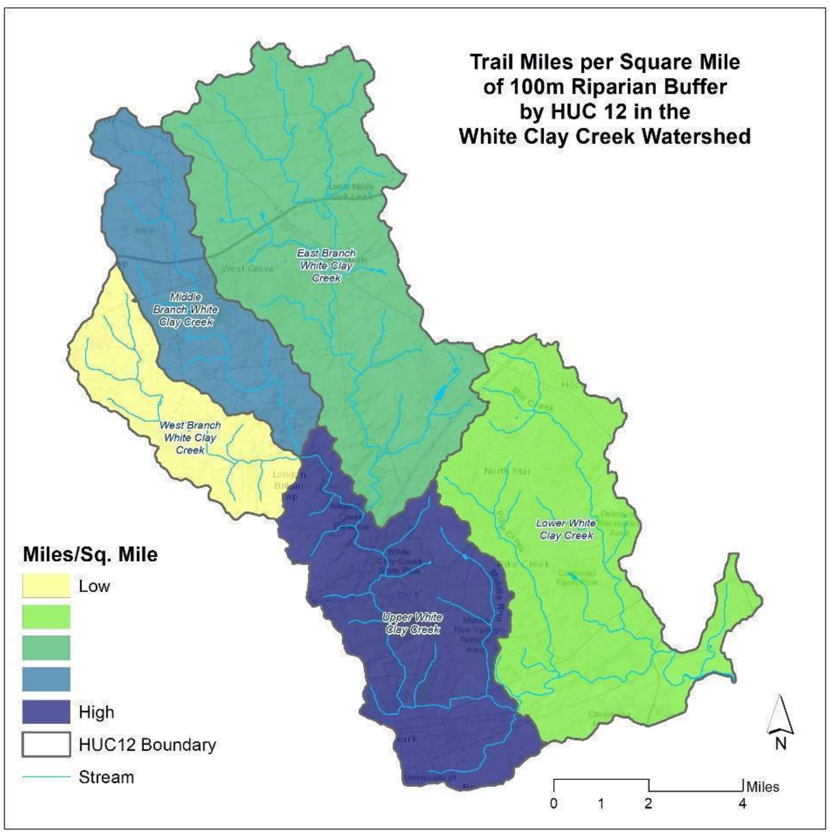

Figure 74. Riparian trail density in the subwatersheds of the White Clay Creek watershed

The map in Figure 74 shows the relative density of trails in the riparian zone for each HUC 12.

Table 49 presents the Z-Scores for each of the five HUC 12s, indicating the number of standard deviations above (positive values) or below (negative values) the average trail density, along with the score (grade) for each HUC 12, and an overall grade for the White Clay Creek as a whole.

Scores presented are considered relative to the trails only within the watersheds of White Clay Creek. While this does not compare riparian trail prevalence relative to a large sample of watersheds, the White Clay Creek represents a cross section of trail density, from the White Clay Creek Park and Preserve (with a high density of trails) to areas of urbanization and suburbanization with low prevalence of trails.

Table 49. Riparian trail grades for the White Clay Creek subwatersheds

HUC 12 Name	Z-Score	Rating	Grade
Lower White Clay Creek	(0.50)	Fair	C
Upper White Clay Creek	1.84	Excellent	A
East Branch White Clay Creek	(0.40)	Good	B
Middle Branch White Clay Creek	0.16	Good	B
West Branch White Clay Creek	(1.09)	Poor	D
TOTAL	0.11	Good	B

Based on these rankings, the White Clay Creek overall has a riparian trail grade of “B.”

Fish Consumption Advisories

Fish consumption advisories are recommendations to limit or avoid eating certain species of fish caught in local waters due to potential health risks from contaminants. In Delaware, DNREC and the Division of Public Health and in Pennsylvania the Pennsylvania Fish and Boat Commission (PAFBC) provide fish consumption advisories for the White Clay Creek.

In the Delaware portion of the White Clay Creek, the primary contaminant of concern in fish in this area is polychlorinated biphenyls (PCBs), an industrial chemical no longer manufactured in the United States but once commonly used in heavy-duty electrical equipment and in other applications. The concentration of PCBs in the fish from the White Clay Creek has dropped significantly over time. Much of the improvement is attributed to a concerted effort to identify and control remaining land-based sources. Secondary contaminants of concern for this area include dioxins and furans (mostly from combustion sources) and Dieldrin (used in the past as an insecticide for corn and for termite control). Long-term records show that the concentrations of dioxins, furans and Dieldrin are dropping in the fish. The advisories in the

Delaware portion of the White Clay Creek have shown improvement since 2008 with consumption advisories increasing at all three sites in the White Clay Creek watershed (Table 50).

Mercury is increasingly a source of concern in Pennsylvania. The PAFBC has issued a fish consumption advisory for American eel for the entire White Clay Creek basin. The 2022 advisory for the Pennsylvania portion of the White Clay Creek remains consistent with the 2018 advisory (Table 50).

In addition to these species- and location-specific advisories, DNREC and PAFBC have established a general statewide fish consumption advisory—eat no more than one 8-oz. meal per week of any fish species caught in Delaware and Pennsylvania's fresh, estuarine and marine waters. These advisories apply to all waters and fish species not otherwise explicitly covered by an advisory.

Table 50. White Clay Creek fish consumption advisories

Waterbody	Species	Geographical Extent	Contaminant of Concern[1]	Advisory (2018)	Trend (2008/2015/2018)
Tidal White Clay Creek	All Finfish	River Mouth to Route 4	A, B, C, D	No more than 1 meal/year	Increased from no consumption
Non-Tidal White Clay Creek	All Finfish	Route 4 to DE/PA Line	A, B	No more than 12 meals/year	Increased from 1 meal/year
Designated Trout Streams	Stocked Trout	WCC above Newark, Pike Creek, and Mill Creek	A	No more than 12 meals/year	Increased from 1 meal/year
White Clay Creek Basin[2]	American Eel	Pennsylvania	E	No more than 2 meals/month	Constant

[1]Contaminants of concern: **A)** PCBs **B)** Dieldrin **C)** DDT, DDD, and DDE **D)** Chlordane **E)** Mercury [2]PAFBC data from 2022

DNREC fish consumption advisories range from "do not eat" to "24 meals/year" depending on the location and the fish species. Similarly, the PAFBC fish consumption advisories range from "do not eat" to "2 meals/month" (equivalent to 24 meals/year). Both states recommend that if a stream or water body is not listed, the consumption limit is 52 meals/year.

The grading methodology for fish consumption advisories for both DE and PA considers that in the Delaware River Basin, DNREC and the PAFBC have applied fish consumption advisories spanning the entire range from “no advisories” to “do not eat” (Table 51). In order to assign a scoring grade, the DNREC and PAFBC consumption advisories have been grouped to provide a range that aligns with a corresponding letter grade (Table 51). The assigned grades are applied to the geography in which the fish consumption advisory has been placed. In the Delaware portion of the White Clay Creek this includes the non-tidal and tidal portions and in Pennsylvania this includes the non-tidal portion of the White Clay Creek.

Based on the DNREC and PAFBC fish consumption advisories and the scoring provided in Table 51 the tidal portion of the White Clay Creek is assigned a grade of “F” and the non-tidal portion is assigned a “C.”

Table 51. Scoring Rubric for fish consumption advisories

Scoring	**Advisory (8 oz. serving)**	**Description**
A	No Advisory	No advisory
B	52 meals/year	All areas not listed for all species, the general public should limit consumption to 52 meals per year.
C	12-24 meals/year	The general public should limit consumption of affected fish species to 12-24 meals per year.
D	3-6 meals/year	The general public should limit consumption of affected fish species to 3-6 meals per year.
F	1-2 meals/year or No Consumption	The general public should limit consumption of affected fish species to 1-2 meals per year or no one should consume fish from this water body.

The map in Figure 75 shows the tidal and non-tidal portions of the White Clay Creek watershed in Delaware and Pennsylvania, graded based on the scoring system presented in Table 51. An overall grade is not assigned to the entire watershed or any subwatersheds because advisories are species-dependent and because relevant data are spatially and temporally limited. Similarly, the grades are not included in the grading table at the beginning of this section, nor in the color wheel grading charts.

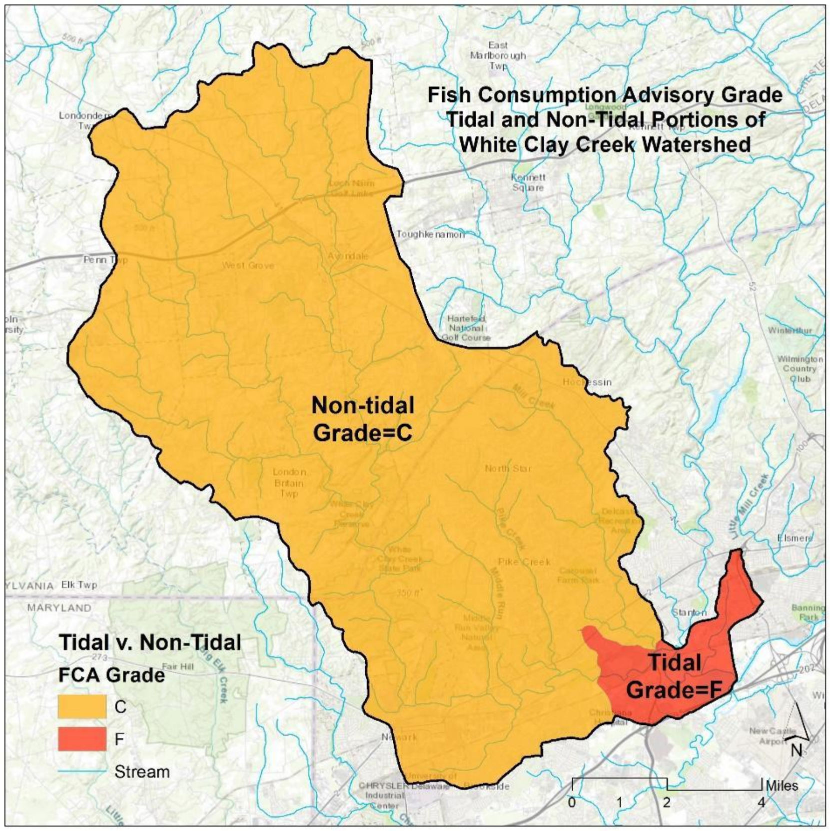

Figure 75. Grading for fish consumption advisories, showing assessed grades for tidal v. non-tidal portions, 2022

Bacteria

Bacteria, viruses and parasites are everywhere in our aquatic and terrestrial environments. In many cases these occur naturally, but in other cases they can represent contamination associated with livestock and human fecal waste. Disease-causing bacteria, viruses or parasites are collectively called pathogens. Monitoring for the presence of fecal contamination has a long history associated with protecting drinking water as well as recreational contact with lakes, streams and oceans. Fecal indicator bacteria are the most common indicators of potential pathogens, but generally do not cause disease. Historically, evidence of fecal contamination was assessed as total coliform bacteria. However, this measure was complicated by the presence of non-fecal coliform bacteria. More recently there has been an emphasis on greater taxonomic resolution by measuring *Escherichia coli* (*E. coli*) and *enterococci* (*Enterococcus spp.*) as indicators of fecal contamination for fresh water. Both of these are commonly found in the intestines of warm-blooded animals, and most varieties do not cause disease.

The map in Figure 76 shows the status of impairment for bacteria in the streams of the White Clay Creek watershed in Delaware and Pennsylvania, based on the integrated reports on impairments produced by the PA DEP and DNREC.

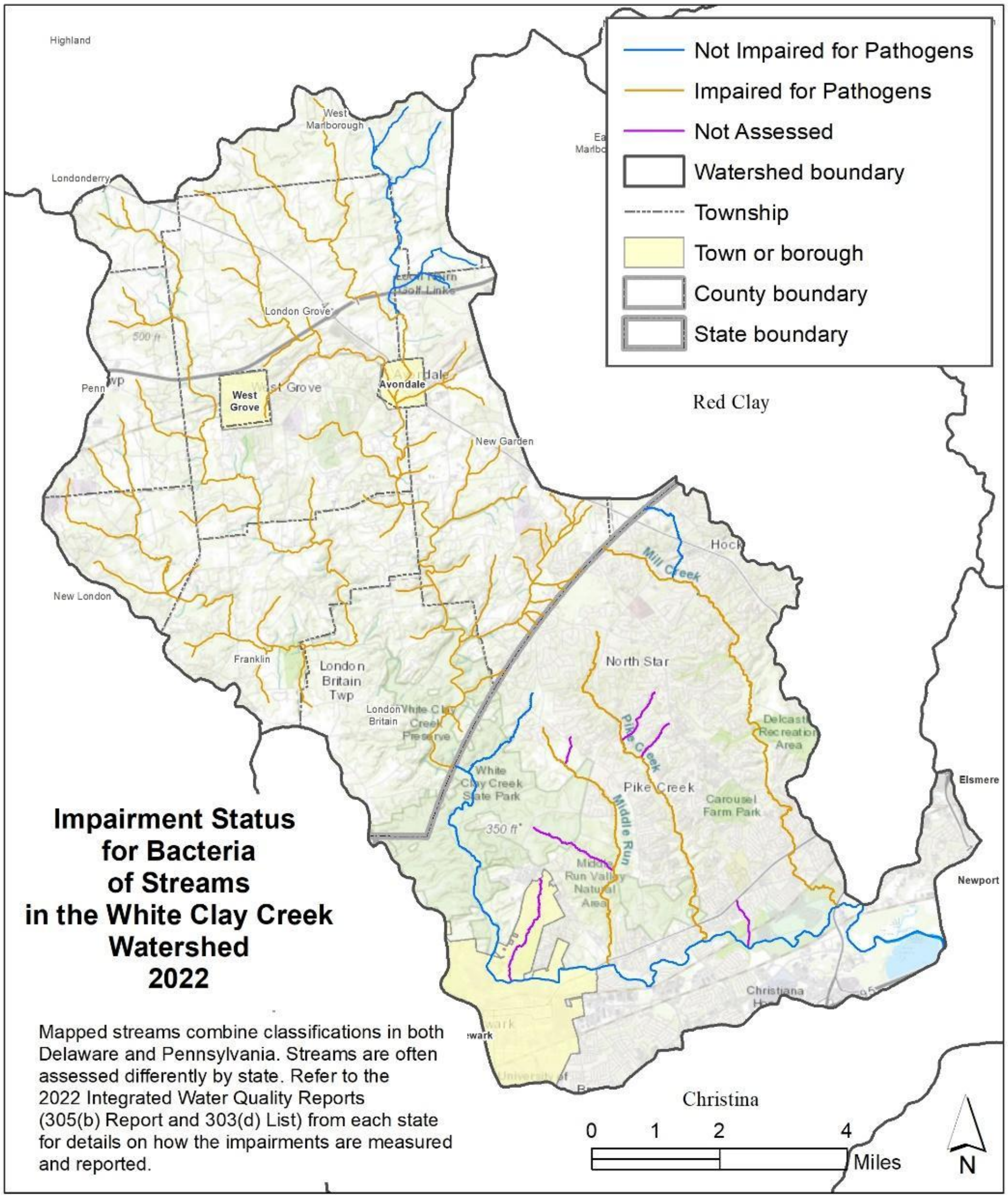

*Figure 76. Streams impaired for pathogens (*E. Coli *or* Enterococcus *bacteria) in the White Clay Creek watershed, 2022*

Methodology

Bacterial sampling within the White Clay Creek generally only occurred once annually with a few sites having two samples in a given year. Sampling data was not confined to only summer months. Even though it wasn't strictly necessary, the same temporally averaging strategy described for the chemical/physical water-quality parameters was applied with the bacteria data to arrive at annual mean values. Rather than use arithmetic means, geometric means were applied to bacteria concentrations which were expressed as colony forming units per 100 mL of sample (cfu/100 mL, see Figure 77). Geometric mean is defined as the n^{th} root of the product of n numbers; for example, the geometric mean of two numbers, 98 and 120 is the square root of the product of 98 and 120 (ie. √ [98*120]) which is 108.

The annual means were converted to a sub-index score by employing the following Recreational Water Quality Criteria for *E. coli* and *Enterococcus:*

E. coli: 126 colony forming units per 100 milliliters (126 cfu/100 mL)

Enterococcus: 35 colony forming units per 100 milliliters (35 cfu/100 mL)

These criteria are for an Estimated Illness Rate (NGI) of 36 per 1,000 primary-contact recreators.

The distribution of available data for both *E. coli* and *Enterococcus* were assessed in separate histograms (Figure 77) using the recreational criteria defined above in order to then establish six WQIS-equivalent scoring categories (Table 52).

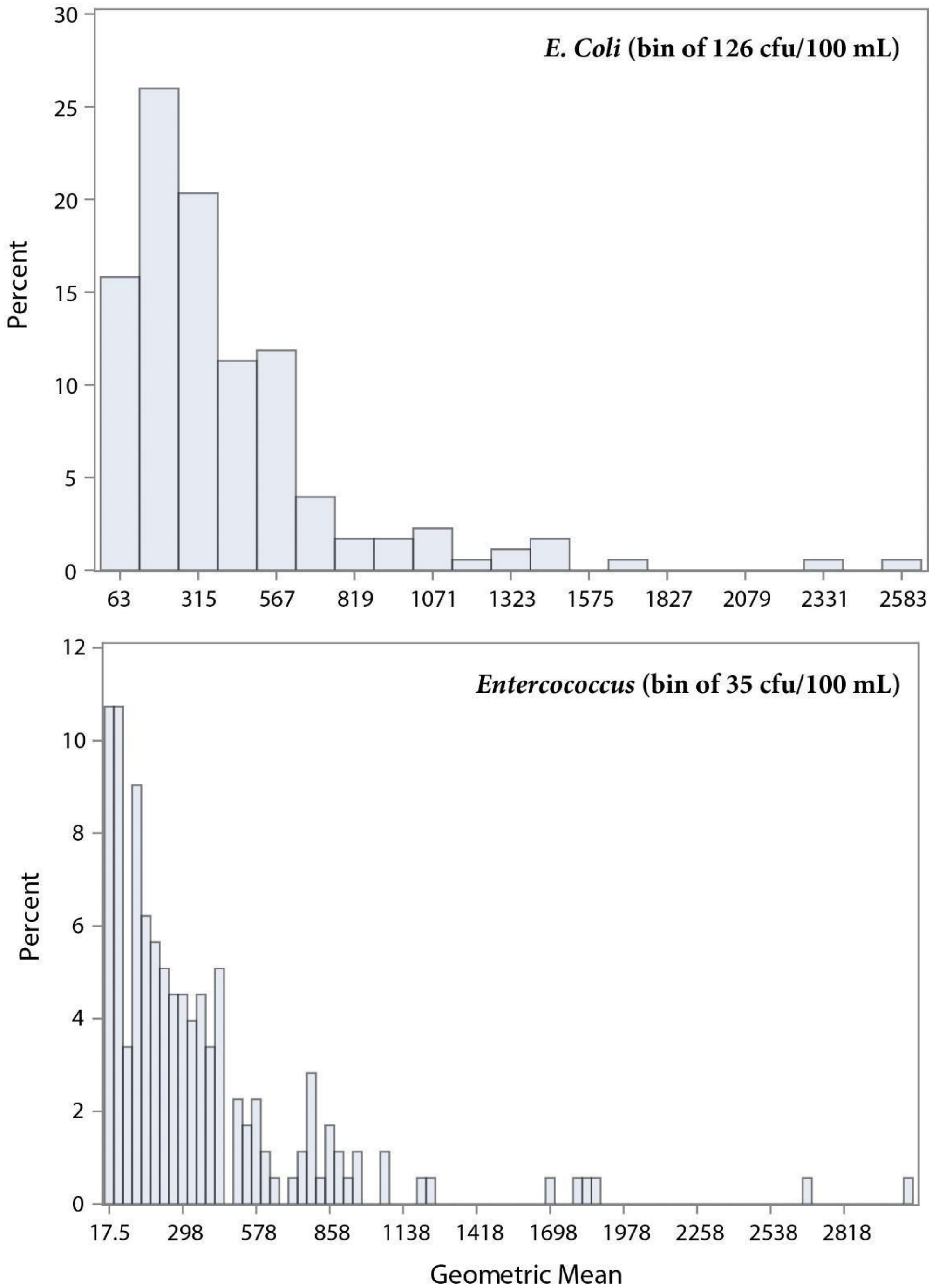

Figure 77. Relative distribution of E. Coli (top) and Enterococcus (bottom) concentrations across all White Clay Creek bacteria monitoring sites based on annual average (geometric) means.

Table 52. Recreation sub-index scores and associated concentration ranges for Entercococcus *and* E. Coli.

Sub-Index Score value	*Concentration ranges (cfu/100mL)for each associated score value*	
	E. Coli	*Enterococcus*
100	< 126	< 35
80	126-378	35-105
60	378-630	105-175
40	630-882	175-245
20	882-1134	245-315
0	>1134	> 315

Results

Table 53. Final RQIS parameter values, associated water-quality letter grades, geometric mean concentrations/values, number of sites and year range for the five WCC HUC 12 watersheds and the entire WCC watershed.

Parameter	**Type**	**E Br White Clay Cr**	**Middle Br White Clay Cr**	**W Br White Clay Cr**	**Upper White Clay Cr**	**Lower White Clay Cr**	**White Clay Cr**
E. Coli (cfu/100mL)	Grade	B	A-	B	B+	B	B+
	Score	68	85.4	68.6	79.7	74.6	75.8
	Mean	417	229	378	357	326	377
	n sites	27	5	1	9	3	45
	Yr range	2015-22	2016-22	2016-22	2016-22	2017-22	2015-22
Entero. (cfu/100mL)	Grade	C	D+	C	B	C	C+
	Score	49.1	38.7	48.6	69.4	47.9	56.9
	Mean	375	284	177	283	309	338
	n sites	27	5	1	9	3	45
	Yr range	2015-22	2016-22	2016-22	2016-22	2017-22	2015-22

Fecal indicator bacteria were sampled at 45 sites in the White Clay Creek watershed, 27 sites in East Branch White Clay, five sites in Middle Branch White Clay, one site in West Branch White Clay, nine sites in Upper White Clay, and three sites in Lower White Clay. Based on available data, *E. coli* counts averaged 11 to 1750 cfu/100 ml (Table 53; Figure 78). Across all sites and years, only 16% were below the Recreational Water Quality Criteria for *E. coli.* Thus 84% exceeded the Recreational Water Quality Criteria and would have been considered impaired for bacteria (i.e., not supporting recreational uses). In some cases, the bacteria counts far exceeded the Recreational Water Quality Criteria for primary recreational contact. Because much of the data exceeded the Recreational Water Quality Criteria, we considered any CFU under the Recreational Water Quality Criteria as “Good” and gave it a score of 100. We then created five additional categories based on large increases over the criteria—i.e., up to 200%, 200-400%, 400-600%, 600-800%, and >800%.

When summarized by HUC 12, *E. coli* counts averaged 417 cfu/100 ml across East Branch sites (area weighted score = 68 or “B”), 229 cfu/100 mL across Middle Branch sites (area weighted score = 85 or “A”), 378 cfu/100 mL across West Branch sites (area weighted score = 69 or “B”), 357 cfu/100 mL across the Upper White Clay sites (area weighted score = 80 or “A-"), and 326 cfu/100 mL across the Lower White Clay sites (area weighted score = 75 or “B+”). See Table 53 for the final grades, scores, mean values, number of sites and year range for *E. Coli*.

Across all sites in the five HUC 12s, the area weighted score for *E. coli* = 76 or “B+.”

Based on available data, *Enterococcus* counts averaged 6 to 1897 cfu/100 mL (Table 53; Figure 79). As with *E. coli*, *Enterococcus* counts often exceeded the Recreational Water Quality (i.e., *Enterococcus*: 35 cfu per 100 mL). Overall, only 11% of the observations were below Recreational Water Quality Criteria for *Enterococcus*. Like *E. coli*, we considered any CFU for *Enterococcus* under the Recreational Water Quality Criteria as “Good” and gave it a score of 100, and then created five additional categories based on large increases over the criteria—i.e., up to 200%, 200-400%, 400-600%, 600-800%, and >800%.

When summarized by HUC 12, *Enterococcus* counts averaged 375 cfu/100 mL across East Branch sites (area weighted score = 49 or “C”), 284 cfu/100 mL across Middle Branch sites (area weighted score = 39 or “D+”), 177 cfu/100 mL across West Branch sites (area weighted score = 49 or “C”), 283 cfu/100 mL across the Upper White Clay sites (area weighted score = 69 or “B”), and 308 cfu/100 mL across the Lower White Clay sites (area weighted score = 48 or “C”). See Table 53 for the final grades, scores, mean values, number of sites and year range for *Entercoccus*.

Across all sites in the five HUC 12s, the area weighted score for *Enterococcus* = 57 or “C+.”

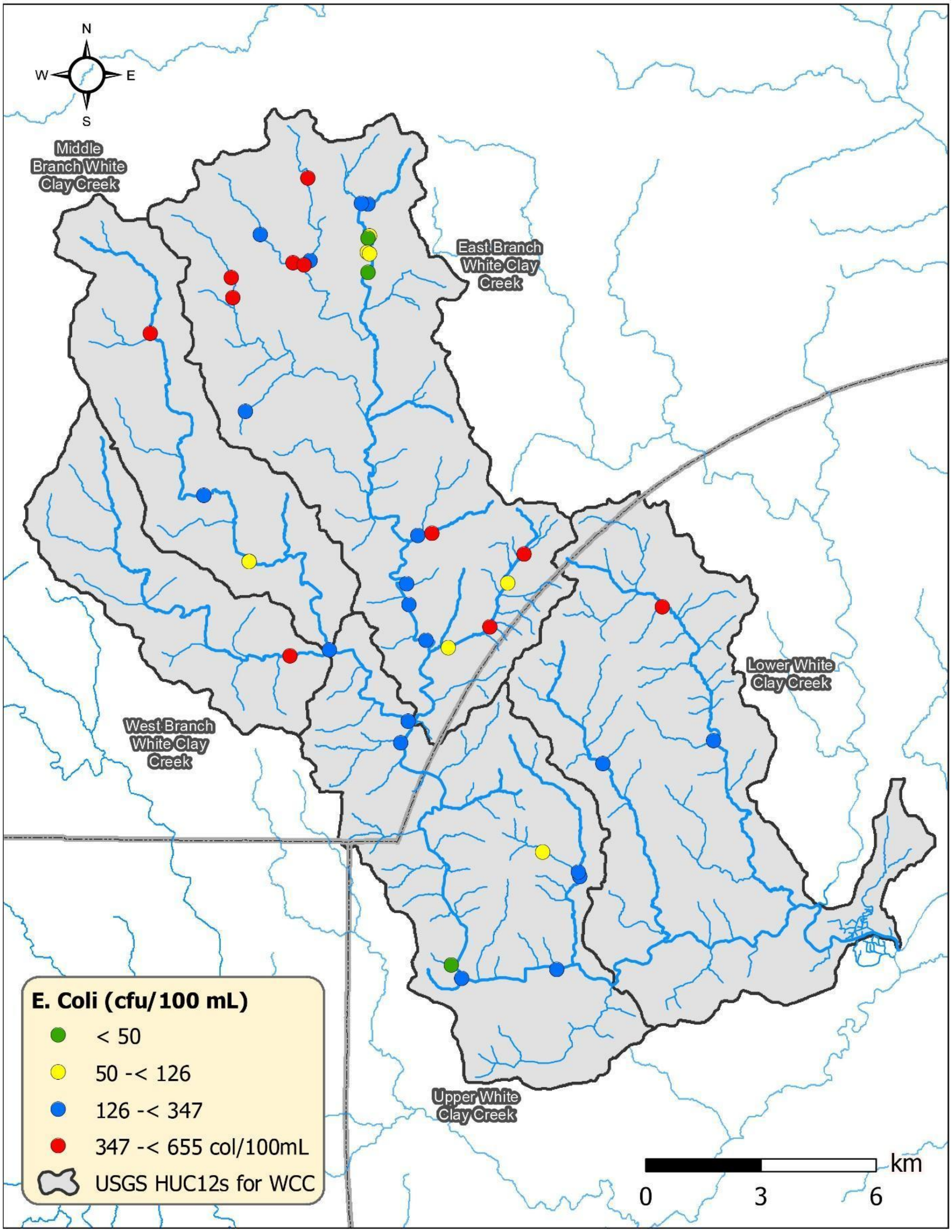

Figure 78. Map of average E. coli *counts (cfu/100 mL) measured at White Clay Creek sites.*

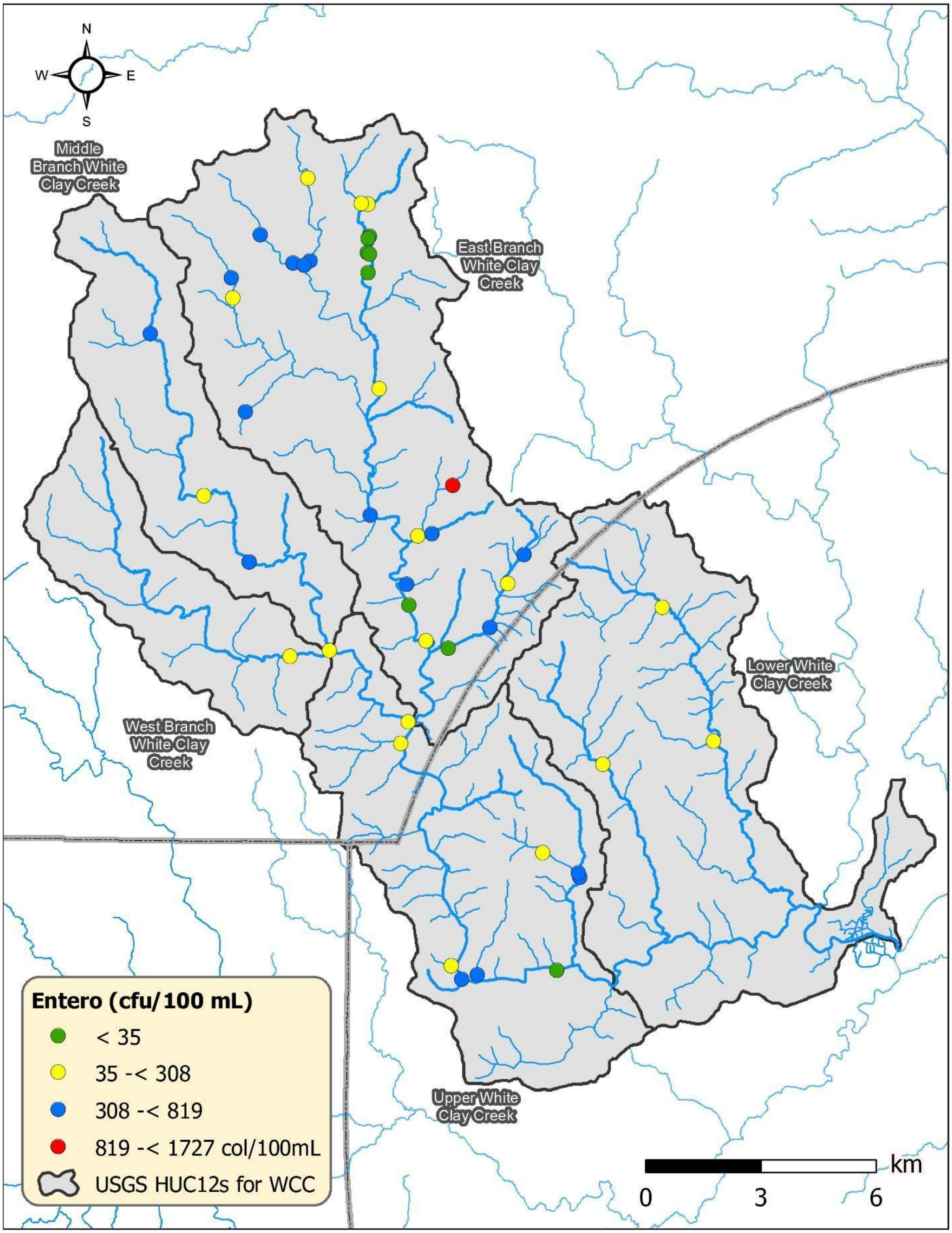

Figure 79. Map of average Enterococcus *counts (cfu/100 mL) measured at White Clay Creek sites.*

3. Overall Assessment and Recommendations

3.1 Overall Assessment

This *White Clay Creek State of the Watershed Technical Report 2023* provides an assessment of 20 indicators in five categories—Hydrology, Habitat, Water Quality, Scenery and Recreation. Section 2 of this report provides detailed data and analysis for each of the 20 indicators to determine a score and corresponding grade for each indicator. Based on the data and analysis of each indicator in Section 2 of this report, the scores for these five categories were then combined into an overall health score for the watershed and each of the five HUC 12 subwatersheds—Lower Main Stem, Upper Main Stem, Middle Branch, West Branch and East Branch. The overall grade for the watershed is the average of the five subwatershed scores, weighted by area. Overall health grades are presented for the watershed and the subwatersheds in Table 54.

Table 54. White Clay Creek, overall grades

	Lower Main Stem	Upper Main Stem	East Branch	Middle Branch	West Branch	Watershed
Hydrology	B-	B+	B+	B-	B+	B-
Stream Flow	A-	A-	A	B-	A	A-
Peak Flow	D+	N/A	N/A	N/A	N/A	D+
Groundwater Levels	B	B	B	B	B	B
Habitat	C+	B-	C+	B-	B	C+
Impervious Cover	C+	B	A	A	A	B+
Aquatic Connectivity, Dams	A	C+	C	A+	A+	B
Aquatic Connectivity, Culverts	C	D-	C	D+	D	C-
Terrestrial Connectivity, Forest Buffer	C	A-	C+	B-	B	B-
Terrestrial Connectivity, Forest Fragmentation	D-	A-	D+	D-	C+	D+
Water Quality	C+	C+	C+	C	B	C+
Water Temperature	B	B-	C	D	B	C+

Dissolved Oxygen (DO)	A-	A	A	A	A	A
Phosphorus (TP)	A	A-	B+	C+	A+	A-
Nitrogen (NO3-N)	D+	F	F	F	F	F
Chloride (Cl)	A-	A+	A	A+	A+	A
Total Suspended Sediment (TSS)	D	D	C	N/A	N/A	C
Macroinvertebrates	F	D-	D	D	D+	D-
Scenery	N/A	B+	B	B	N/A	B
Scenic Quality	N/A	A-	A-	A	N/A	A
View Importance	N/A	B	B-	C	N/A	B-
Recreation	C+	A-	B-	B-	C	B
Trails	C	A	B	B	D	B
Fish Consumption Advisories	N/A	N/A	N/A	N/A	N/A	N/A
Bacteria (E. coli*)*	B	B+	B	A-	B	B+
Bacteria (Enterococcus*)*	C	B	C	D+	C	C+
Overall Grade	B-	B	B-	B-	B	B-

Figures 80 - 85 in this section of the report use the information tabulated in Section 2 and presents it in color wheels to provide a snapshot of watershed health for the White Clay Creek watershed and each subwatershed. The information used to form the color wheels, as discussed in detail in Section 2, was collected from a variety of data sources and analyzed using various methodologies based on science and professional expertise to determine a score and corresponding grade for each indicator. The color wheels are composed of the grades determined in Section 2 and provide a visual representation of the scores for each of the watershed indicators.

The White Clay Creek receives a "B-" for overall watershed health. The subwatersheds receive scores in the "B-" to "B" range for watershed health, with the West Branch and Upper Main Stem receiving a "B" and the Middle and East Branches and Lower Main Stem receiving a "B-." The following sections discuss the categories of indicators, highlighting specific themes of particular interest.

Hydrology

The White Clay Creek watershed scores in the middle-range for Hydrology, with overall grades ranging from "B-" to "B+." The entire watershed gets a "B-." The White Clay Creek watershed overall is relatively highly affected by peak flows leading to flooding and receives a "D+" for that indicator due to the increasing frequency of high-flow events in the past two decades. Peak flow score was based on a single stream gage in the Lower Main Stem, so that subwatershed receives "D+," while other subwatersheds are not given a grade. Stream flow remains good in the watershed, which receives an "A-," and throughout the subwatersheds, which receive "A-" or "A," except for the Middle Branch, which gets a "B-." Groundwater levels are stable for the watershed, which receives an overall grade of "B," and the same grade is applied to all subwatersheds.

Habitat

The White Clay Creek watershed receives a "C+" in the Habitat category, with overall grades for the subwatersheds in the "C+" to "B" range. The White Clay Creek watershed overall receives a "B+" for impervious cover (reflecting the level of development), while the subwatersheds reflect a highly variable level of development, resulting in a range from "C+" to "A." Culverts present a challenge to many areas in the watershed, and the scores relating to habitat connectivity reflect this. Overall, the subwatersheds receive grades of "D-" to "C" for Culverts. Forest fragmentation in much of the watershed is poor (highly fragmented), except for the Upper Main Stem, which scores highly, receiving an "A-." The other subwatersheds and the overall watershed receive scores of "D-" to "C+." The overall watershed and three out of four subwatersheds get good grades—"B-" to "A-"—for riparian buffers, reflecting the relatively high level of forestation in the non-urban areas of the watershed.

Water Quality

The White Clay Creek watershed receives a "C+" in the Water Quality category. The subwatersheds get grades in the "C" to "C+" range, except for the West Branch, which receives a "B." The watershed overall, and all subwatersheds, ranks highly for both Dissolved Oxygen (DO) and Chlorides. The overall watershed and the subwatersheds score in the "B+" to "A+" range for Phosphorus, except for the Middle Branch, which receives a "C+." The White Clay Creek watershed and all its subwatersheds, score poorly for Nitrates and Macroinvertebrates with grades in the "F" to "D+" range. Three (of five) subwatersheds for which Suspended Sediments are assessed score in the "C" to "D" range, with the watershed overall receiving a "C." Throughout the watershed scores for Water Temperature are variable.

Scenery

As a nationally designated Wild and Scenic River system, the White Clay Creek watershed unsurprisingly scores well for Scenery, receiving a "B." Of the five subwatersheds, three were assessed and used in scoring calculations—the East Branch, Middle Branch and Upper Main Stem. The White Clay Creek watershed and all three assessed subwatersheds receive an "A-" or

"A" in Scenic Quality. The watershed and subwatersheds scored less highly for View Importance, receiving a "B-" or "B" for the watershed overall and the East Branch and Upper Main Stem, while the Middle Branch scores a "C."

Recreation

Recreational aspects of the watershed are an important component of the White Clay Creek in its role as a designated Wild and Scenic River system. Overall, the White Clay Creek receives a "B" for Recreation, while the subwatersheds range from a "C" in the West Branch, a "C+" in the Lower Main Stem, "B-" in the East Branch and Middle Branch, and an "A-" in the Upper Main Stem. The watershed and subwatersheds rank poorly for *Enterococcus* bacteria, scoring in the "D+" to "C+" range, except the Upper Main Stem, which receives a "B." For *E. Coli*, the watershed and all subwatersheds receive a "B" or "B+," except the Middle Branch, which receives an "A-." The Upper Main Stem scores well for Trails, receiving an "A." Other subwatersheds, which do not include significant tracts of state parkland, score somewhat lower. The East Branch and Middle Branch receive a "B," the Lower Main Stem gets a "C" and the West Branch a "D." Watersheds and subwatersheds were not graded for Fish Consumption Advisories. Instead, grades were assigned based on tidal/non-tidal designations. The tidal White Clay Creek receives an "F," while the non-tidal portions of the watershed receive a "C."

The color wheels in the following figures provide a snapshot of the data and analysis conducted in this report. These summarize and present the data in a concise manner. More detailed data and information can be found in the technical sections of this report. Table 55 shows the color scheme indicating whole letter grade used in the color wheels.

Table 55. Color wheel color scheme showing color corresponding to whole letter grades

Letter Grade By Color
A
B
C
D
F

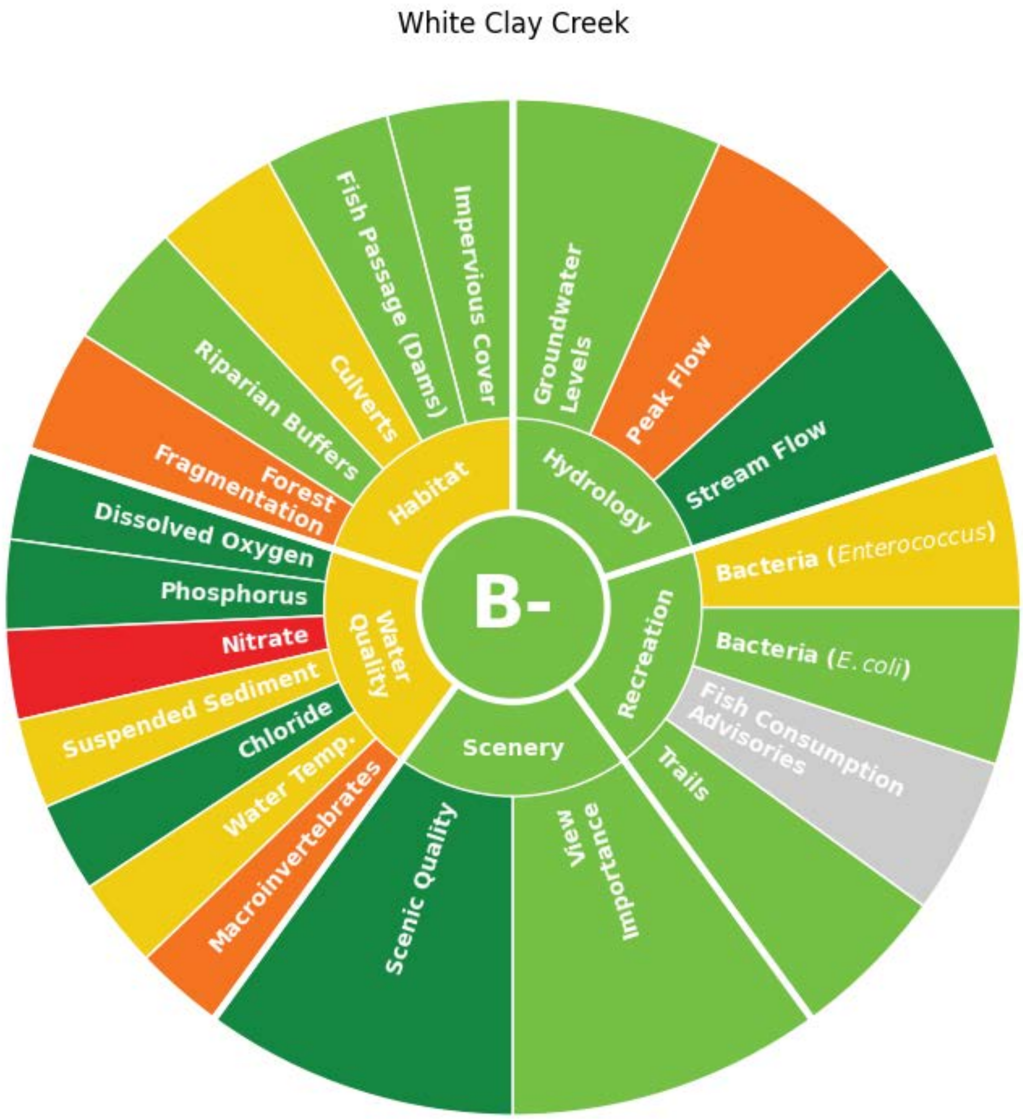

Figure 80. White Clay Creek watershed scoring for each category and indicator

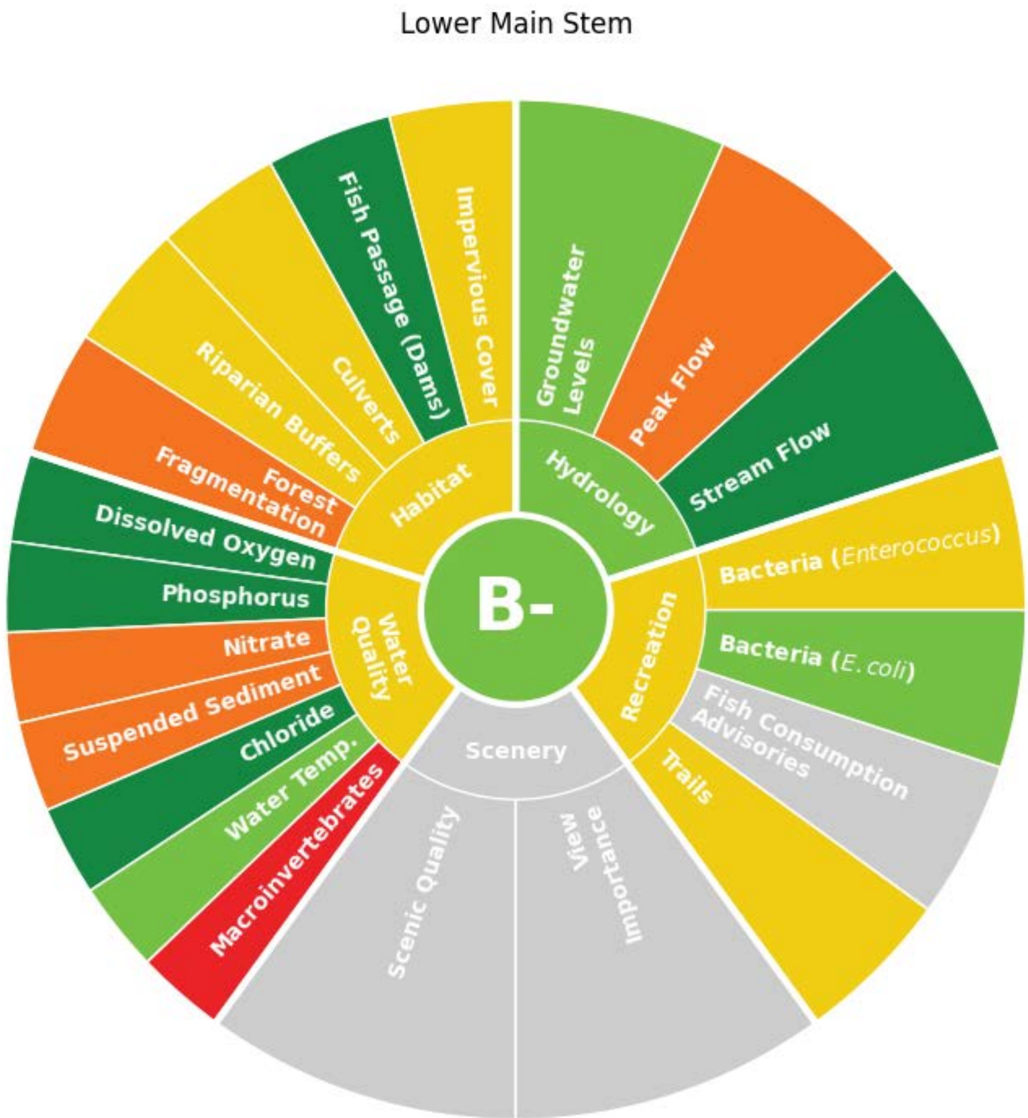

Figure 81. Lower Main Stem subwatershed scoring for each category and indicator

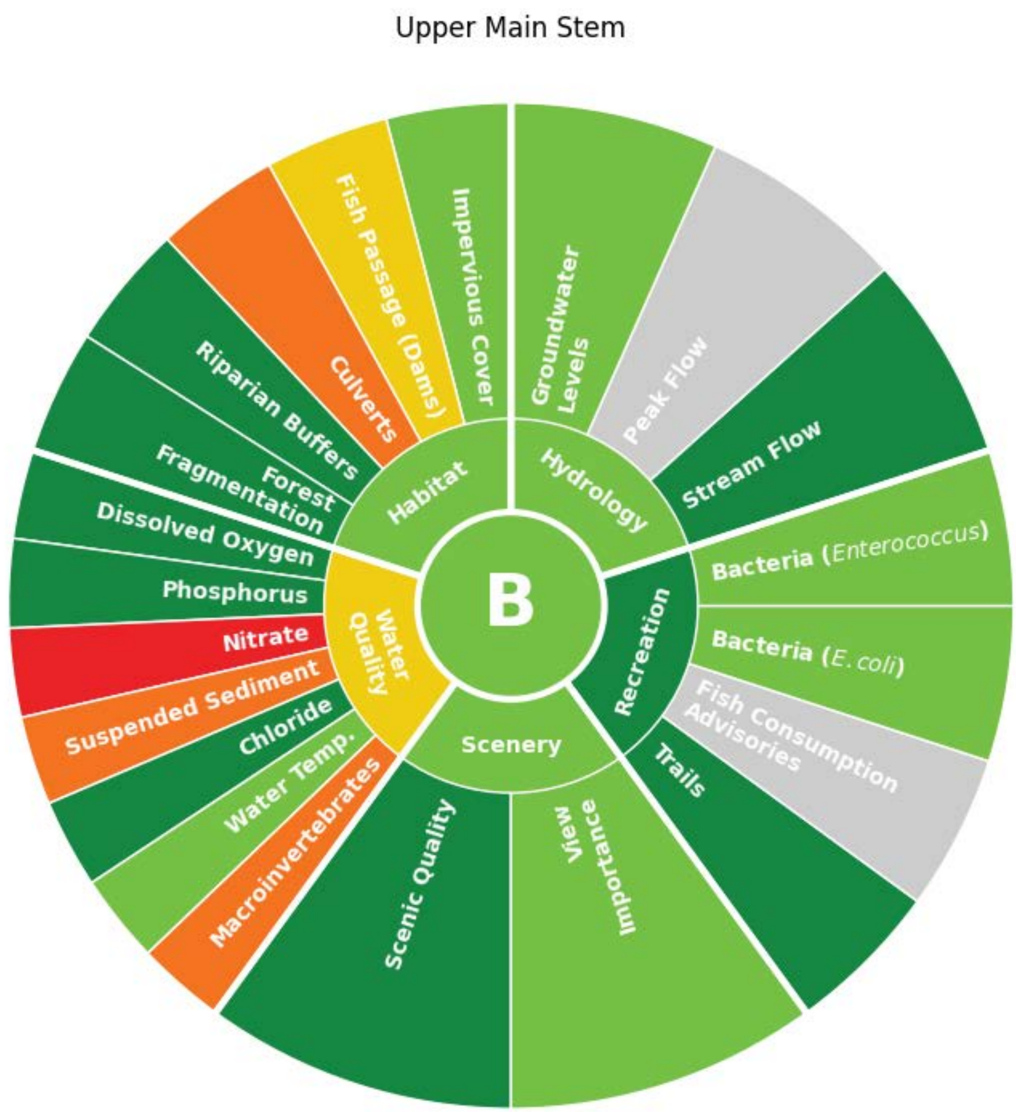

Figure 82. Upper Main Stem subwatershed scoring for each category and indicator

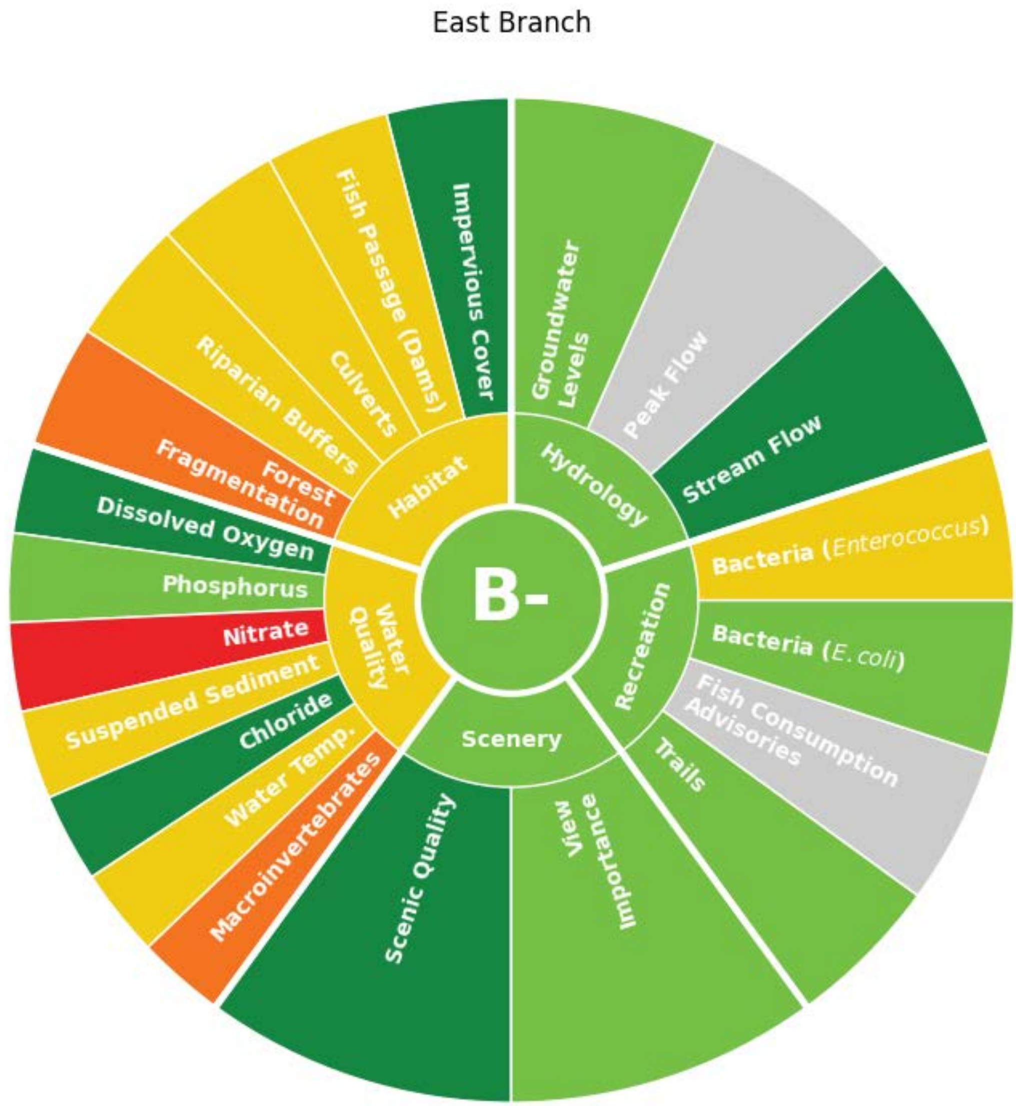

Figure 83. East Branch subwatershed scoring for each category and indicator

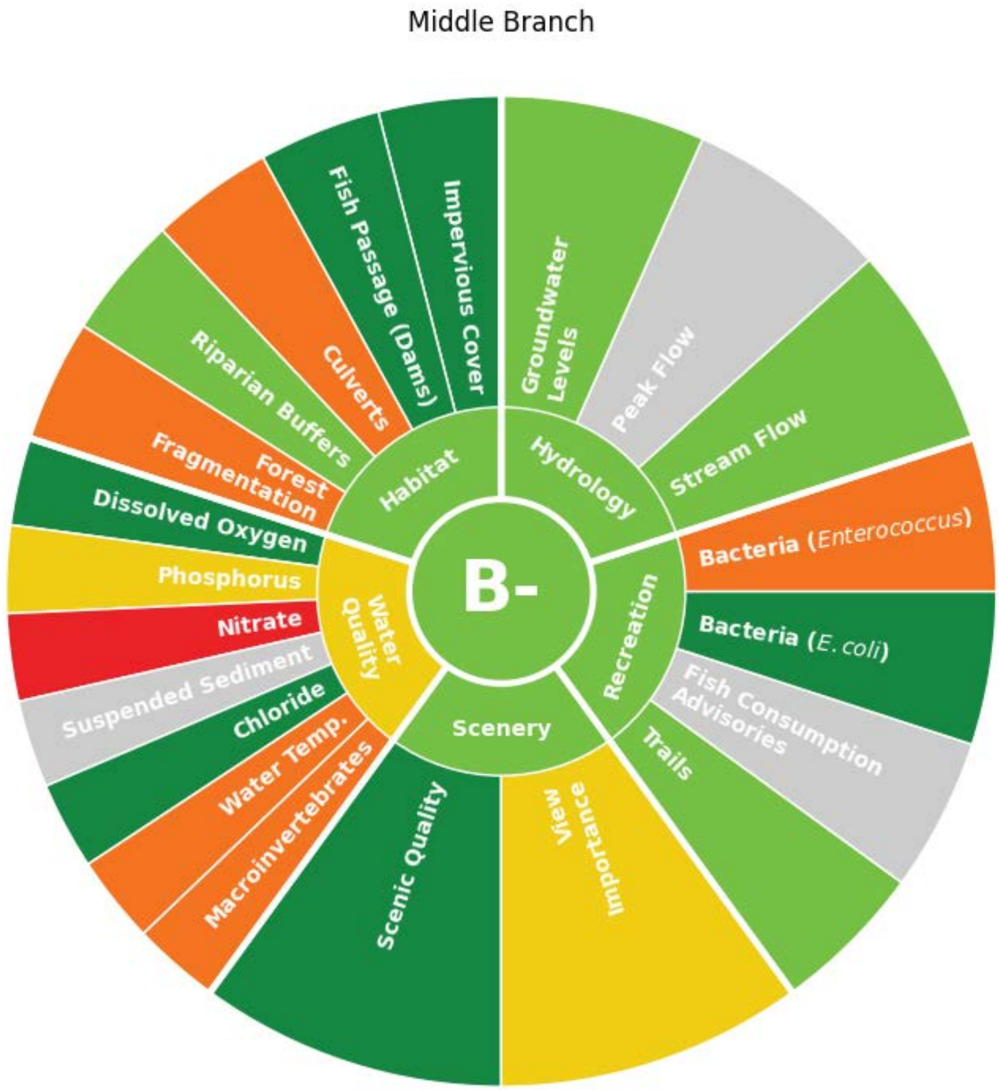

Figure 84. Middle Branch subwatershed scoring for each category and indicator

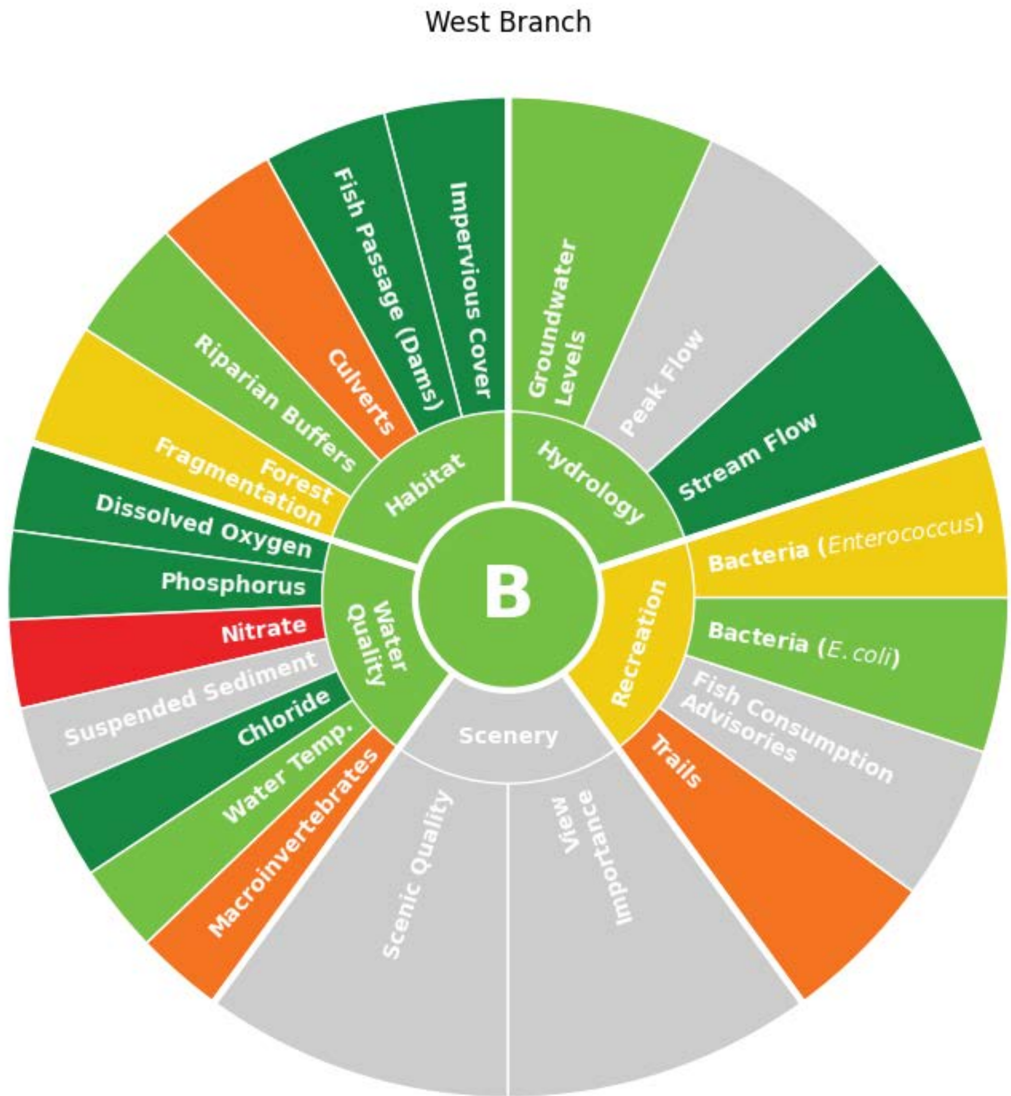

Figure 85. West Branch subwatershed scoring for each category and indicator

3.2 Recommendations and Progress Update

This section of the report provides a summary of the White Clay Creek watershed's twenty indicators within the five categories—Hydrology, Habitat, Water Quality, Scenery and Recreation—and the grades determined for each indicator. An updated summary of recommendations and accomplishments for each indicator is compiled in Table 56 using information from the 2008 and 2016 *State of the Watershed* reports, and the trend analysis in this report. The recommendations and accomplishments provided in Table 56 are specific to the assessment provided in this report and are not a complete guide to preserving and maintaining the unique and outstanding resource that is the Wild & Scenic White Clay Creek watershed.

Numerous accomplishments and progress have been made since the White Clay Creek Watershed Management Plan (2000) and the White Clay Creek *State of the Watershed* reports (2008, 2016). As future resources are allocated and management decisions are considered, stakeholders working in the watershed can use the recommendations and accomplishments provided in this report as a guide for actions and investments to improve the health of the watershed. The future of the watershed is dependent upon effective natural resources management and preservation efforts of the many partners working in coordination within the watershed and this report serves as a useful tool to guide the actions and investments in the White Clay Creek watershed.

HYDROLOGY

Indicator	Recommendations	Accomplishments/Progress
Streamflow A **Peak Flow** D **Groundwater** B	• Implement more and better stormwater control measures in rural and urban areas to increase the capture, infiltration and treatment of stormwater. Efforts should prioritize reductions in stormwater volume reaching the stream and avoid using the stream corridor to facilitate conveyance of elevated/excessive stormwater volume. • Encourage states and local governments to include recent increase in extreme precipitation events or extended droughts in all new or revised stormwater and source water protection/management plans, and infrastructure maintenance plans. • Ensure all new development and infrastructure maintenance/upgrades in EV portion of the East Branch have more efficient stormwater treatments that support the anti-degradation requirements for Special Protection Waters. • Conduct a watershed-wide flood study that incorporates the recent increase in extreme precipitation events and annual peak flows. Evaluate the capacity of current FEMA floodplain designations, and communicate current flood risk for people, property and infrastructure (e.g., bridges, roads, culverts) to relevant residents, landowners, municipalities and state agencies. • Support Subdivision and Land Development Ordinances (SALDO) and Zoning Ordinances that encourage redevelopment that protects natural resources and minimizes impervious cover and maximizes stormwater capture. • Monitor USGS streamflow gages for changes in flow as well as physical and chemical conditions, especially at stream gage USGS 01478185 on the Middle Branch, which may be showing a fair/degrading trend for flow based on limited data. • Collaborate with the Delaware River Basin Commission (DRBC) to set monitoring standards for future groundwater withdrawals in the White Clay Creek watershed, especially for longer droughts predicted as part of future climate change.	• Developed two Green Stormwater Infrastructure (GSI) Plans: West Grove Borough (2020) and Avondale Borough (2023). • Established the Catch the Rain Program in 2016, a voluntary partnership between landowners and White Clay Watershed Association (WCWA) that promotes individual actions to achieve a greater reduction in stormwater runoff to White Clay Creek. 111 voluntary small scale green stormwater practices implemented on private property. • Since 2014, installed extensive Best Management Practices (BMPs) to reduce stormwater runoff originating from agricultural lands in headwaters of the East Branch. These include: 141.29 acres of forested buffers (i.e., approx. 28,300 trees) along 10.65 miles of stream, 17,247 feet of field terraces, 11,938 ft of level-lip spreaders (infiltration trenches), and approx. 1909 acres of soil-health practices that include cover crops installed or enhanced. • US Geological Survey added four stations and upgraded sensors within the White Clay Watershed in 2020 as part of their USGS Next Generation Water Observing System (NGWOS) in the Delaware River Basin • In collaboration with US Geological Survey, Chester County Water Resources Authority and Delaware Department of Natural Resources and Environmental Control, recorded historic and present-day flooding events for analysis and future recommendations. • Worked with Stroud Water Research Center, University of Delaware Water Resources Center and Chester County Water Resources Authority to gain additional monitoring of a well located in New Garden Township. Reviewed projects that fall under Section 7 of the Wild & Scenic Rivers Act to ensure implemented projects manage stormwater during peak flows and protect natural floodways and floodplains. (on-going).

HABITAT

Indicator	Recommendation	Accomplishments/Progress
Impervious Cover B	• Limit impervious area (as a measure of urban development) to less than 10% in the East (especially in, near, and downstream of Avondale), Middle and West Branch subwatersheds where impervious cover levels are still below the impact threshold. • Encourage redevelopment and the reduction of impervious surfaces in high-growth or heavily developed areas in the Upper and Lower White Clay Creek subwatersheds where impervious area already exceeds 10%. • Support Land Preservation	• Updated population estimates based on the 2020 Census. • Identified subwatersheds with increasing population trends or growth areas. • Protected 16,742 acres of land or 24.6% of entire watershed (through 2020)
Aquatic Connectivity, Dams B **Aquatic Connectivity, Culverts** C	• Assess the feasibility of fish passage throughout the White Clay Creek watershed. While primarily focused on bridges and culverts, also identify and evaluate other barriers to fish passage (sedimentation, increased temperature) and appropriate restoration measures. • Assess dam removals to promote fish passage and other ecological goals while weighing the impact to preservation of historic and cultural resources. • Consider fish passage as part of efforts to replace or repair culverts and bridges, especially in the West Branch and Upper Main. Encourage the use of open span bridges with natural stream bottoms and stream-level culverts. • Fund fish abundance surveys as the need arises to establish trends in fish populations and incorporate abundance surveys into the dam removal process when feasible.	• Partially removed the Byrnes Mill Dam (Dam 1) in 2014. The Red Mill Dam (Dam 2), Curtis Mill Dam (Dam 4), Tweeds Mill Dam (Dam 7) and the Evan's Fulling Mill Dam (Dam 8) are all currently being assessed and are in process for removal. • Funded research to evaluate river habitat conditions between the Delaware-White Clay Creek confluence and Dam #2 on the White Clay Creek and identify any potential limiting factors preventing fish migration (2022-23). • Reviewed projects that fall under Section 7 of the Wild & Scenic Rivers Act (culverts, bridge replacements) for aquatic connectivity (on-going).

	Terrestrial Connectivity, Riparian Buffers B **Terrestrial Connectivity, Forest Fragmentation** D	• To increase terrestrial connectivity and reduce forest fragmentation, encourage and implement stream buffers on both public and private property. • Encourage municipalities to include riparian buffer plantings as part of their stormwater MS4 and TMDL strategies. • Monitor and work with municipalities to improve their riparian buffer ordinances based on the latest science. • Use the buffer gap analysis to identify future opportunities outside of the upper East Branch above Route 1. • Encourage wider buffers (300') when feasible to fill gaps and edges and create more interior (core) forest for outstanding resource values (ORVs) such as the Cerulean Warbler. • Reduce forest cover loss in urbanizing portions of the watershed through forest-protection and reforestation programs, especially along riparian stream corridors, and contiguous to large, wooded tracts. • Work with municipalities to improve woodland protections. Currently they are overall under-protected. • Support land preservation and budgeting for land stewardship. • Work with HOAs to plant more trees along streets and in open space areas.	• Published the White Clay Creek Reforestation Plan for Pennsylvania (2009) to guide future protection of forests and buffers and target future reforestation priorities. • Completed a riparian gap analysis for the entire White Clay Creek watershed (2015). • Increased forest cover and connectivity between forest fragments in the upper East Branch (since 2014) by installing 141.29 acres of forested buffers (i.e., approx. 28,300 trees) along 10.65 miles of stream. Most of these buffers were at least 100' wide on each side. Funding was provided to support 3-4 years of buffer maintenance for the young trees. • Consulted with municipalities to improve their riparian buffer ordinances. • Worked with Franklin Township to include riparian buffers in their Total Maximum Daily Load (TMDL) plans as a cost-effective stormwater control measure. Obtained funding and implemented two buffers spanning seven acres on private land. • Worked with Penn State Master Watershed Stewards to obtain funding and implement a buffer and live stake nursery on municipal land in New Garden Township. • Installed a two-acre buffer in coordination with an HOA in London Grove Township. • Supported volunteer efforts to remove invasive species and replant native species (trees, shrubs and perennials) in the Judge Morris area of White Clay Creek State Park • Encouraged long-term management of forest buffers. (including establishing budgets for long-term care and seeking funding)

WATER QUALITY

<table>
<tr><th>Indicator</th><th>Recommendations</th><th>Accomplishments/Progress</th></tr>
<tr><td>Water Temperature
C</td><td rowspan="7">● Install and/or support agricultural and urban conservation projects that reduce pollutants, including temperature, phosphorus, nitrogen, sediment and common toxins such as herbicides, fungicides, insecticides, and where applicable road salt, petroleum products, and other chemical toxins in White Clay Creek. Incorporate the most effective, science-based perspectives and practices surrounding pollution and stormwater reduction BMPs.
● Efforts to reduce agricultural and urban pollutants should prioritize reductions where pollutants originate from land and water uses, before reaching the stream corridor. Avoid trying to use the stream corridor to address pollutants that originate throughout the watershed.
● In partnership with US Geological Survey, Chester County Water Resources Authority, Pennsylvania Department of Environmental Protection, Delaware Department of Natural Resources and Environmental Control, and Stroud Water Research Center, continue physical, chemical and biological monitoring throughout the watershed to update condition and stressor assessments, and assess progress toward environmental improvement goals.
● In more urbanized areas, work with local organizations and volunteers to better understand current road salt contamination of surface and groundwater, and with private applicators, municipalities and DOTs on managing winter salt applications.
● Revisit macroinvertebrate sampling to establish long-term trends as funding permits at the 16 original sites sampled by the White Clay Watershed Association and Stroud Water Research Center.
● Support watershed municipalities as they implement their TMDL and MS4 Pollution Reduction Plans.
● Continue to engage landowners and municipalities to increase understanding and opportunities for meaningful pollution- and stormwater-reduction BMPs throughout this landscape.</td><td rowspan="7">● Continued physical, chemical and biological monitoring throughout the watershed. Implemented year-round monitoring for nitrate, orthophosphate and chloride at six sites located in the East Branch (3), Upper White Clay (2), and Lower White Clay (1) (2018- 2023). Implemented continuous temperature monitoring at five of the six aforementioned sites (2018-2023). Stroud added four temperature sites in the East Branch.
● US Geological Survey added four stations and upgraded water quality sensors within the White Clay Watershed in 2020 as part of their USGS Next Generation Water Observing System (NGWOS) in the Delaware River Basin
● Re-invigorated the Christina Watershed Municipal Partnership (CWMP), a group of municipal and non-profit partners focused on developing strategies to address stormwater pollution in the Brandywine-Christina watersheds of Chester County, PA.
● Implemented several stormwater control measures aimed at improving water quality including rain gardens, forest buffers and agricultural best management practices.
● Since 2014, installed extensive Best Management Practices (BMPs) to reduce pollutants coming from agricultural lands across the headwaters of the Upper East Branch. These include: 141.29 acres of forested buffers (i.e., approx. 28,300 trees) along 10.65 miles of stream, 17,247 feet of field terraces, 11,938 ft of level-lip spreaders (infiltration trenches), and approx. 1909 acres of soil-health practices that include cover crops installed or enhanced across 31 different properties or property managers. An additional 83 BMPs were installed as part of these projects, including livestock fencing, stabilized stream crossings for livestock, grass waterways, manure storage and handling structures, and stormwater diversions. In support of these pollution-reduction efforts, we created or updated numerous conservation plans, nutrient management plans, comprehensive nutrient management plans (CNMP) for livestock operations, manure management plans, Conservation Reserve Enhancement Program (CREP) plans, grazing management plans, environmental management plans for mushroom farms, etc.</td></tr>
<tr><td>Dissolved Oxygen (DO)
A</td></tr>
<tr><td>Phosphorus (TP)
A</td></tr>
<tr><td>Nitrogen (NO3-N)
F</td></tr>
<tr><td>Chloride (Cl)
A</td></tr>
<tr><td>Total Suspended Sediment (TSS)
C</td></tr>
<tr><td>Macroinvertebrates
D</td></tr>
</table>

SCENERY

Indicator	Recommendations	Accomplishments/Progress
Scenic Quality A **View Importance** B	• Conduct Visual Resource Inventories (VRI) to document and evaluate scenic resources to include in land management and protection goals. • Use VRI for evaluating potential visual impacts on proposed projects.	• Trained sixteen volunteers to use the National Park Service's Visual Resource Inventory methodology. • Completed 10 visual resource inventories in the watershed during 2020-2021 to gather baseline visual data.

RECREATION

Indicator	Recommendations	Accomplishments/Progress
Trails B	• Support and encourage trail easements on public open space, parks and private conservation easements to improve connectivity. • Support local land trusts and municipal open space boards in planning future trail connections and acquiring trail easements. • Encourage municipalities to include pedestrian connectivity as they update their Comprehensive Plans. • Support and encourage expansion of recreational use (e.g., wading, swimming, fishing) of the waters of the White Clay Creek.	• Supported municipal open space boards, parks committees and trail groups to identify pedestrian connectivity opportunities and offered technical support to maintain existing trails. • Participated in municipal, county and state planning meetings for Comprehensive Plan Updates, Open Space and Park Planning efforts. • Annual 'Learn to Fly Fish' sessions are offered by White Clay Fly Fishers. A five-week course to learn the basics of fly fishing.
Fish Consumption Advisories N/A	• Monitor changes in the advisories for the White Clay Creek streams. • Remap the stream miles under Delaware and Pennsylvania fish consumption advisories in the White Clay Creek watershed as needed.	• Fish consumption advisories for finfish and stocked trout have improved slightly over time.

	Bacteria (E. coli) B **Bacteria (Enterococcus)** C	• Install and/or support agriculture conservation projects that reduce bacteria loads to the White Clay Creek (livestock fencing and crossings, manure management practices). • Implement pollution-reduction measures that target bacteria sources outside of agricultural lands (buffers to deter geese, pet waste programs, septic management education). • Detect and fix leaking septic systems and/or sewer lines based on monitoring data.	• Initiated bacteria sampling program with Pennsylvania Department of Environmental Protection (DEP) in 2012–2014 during the recreational season (June–August) assessing both fecal coliform and *E. coli.* In 2015, Stroud Water Research Center and National Park Service continued to sample for *E. coli* at 14 sites in the Pennsylvania portion of White Clay. • Stroud Water Research Center and National Park Service expanded recreation season fecal indicator bacteria (FIB) monitoring for *Enterococcus* and *E. coli* at 20 sites in Pennsylvania and 10 sites in Delaware (2016- 2023) • Conducted limited microbial source tracking to identify sources of FIB. • Carried out more detailed studies on a tributary with especially high counts of fecal bacteria to assist in locating and monitoring sewer repairs in the City of Newark. • Installed extensive Best Management Practices to reduce bacterial contamination from agricultural lands across the headwaters of White Clay as part of pollution reduction efforts noted above, including forested buffers, field terraces, level-lip spreaders (infiltration trenches), livestock fencing, off channel water sources and stabilized stream crossings for livestock, manure storage and handling structures, and stormwater diversions away from livestock areas, and implementation of manure management plans.

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