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**Re: Proposed Conditional State Water Quality Certification for the Army Corps of Engineers Pennsylvania State Programmatic General Permit (PASPGP-5) - Special Public Notice # SPN 16-22**

To whom it may concern:

This letter is provided on behalf of the Exceptional Value workgroup of the Pennsylvania Campaign for Clean Water, a coalition of over 180 environmental, conservation, sporting, and religious groups from all corners of the state. The Exceptional Value workgroup that is a working arm of the Campaign for Clean Water (EV Campaign) concentrates its efforts to the protection of Pennsylvania's pristine high quality and exceptional value waterways. The EV Campaign submits the following concerns to the Pennsylvania Department of Environmental Protection for consideration.

The document open for public comment and to be put into effect for the next five years per the May 28, 2016 Pennsylvania Bulletin, Vol. 46, No 22. currently states: *The following Category Ill Activities under PASPGP-4 are Non-Reporting Activities under PASPGP-5: "b. Some activities waived at 25 PA Code§ 105.12(a)(2)-Waiver 2 –Water Obstructions in a Stream or Floodway With a Drainage Area of 100 Acres or Less (250 linear feet of permanent impact to streams and/or rivers must be submitted to the Corps as a Reporting Activity) (Part IV, (A)(13));"*

**Comment**: Under this Chapter 105 Waiver 2, any stream in Pennsylvania where the drainage area is 100 acres or less --- including any EV or HQ stream --- can be filled in and eliminated. Such impacts to Special Protection waters would qualify for the SPGP (general permit) as non-reporting which means that they would not be reviewed at any level. Despite the science that clearly documents the harm this headwater filling practice causes, it appears no changes are being considered at this time to stop this practice for the next five years. This type of waiver should not be allowed in any stream and definitely should not be allowed in Special Protection waters. The science on headwater streams clearly indicates that these important headwaters provide essential watershed health qualities, habitat for benthic macroinvertebrates and other wildlife and fauna, nutrient cycling, and reduction of sediment and pollutants to help purify water quality downstream[1]. Stroud Water Research Center, in 2008 made the case and went so far as stating:

*"Evidence shows that very small watersheds (some as small as 5.5 acres) can support both permanent and intermittent headwater streams. But the Commonwealth of Pennsylvania allows waivers for the disturbance of watersheds with drainage areas of 100 acres or less. Based on our current understanding of their ability to support vital headwater streams, we (Stroud) recommend that these smaller watersheds be protected."*

Headwater streams are an integral component of river networks and account for more than 90 percent of the streams within a stream network and nearly half of all river miles in the United States (Leopold et al. 1964). We attach this scientific white paper with our comment to provide more details and support for not allowing this waiver to continue. At the very least, the Department should not allow this waiver in EV and HQ streams.

Second, it appears from the language that certain Chapter 105 General Permit registrations still are allowed in HQ and EV waters.

In both of these situations the projects impacting our streams and wetlands will get little to no review and so are essentially on the "honor" system of the applicant. We believe that such impacts being automatically allowed in EV (and possibly in HQ) waters would be in direct opposition to state and federal (Tier 3) antidegradation requirements, the Clean Streams Law, and Article 1, Section 27 of the Pennsylvania Constitution. We believe that all activities proposed in HQ and EV waters should be authorized only after careful individual permit review, and that no waivers or general permits should be allowed in EV or HQ waters --- otherwise, the Department cannot ensure that these streams are being afforded "special protection" or that activities proposed in them will satisfy state and federal anti-degradation requirements.

The EV Campaign also has concern that wetlands are not being properly monitored and therefore are not being adequately protected: See the following language: "*Monitoring is required for temporary impacts to wetlands that exceeds 0.10 acre Part VI, (A)(23)). Monitoring would be completed using a standardized monitoring form which will be available on the Corps website at: http://www.nab.usace.army.mil/Missions/Regulatory/PermitTypesandProcess.aspx. The monitoring requirement may be waived after Corps consideration of a written request from the applicant; or the monitoring requirement may be superseded if the Corps determines more stringent monitoring is required and incorporates the requirement as a Special Condition of a PASPGP-5 verification*;

**Comment:** In this instance, there should not be a waiver allowed simply when an applicant writes a request to avoid this step. The importance of wetlands cannot be overstated and allowing such a waiver is not in the best interest of the wetlands that still remain intact. Also, the link to the monitoring protocol leads to an error page -– 404 error --- so we were unable to review that

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[1] Kaplan, Louis A. et.al. "*Protecting Headwaters: The Scientific Basis for Safeguarding Stream and River Ecosystems A Research Synthesis*", Stroud™ Water Research Center, 2008.

component of the monitoring protocols at the time of review. We understand there may be valid concerns that applications get accepted by the Department on winter assessments which does not adequately protect these wetlands from harm.

For these reasons we urge that the current proposals be tightened up to better protect our most sensitive headwater streams and wetlands and to address issues with this practice that have been on the books for far too long. To let this practice continue another five years would be a gross failure not grounded by the science that we cannot afford.

Thank you for your time and consideration of our concerns and comments and we look forward to a response.

Sincerely,

Krissy Kasserman

CCW Exceptional Value Co-Chair

Faith Zerbe

CCW Exceptional Value Co-Chair

cc. Ms. Mary Lou Martin, US Army Corps of Engineers
Ms. Patricia Strong, US Army Corps of Engineers
Mr. Wade Chandler, Chief Pennsylvania Section, Regulatory Branch
Maya van Rossum, the Delaware Riverkeeper

Enclosure. *Protecting Headwaters: The Scientific Basis for Safeguarding Stream and River Ecosystems A Research Synthesis*", Stroud™ Water Research Center, 2008

# Protecting Headwaters:

## The Scientific Basis for Safeguarding Stream and River Ecosystems

A Research Synthesis from the Stroud™ Water Research Center

STROUD™
WATER RESEARCH CENTER

# Protecting Headwaters:
## The Scientific Basis for Safeguarding Stream and River Ecosystems

### About The Stroud Water Research Center

The Stroud Water Research Center seeks to advance knowledge and stewardship of fresh water through research, education and global outreach and to help businesses, landowners, policy makers and individuals make informed decisions affecting water quality and availability around the world. The Stroud Water Research Center is an independent, 501(c)(3) not-for-profit organization located at 970 Spencer Road, Avondale, PA 19311. For more information, please visit: **www.stroudcenter.org**.

*The Sierra Club provided partial support for writing this white paper and provided funds for editing and printing. Editing, design, and executive summary by Matt Freeman.*

**The following Stroud Water Research Center scientists authored *Protecting Headwaters:***

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Left: Louis A. Kaplan, Stroud Water Research Center senior scientist and principal investigator of the Biogeochemistry group, samples water from a forested stream reach. Below: The Stroud Water Research Center entrance. Photos at left, on cover, and on pages 3 and 19 © David H. Funk, Stroud Water Research Center. Below courtesy of Stroud Water Research Center.

# Executive Summary

Scientific evidence clearly shows that healthy headwaters—tributary streams, intermittent streams, and spring seeps—are essential to the health of stream and river ecosystems. The evidence demonstrates that protecting these headwater streams with forested riparian buffer zones and protecting and restoring the watersheds in which they arise will provide benefits vital to the health and well-being of Pennsylvania's water resources, and thus its citizens.

Healthy, undisturbed headwaters supply organic matter that contributes to the growth and productivity of higher organisms, including insects and fish. Headwaters also help to keep sediment and pollutants out of the stream system's lower reaches. In addition, they enhance biodiversity by supporting flora and fauna that are uniquely acclimated to this habitat.

Forested buffer zones protect these headwaters in a variety of ways. They promote broad, shallow streams with a greater total area of aquatic habitat and a broader diversity of habitats. They help protect headwaters from both point-source and non-point-source pollution.

Forested buffer zones slow erosion from flooding and help to keep water cool, a critical factor in streams that support trout and other cold-water species. These types of protection will grow more important as climate change raises average temperatures, and if the frequency and severity of storms increases.

The small size of these headwaters and their integration into the landscape makes them exceedingly vulnerable to degradation when those landscapes are altered by construction or agriculture. Their small size also means that the degradation of just one headwater may escape detection downstream, but cumulatively the destruction of many small headwaters would have negative impacts on water resources. Headwaters are not as resilient as larger streams when disturbed because they lack sufficient flows to transport sediments associated with erosion and sedimentation, and animal life in them is usually cold-water adapted and thus sensitive to temperature increases associated with forest removal.

We know that headwaters provide important benefits for entire stream systems. We know how they are damaged, and how they can be protected. Unfortunately, current regulations do not provide adequate protection for these important resources because they have not been updated to reflect the research-based knowledge we now possess.

Evidence shows that very small watersheds (some as small as 5.5 acres) can support both permanent and intermittent headwater streams. But the Commonwealth of Pennsylvania allows waivers for the disturbance of watersheds with drainage areas of 100 acres or less. Based on our current understanding of their ability to support vital headwater streams, we recommend that these smaller watersheds be protected.

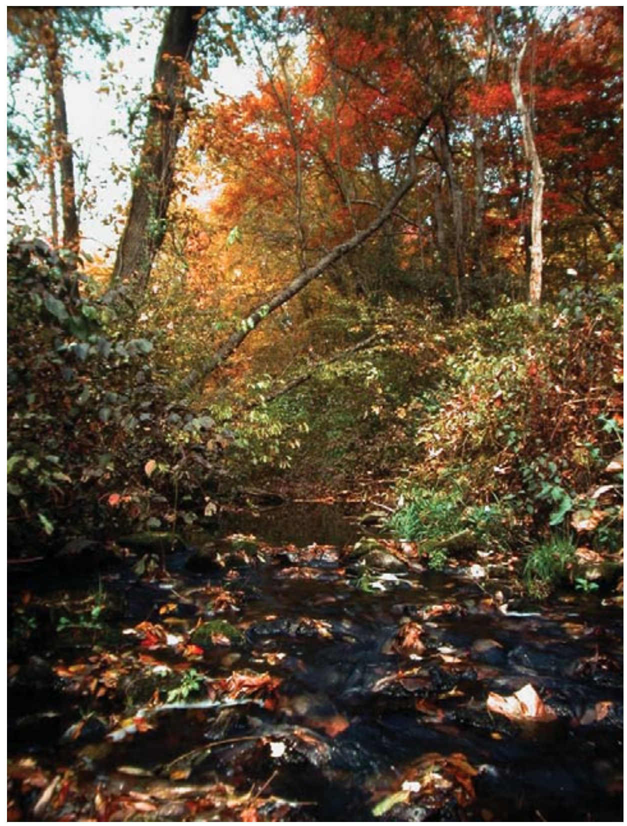
We further recommend that riparian forests be adopted as a best management practice and that these forested buffers be preserved and restored along as many reaches as possible in Pennsylvania and throughout the Piedmont and other landscapes that were historically forested.

# Introduction

Headwater streams are an integral component of river networks and account for more than 90 percent of the streams within a stream network and nearly half of all river miles in the United States (Leopold et al. 1964). As major sources of water and the dissolved and suspended organic and inorganic constituents in transport, the vitality of headwater habitats is crucial to the integrity of the downstream ecosystems into which they flow (Meyer et al. 2003; Meyer et al. 2007; Freeman et al. 2007). It is our contention that the scientific evidence clearly shows that healthy headwater streams are essential for the health of stream and river ecosystems and their destruction would pose a serious threat to water resources. Here we present evidence to support that contention.

In this paper we describe the special nature of headwater streams, their critical role in stream ecosystems, their fragility and vulnerability to human disturbance, and the benefits that ensue when headwaters are protected by forested riparian buffers. In particular, we argue that headwaters: (1) support a biodiversity of communities including species of aquatic insects that are primarily restricted to spring seeps and first-order channels and communities of microorganisms that are selected for by the physical and chemical conditions found in headwaters; (2) provide energy that helps support the life forms in larger downstream reaches and are largely responsible for establishing the chemical signature of the water downstream; (3) can arise as permanently flowing streams from very small watershed areas and can include ecologically important intermittent streams that flow from even smaller watershed areas; (4) are integrated into landscapes, which makes the quality of headwaters dependent upon land use conditions; and (5) with intact forested riparian buffers have a physical form that influences the processing of nutrients and contaminants and reproduce the conditions under which their biological communities evolved.

The Stroud Water Research Center began as a freshwater field station for the Academy of Natural Sciences of Philadelphia. Dr. Ruth Patrick founded the Center on the banks of the East Branch White Clay Creek with a mission of studying the ecology of stream ecosystems and disseminating knowledge about them. The Stroud Center now has a 40-year record of biological, chemical, and physical data for the third-order White Clay Creek watershed and its lower-order tributaries, making this one of the most intensely studied streams worldwide. While the wealth of information about White Clay Creek sets this stream apart from others, the ecology of White Clay Creek is not unique, but rather representative of small streams that exist within the eastern deciduous forest and beyond. So, while the data on White Clay Creek provide specific examples from the Pennsylvania Piedmont of ecosystem services provided by headwater streams, the generality of these findings is pertinent to our understanding of stream ecology as a whole.



Clearly, the additional ability of forested streams to process a portion of the nonpoint-source nutrients that get through the buffer seems sufficient reason in itself to make forested buffers best management practice (BMP) for riparian areas along headwater streams. Based on these benefits as well as the other benefits of forested buffers cited above, we have recommended that riparian forests be preserved and restored along as many reaches as possible in the Piedmont and other landscapes, especially those that were historically forested (Sweeney et al. 2004). However, if a small forested stream can process two to 10 times the ammonia per unit length a deforested stream can (Sweeney et al. 2004), it will do so regardless of whether the ammonia had entered the stream from a farm field or a sewage treatment plant. This led to the further recommendation that riparian forests be designated as a BMP for protecting small streams from both point- as well as nonpoint-source pollution (Sweeney and Blaine 2007).

## Headwater Streams As Repositories of Biodiversity

Aquatic macroinvertebrates (primarily aquatic insects) are the dominant animals in temperate streams and rivers, including headwater streams and their adjoining wetlands. White Clay Creek supports a diversity and abundance of aquatic insect species that typifies the assemblages of the highest-quality streams in the region. The first study of White Clay Creek at the Stroud Center demonstrated that aquatic insects clearly play a major role in the structure and function of headwater streams. They consume algae and leaves in streams, thus converting plant matter to animal tissue that is available to predators such as fish or riparian birds. Their importance to energy flow is illustrated by the fact that, although the small headwater streams contained hundreds of species, the annual biomass production of just a few species is enough to support, in theory, the annual production of all the fish in the stream. Moreover, the organic byproducts from insects feeding, growing, and dying are washed downstream by the current and become a valuable food resource to downstream stream reaches, as described in the River Continuum Concept (Vannote et al. 1980).

Our research over the last 43 years shows that the aquatic insect fauna is diverse. To date, we have collected a total of 298 species of aquatic insects (Table 2) from the headwaters of White Clay Creek. This list is undoubtedly a significant underestimate of the actual total because the lowest taxonomic resolution achieved for some orders (e.g., Diptera) was frequently at the genus level because the specimens were immature larvae collected from the stream, while species identifications often require adult specimens. Thus, we know there are many more species present, but not identified. For example, if we conservatively assume that each of the genera of Diptera has at least two species, this would add another 101 species for a total of 399.

Among the 298 species identified for White Clay Creek, 126 are considered pollution sensitive (i.e., representatives of mayflies (Ephemeroptera), stoneflies (Plecoptera), or caddisflies (Trichoptera) (Appendix, Table 2)). This abundance of pollution-sensitive species is one of the reasons this section of White Clay Creek was awarded Exceptional Value status by Pennsylvania in 1984. Within the 298 species, there are at least 43 species that we find exclusively (17) or predominantly (26) in the smallest of headwater habitats—springs, spring brooks, 0-order streams, and wetlands (Appendix, Table 3). This total for headwater specialists is also an underestimate because the effort in these habitats has been limited relative to those in the second- and third-order streams. While there is an exceptionally diverse aquatic insect fauna in White Clay Creek, we believe that it is likely characteristic of any high-quality headwater in Pennsylvania, if enough time and effort were taken to do the inventory. Species diversity is high because of the wide range of environmental conditions present in any section of headwater stream—fast versus slow current, cobble versus silt substrate, warm versus cool temperature, deep versus shallow water, leaves versus algae for food, fish versus fishless areas—and the fact that aquatic insects show a high degree of specialization for physical, chemical, and biological habitats.

*Healthy headwaters are essential to the health of stream and river ecosystems.*

Aquatic insects are far more abundant in streams than is commonly realized. Even though there are fewer insect species in headwater spring seeps because the unique conditions in these habitats select for a smaller subset of specialized species, macroinvertebrate densities in headwater springs average 15,707 individuals/ m2, 68 percent of which were aquatic insects. This translates to about 1.5 million macroinvertebrates in a stream reach 1 meter wide and 100 meters long. Greater abundance translates into greater contributions to energy and nutrient processing and flow through headwater ecosystems, and therefore to the structure and function of headwater streams, springs, and wetlands.

## Aquatic Bacteria

The study of microbial ecology has changed rapidly over the last two decades as molecular techniques have opened a window into the world of bacteria. It is now possible to describe the composition of a bacterial community without relying upon growing species in culture. As a result, microbial ecologists are beginning to describe the spatial distributions of bacterial communities and identify biogeographical patterns within specific habitats (Crump et al. 2007, Dolan 2005). Biogeography of aquatic bacteria is in its infancy, but a globally consistent pattern has begun to emerge that involves a biome-scale biogeography for stream communities. A biome is a region with distinct climax vegetation such as the eastern deciduous forest, the deserts, or the prairies. We have observed clear biome-level patterns in a study of nine streams, three from each of three different biomes (Findlay et al. 2008). To the extent that the quality of food resources influences the spatial distribution of bacterial species, our finding of a biome-scale biogeography suggests that bacterial communities are influenced by the dominant terrestrial vegetation within their drainages and that further investigations into the microbial communities present in low-order streams may provide clues to the physical, chemical and biotic factors influencing the biogeography of bacteria.

In an investigation of bacterial community composition in small streams and a river in central Germany, the communities associated with sediments in two small springs differed from the communities downstream and the changes in community composition were correlated with geographic distance downstream (Beier et al. 2008). While knowledge of the composition of the bacterial communities currently does not provide insight into the functional roles that various populations of bacteria play within the community, the differences reported for different stream orders suggests that biodiversity of these organisms is enhanced by habitat diversity and that many of these organisms would be adversely impacted with the alteration of headwater habitats.

## Contributions of Headwaters to Energy for Downstream Biota

Plants, whether terrestrial or aquatic, use the energy in sunlight to combine the hydrogen from water with carbon and oxygen from carbon dioxide to produce sugar. In streams, this organic energy can be produced within the stream by algae, aquatic mosses, and rooted aquatic plants. Organic subsidies to streams from the terrestrial environment come from rooted vegetation, including trees, understory shrubs, and herbaceous vegetation. Measurements of the production of organic energy (algal photosynthesis) and its consumption (algal and bacterial respiration) in first-order streams complement our findings that headwaters have high levels of organic inputs (Bott et al. 1976, Appendix, Table 1) and further substantiate the importance of small 0- to first-order streams to the flow of energy within a drainage network. Respiration of the streambed community is driven by a combination of energy derived from primary production by algae as well as a subsidy of organic matter entering from the terrestrial environment, such as leaf litter (Bott et al. 1985). In fact, estimates of litter inputs to the first-order stream are approximately eightfold greater than rates of algal productivity. The processing of organic matter in the first-order stream is 33 percent greater than in the next-larger-sized down-

stream reaches (Bott et al. 1985). Headwaters supply organic matter that contributes to the growth and productivity of higher organisms including insects and fish.

Bacteria attached to sediments within the Saw Mill Spring, a 0-order spring seep, derive over 50 percent of their energy from the organic matter dissolved within the water flowing out from the spring seep source (Bott et al. 1984), and productivity is high enough for bacteria within the seep to double approximately every two days under typical spring and autumn temperatures (Bott and Kaplan 1985). Bacteria are important decomposers or mineralizers within ecosystems because they metabolize or oxidize organic matter for energy and in the process generate essential nutrients such as the inorganic forms of both nitrogen and phosphorus. Another role for bacteria is the production of bacterial biomass that supplements plant-derived food webs and provides carbon and energy for higher life forms through a "microbial loop" (Pomeroy 1974), wherein protozoa and small insects feed upon the bacteria. Our data from White Clay Creek reveal that protozoa consume slightly more than 50 percent of the bacterial productivity annually (Bott and Kaplan, 1990). Thus, while bacterial activity contributes to the decomposition of organic matter and nutrient cycling, bacterial growth also contributes energy to the stream food web, ultimately resulting in greater productivity of higher organisms such as insects and ultimately fish.

In an extensive review of published measurements of stream ecosystems from 98 streams and rivers around the world, we found that community respiration is highest in headwaters and declines with distance downstream (Battin et al. 2007). In an analysis of the importance of headwaters within a river network, we suggest that collectively, the respiration within all first-order streams in a river network exceeds the respiration associated with any single larger stream order within a river network. This further emphasizes the importance of headwaters to the energy flow in stream ecosystems.

## Transformations of Organic Chemistry within Headwater Streams

Molecules of organic matter typically contain atoms of carbon, hydrogen, and oxygen, and have their origin, by and large, in photosynthesis. The initial step in photosynthesis that produces a simple sugar provides the carbon building blocks for the thousands of different organic molecules that form the basis of the food chain (Kim et al. 2006). Organic matter produced in the terrestrial environment enters streams as particles (leaves) blown in by the wind or as a cold-water "tea" as rain extracts molecules from living and dead terrestrial vegetation and the molecules dissolved in the water flow into streams as groundwater or surface runoff. In most streams and rivers, the dissolved forms of organic matter dominate the energy budgets (Wetzel and Manny 1977) and these molecules provide energy to fuel metabolism in streams (Kaplan et al. 2007).

In a study of three spring seeps within the White Clay Creek watershed, we observed a consistent pattern of changes in dissolved organic matter as low concentrations in the groundwater entering the seeps increase dramatically with distance from groundwater sources at all times of year, more than doubling within 100 meters of travel (Kaplan et al. 1980). In general, dissolved organic matter concentrations tend to be very low in ground waters as soil processes remove the organic molecules from the water as it slowly infiltrates downward through soils to the water table (Thurman 1985), and it is the tremendous levels of biological production in 0-order seep combined with a large terrestrial subsidy of leaf litter that generates the chemical signature that is imparted to much larger streams within a drainage network. In fact, in the short distance that water travels through spring seeps to form stream channels the organic matter signature of the water is trans-

***Forested buffer zones and protected watersheds provide benefits important to the health of our water resources.***

formed from that of ground water to a stream water signature typical of larger streams and that signature persists over several kilometers.

These transformations over very short distances within spring seeps are due to the highly productive nature of spring seeps. Deciduous trees growing in and around seeps in poorly drained silt loam soils with seasonally high water tables have broad, shallow root systems, making them extremely susceptible to being blown over by wind throw. The resulting openings in the forest canopy permit extensive growth of wetland plants such as jewel weed and skunk cabbage throughout the seeps during late spring and summer. Those wetland plants release organic matter to the water through their roots as they grow and then from the decomposition of their plant tissues as the plants die back in late summer. In early spring and autumn, in the absence of shading from herbaceous wetland plants, dense algal growths can occur, contributing more organic matter to the water. In addition, seeps are depressions within the landscape, so direct deciduous litter inputs and leaves blowing across the landscape accumulate in seeps, providing an important terrestrial subsidy of the production within the seeps. These multiple sources of organic matter to spring seeps make them highly productive aquatic habitats. In fact, the total inputs of plant biomass from all sources within seeps, expressed on a square meter basis, exceed those reported for most aquatic environments, except for swamps, marshes, and estuaries (Whittaker and Likens 1973) and often exceed the productivity of higher-order streams by a factor of three (Kaplan et al. 1980).

## Small Headwaters Originate in Small Watersheds

Within the Piedmont physiographic province, streams often begin within shallow depressions where groundwaters intersect the land surface. In the White Clay Creek watershed, these areas are underlain by soils classified as Worsham silt loams that are poorly drained and have a shallow depth to the water table. It is within these soils that groundwater intersects the land surface and creates spring seeps, broad wetted areas fed by upwelling groundwater. The groundwaters ultimately coalesce to form stream channels such as the headwaters of the White Clay Creek. These spring seeps, sometime referred to as 0-order streams, as well as most first-order streams, are not found on United States Geological Survey (USGS) maps, but are indeed permanent streams. We have studied many of these spring seeps within the White Clay Creek watershed and within the Brandywine River drainage, and use these direct observations as an empirical basis for identifying the minimum drainage area that can support a headwater stream. Within the upper East Branch White Clay Creek and the headwaters of the Brandywine drainage, both within southeastern Pennsylvania, watershed areas for six perennial springs or first-order streams range from 5.5 acres to 37 acres.

A more general theoretical approach to identify the drainage basin size that would support a flow large enough for a perennial stream uses a calculation based on regional estimates of groundwater yield. The average annual baseflow yield in the upper East Branch of the White Clay is 12.5 inches (0.318 m) per year or 0.1 L/s/hectare. For Chester County, the average annual baseflow runoff is similar at 13.5 inches per year. Flows in small perennial streams vary seasonally but average annual baseflows are in the range of 1.0 L/s. Thus we consider 0.5 L/s as an estimate of average annual baseflow that characterizes the smallest streams that are perennial and can support macroinvertebrate communities that require a year-round aquatic habitat. Combining the yield of 0.2 L/s/hectare with the flow of 0.5 L/s gives an estimate of 5 hectares (12 acres) as the drainage area that is likely to produce a perennial stream. This figure agrees well with the 5.5- to 37-acre range for the drainage areas of actual perennial headwater streams cited above.

Even a watershed too small to support a perennial stream may be the source of an intermittent stream, defined as a stream that stops flowing during a year of normal rainfall levels. These ecologically important habitats that are truly aquatic only part of year support fewer species of invertebrates than permanent streams, but some invertebrates that are rarely found in permanent streams are abundant in intermittent streams (Storey and Quinn 2007). The survival of these organisms depends, in part, on the survival of both their wet-season stream channels and their dry-season refugia, and their acclimation to the intermittent stream habitat contributes to the overall macroinvertebrate biodiversity.

## The Vulnerability of Headwaters and the Critical Need for Protection

Headwater streams, beginning as spring seeps and first-order stream channels in a steam and river network, have an immediate and intimate connection with the terrestrial environment, forming an extensive terrestrial/aquatic mosaic. However, the very attributes of headwaters that make them critical to the health of stream networks also make them exceedingly vulnerable to degradation when landscapes are altered. Because small streams are so integrated into landscapes, they are most at risk as landscapes are urbanized, and because of their small size, the impacts of the degradation of a single headwater stream on larger downstream reaches are difficult to observe or quantify. The small size of watersheds that can support both permanent and intermittent headwater streams, referenced above, contrasts sharply with the waiver in Pennsylvania for the disturbance of areas of 100 acres or less. One sad irony of this regulation is that headwaters are less resilient to disturbance than larger streams as they lack sufficient flows to transport sediments associated with erosion and sedimentation and their biota is usually cold-water adapted and thus sensitive to temperature increases associated with forest removal.

Additionally, we would argue that the health of downstream reaches is only as good as the protection afforded to headwater streams. Indeed, The River Continuum Concept (Vannote et al. 1980), a seminal paper in stream ecology that was developed at the Stroud Center, explicitly describes the importance of headwater streams to downstream reaches. The River Continuum Concept emphasizes the connections among stream orders within a drainage network and predicts that the organisms within downstream ecosystems have evolved to exploit the organic energy that "escapes" complete processing to carbon dioxide in upstream ecosystems. This integrative view of a watershed that is the foundation of the River Continuum Concept provides the theoretical underpinnings for the unified protection, conservation, and restoration of watersheds and river basins.

> ***Headwaters supply important nutrients to the flora and fauna in the lower stream reaches.***

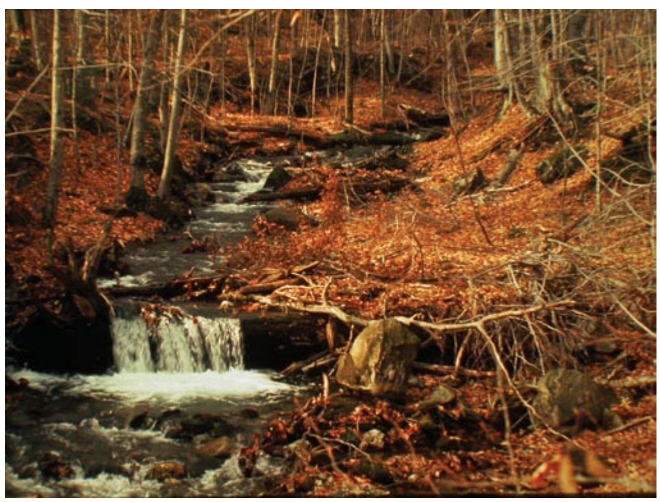
Changes in land and water use adjacent to or upstream of a headwater site often modify water and habitat quality in that stream. This generally results in more stressful environmental conditions within the stream, and therefore a loss of sensitive species that depend on the conditions lost or modified. For example, based on data from 135 stream sites in the Schuylkill River basin as well as 110 stream sites in Delaware and Hudson River watersheds that provide drinking water for New York City, we have consistently found that pollution-sensitive species such as mayflies, caddisflies, and stoneflies are lost in headwater streams as adjacent land use is gradually converted from forest to agricultural or urban/suburban development (Kratzer et al. 2006). The impact of forest conversion is more severe for species requiring highly specialized habitats because the special conditions that characterize these headwater springs, streams, and wetlands are often completely lost due to habitat changes resulting from inputs from land that is tilled, covered, or converted to lawns or stormwater basins.

These reductions in abundance or diversity translate into major changes in the structure and function of a headwater stream, and presumably its downstream reaches. These changes may be in the form of how the stream retains and processes nitrogen or phosphorus, or how food resources are processed and exported to downstream reaches. Indeed, additional studies within the watersheds that provide drinking water for New York City show that forested landcover is a good predictor of the efficiency of nutrient uptake (shorter spiraling lengths) (Newbold et al. 2006). Concentrations of naturally occurring dissolved organic matter, molecules that can form carcinogens when water is chlorinated for drinking, are also lower as the amount of forested land use increases (Kaplan et al. 2006).

In an attempt to understand the implications to the levels of downstream metabolism within stream networks if headwaters were not protected, we developed a model that estimates the contribution of dissolved organic matter supplied by headwater streams to heterotrophic metabolism in downstream reaches within a stream and river network. The model is based on measurements of dissolved organic matter cycling reported made from direct measurements within White Clay Creek (Kaplan et al. 2007). The model estimates that collectively all the first-order tributaries in a fifth-order watershed support 15 percent of the metabolism in the second-order reaches, and 5 percent, 4 percent, and 2 percent of the metabolism in the third-, fourth-, and fifth-order streams, respectively. The first-order tributaries support 4 percent of the metabolism in all of the downstream (second- to fifth-order) reaches considered together. While a 4 percent reduction in the metabolism within an entire fifth-order drainage is a low value, the 15 percent impact on second-order streams is not. Additionally, we believe the 4 percent value is a conservative estimate for two reasons. First, it only considers first-order tributaries and not the spring seeps that feed them and second, we do not currently know how a 15 percent reduction in second-order stream metabolism will cascade throughout the higher-order streams in the drainage network.

## The Effectiveness of Forest Buffers in Protecting Headwater Streams

It has been known for some time that some of the excess sediment, nutrients, and other pollutants associated with human land use can be kept out of small streams by the presence of a riparian forest or "buffer" zone along its length (see earlier reviews by Newbold et al. 1980, Lowrance et al. 1984, Peterjohn and Correll 1984). The magnitude of the in-stream benefits provided by streamside trees extends beyond pollutant control. These benefits include maintaining temperature control, providing food resources and habitat for aquatic organisms, promoting broad, shallow streams that possess a greater total area of aquatic habitat and a broader diversity of habitats, and assisting in bank stabilization.



Unfortunately, a focus on the importance of the riparian area to intercepting pollutants, combined with existing political, social, and even aesthetic ideas, gradually led to grass becoming the vegetation of choice for riparian buffers in many geographic areas and, in the process, pushed out of sight those additional and perhaps more important benefits provided to small streams by riparian forests mentioned above. Important aspects of stream ecosystem structure and function are influenced by forested buffers, as small stream reaches bordered by forest have more macroinvertebrates, total ecosystem processing of organic matter, and nitrogen uptake per unit channel length than contiguous deforested reaches (Sweeney et al. 2004). Largely overlooked was the fact that while buffers are a headwater stream's first line of defense against nonpoint-source pollutants, they were less than 100 percent effective. From the outset it was known that a buffer—whether grass or forest—could intercept anywhere from 10 percent to 85 percent of sediment and nutrients depending on the site characteristics, which means that the remaining 15 percent to 90 percent of overland pollutants were penetrating the buffers and entering the small streams (see Wenger 1999 and Mayer et al. 2005 for historical reviews).

But intercepting some pollutants was a clear improvement over intercepting no pollutants, and so little attention was paid to the potential role that a riparian buffer could play with regard to improving the health of the adjacent stream ecosystem or to what was happening to the pollutants that were getting through the buffers. In terms of the health of small streams, it is well known that a forested riparian zone represents the natural state along most headwater streams east of the Mississippi River (Williams 1989), as well as the riparian areas of even prairie (Matthews 1988, West and Ruark 2004) and desert streams (Minkley and Rinne 1985 as cited by Montgomery and Piegay 2003). By the early 1990s, data suggested that most organisms native to small streams with naturally forested riparian areas were adapted to physical, chemical, and trophic stream conditions that reflect the presence of riparian trees, and that the disappearance of those trees imposed significant stress at the individual, population, community, and ecosystem levels (Sweeney 1992, 1993). In terms of pollutants entering small streams, clearly they were being carried downstream—but what, if anything, was happening along the way? Small streams are not just pipes that transport sediments, nutrients, and other debris to large rivers, estuaries and eventually the oceans. At least in their natural state, they are efficient and effective processors of materials coming from their watersheds. Otherwise, for example, Vicente Gonzalez, the Spanish explorer who sailed into Chesapeake Bay in 1561, would have found the bay and its shores choked by the old-growth timber, leaves, and dead animals that had fallen into the thousands of headwater streams and washed downstream. This ability of small streams to process inputs from the terrestrial environment became the foundation of the River Continuum Concept over 400 years later, and a hypothesis that aquatic species form communities throughout a stream system that effectively process the organic matter moving through it (Vannote et al. 1980).

***Headwaters help keep pollution from entering the stream system and protect against erosion and sedimentation.***

Clearly, the additional ability of forested streams to process a portion of the nonpoint-source nutrients that get through the buffer seems sufficient reason in itself to make forested buffers best management practice for riparian areas along headwater streams. Based on these benefits as well as the other benefits of forested buffer cited above, we have recommended that riparian forests be preserved and restored along as many reaches as possible in the Piedmont and other landscapes, especially those that were historically forested (Sweeney et al. 2004). However, if a small forested stream can process two to 10 times the ammonia per unit length that a deforested stream can (Sweeney et al. 2004), it will do so regardless of whether the ammonia had entered the stream from a farm field or a sewage treatment plant. This led to the further recommendation that riparian forests be designated as a best management practice for protecting small streams from both point- as well as nonpoint-source pollution (Sweeney and Blaine 2007).

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# Tables

Table 1. Algal biomass estimates and stream metabolism rates in Leydard's Spring Branch, a first-order tributary of White Clay Creek (Chester County, PA). Data from Bott et al. (1985). Data in this table are mean +/- standard deviation.

| Season | n | Chlorophyll *a* | Gross Primary Productivity (GPP) | Assimilation Ratio | Community Respiration ($CR_{24}$) | Net Daily Metabolism | Respiration/g Organic Matter (OM) |
|---|---|---|---|---|---|---|---|
| | | ($mg/m^2$) | ($g\ O_2.m^{-2}.d^{-1}$) | ($mg\ O_2.mg\ Chl\ a^{-1}.d^{-1}$) | ($g\ O_2.m^{-2}.d^{-1}$) | ($GPP - CR_{24}$) | ($mg\ O_2/g\ OM$) |
| Winter | 21 | 15.33 ± 8.45 | 0.46 ± 0.26 | 39.61 ± 34.52 | 0.64 ± 0.24 | -0.18 ± 0.28 | 10.91 ± 23.21 |
| Spring | 10, 11 | 15.00 ± 6.84 | 0.70 ± 0.52 | 57.34 ± 56.12 | 2.12 ± 0.45 | -1.43 ± 0.40 | 4.52 ± 2.34 |
| Summer | 7 | 21.36 ± 8.80 | 0.63 ± 0.21 | 37.19 ± 27.87 | 1.69 ± 0.75 | -1.06 ± 0.63 | 7.94 ± 4.74 |
| Fall | 12 | 28.50 ± 15.30 | 0.86 ± 0.32 | 34.97 ± 17.70 | 1.11 ± 0.34 | -0.25 ± 0.34 | 13.55 ± 10.30 |

Table 2. Aquatic insect species that have been collected in the headwaters (HW) or in the second- and third-order sections of the White Clay Creek (WCC).

| Insects | HW | WCC | | HW | WCC |
|---|---|---|---|---|---|
| PLECOPTERA | | | *Isoperla similis* | | X |
| Peltoperlidae | | | *Isoperla frisoni* | | X |
| *Tallaperla maria* | X | X | *Remenus bilobatus* | | X |
| Taeniopterygidae | | | Chloroperlidae | | |
| *Strophopteryx fasciata* | | X | *Haploperla brevis* | | X |
| *Taeniopteryx nivalis* | | X | ODONATA | | |
| Nemouridae | | | Cordulegastridae | | |
| *Amphinemura nigritta* | | X | *Cordulegaster maculatus* | | X |
| *Prostoia similis* | | X | Gomphidae | | |
| *Soyedina carolinensis* | X | X | *Dromogomphus spinosus* | | X |
| Leuctridae | | | *Gomphus lividus* | | X |
| *Leuctra ferruginea* | | X | *Gomphus exilis* | | X |
| *Leuctra variabilis* | X | X | *Lanthus parvulus* | X | X |
| Capniidae | | | *Stylogomphus albistylus* | | X |
| *Allocapnia recta* | | X | *Stylurus* | | X |
| Perlidae | | | Aeshnidae | | |
| *Agnetina capitata* | | X | *Aeshna verticalis* | | X |
| *Eccoptura xanthenes* | | X | *Boyeria vinosa* | | X |
| *Perlesta placida* | | X | Calopterygidae | | |
| Perlodidae | | | *Calopteryx maculata* | | X |
| *Clioperla clio* | | X | *Hetaerina americana* | | X |
| *Diploperla duplicata* | | X | Coenagrionidae | | |
| *Isoperla bilineata* | | X | *Ischnura verticalis* | | X |

Table 2. Aquatic insect species that have been collected in the headwaters (HW) or in the second- and third-order sections of the White Clay Creek (WCC).

| Insects | HW | WCC | | HW | WCC |
|---|---|---|---|---|---|
| ODONATA (continued) | | | Leptophlebiidae | | |
| Corduliidae | | | *Habrophlebia vibrans* | | X |
| *Neurocordulia molesta* | | X | *Habrophlebiodes americana* | | X |
| *Tetragoneuria cynosura* | | X | *Leptophlebia cupida* | | X |
| EPHEMEROPTERA | | | *Paraleptophlebia assimilis* | | X |
| Ephemeridae | | | *Paraleptophlebia debilis* | X | X |
| *Ephemera varia* | | X | *Paraleptophlebia guttata* | | X |
| *Hexagenia atrocaudata* | | X | *Paraleptophlebia strigula* | | X |
| Leptohyphidae | | | Baetidae | | |
| *Tricorythodes allectus* | | X | *Acentrella carolina* | | X |
| Caenidae | | | *Acerpenna macdunnoughi* | | X |
| *Caenis amica* | | X | *Baetis flavistriga* | | X |
| *Caenis macafferti* | | X | *Baetis intercalaris* | | X |
| Ephemerellidae | | | *Baetis tricaudatus* | | X |
| *Dannella simplex* | | X | *Callibaetis fluctuans* | | X |
| *Drunella walkeri* | | X | *Callibaetis skokianus* | | X |
| *Ephemerella dorothea* | | X | *Centroptilum semirufum* | | X |
| *Ephemerella septentrionalis* | | X | *Centroptilum minor* | | X |
| *Ephemerella subvaria* | | X | *Centroptilum triangulifer* | | X |
| *Ephemerella invaria* grp. | | X | *Cloeon cognatum* | | X |
| *Eurylophella funeralis* | X | X | *Diphetor hageni* | | X |
| *Eurylophella verisimilis* | | X | *Plauditus cestus* | | X |
| *Eurylophella aestiva* | | X | *Procloeon rivulare* | | X |
| *Serratella deficiens* | | X | | | |
| *Serratella serrata* | | X | | | |

Table 2. Aquatic insect species that have been collected in the headwaters (HW) or in the second- and third-order sections of the White Clay Creek (WCC).

| Insects | HW | WCC | | HW | WCC |
|---|---|---|---|---|---|
| Baetidae (continued) | | | *Sigara alternata* | | X |
| *Procloeon fragile* | | X | *Trichocorixa calva* | | X |
| *Procloeon "appalachia"* | | X | Notonectidae | | X |
| *Pseudocloeon frondale* | | X | Naucoridae | | X |
| Heptageniidae | | | Gerridae | | |
| *Epeorus pleuralis* | | X | *Gerris marginatus* | | X |
| *Epeorus vitreus* | | X | *Gerris remigis* | | X |
| *Leucrocuta hebe* | | X | Veliidae | | |
| *Stenacron carolina* | X | X | *Rhagovelia obesa* | | X |
| *Stenacron interpunctatum* | | X | Mesoveliidae | | |
| *Stenonema meririvulanum* | X | X | *Mesovelia mulsanti* | | X |
| *Stenonema modestum* | | X | TRICHOPTERA | | |
| *Stenonema pudicum* | | X | Glossosomatidae | | |
| Siphlonuridae | | | *Agapetus minutus* | | X |
| *Siphlonurus quebecensis* | | X | *Glossosoma nigrior* | | X |
| Ameletidae | | | Philopotamidae | | |
| *Ameletus lineatus* | | X | *Chimarra aterrima* | | X |
| *Ameletus ludens* | | X | *Dolophilodes distinctus* | | X |
| Isonychiidae | | | *Wormaldia moesta* | X | |
| *Isonychia bicolor* | | X | Psychomyiidae | | |
| HEMIPTERA | | | *Lype diversa* | | X |
| Corixidae | | | *Psychomyia flavida* | | X |
| *Hesperocorixa* | | X | Hydropsychidae | | |

Table 2. Aquatic insect species that have been collected in the headwaters (HW) or in the second- and third-order sections of the White Clay Creek (WCC).

| Insects | HW | WCC | Insects | HW | WCC |
|---|---|---|---|---|---|
| Hydropsychidae (continued) | | | *Pycnopsyche lepida* | | X |
| *Cheumatopsyche analis* | | X | *Pycnopsyche luculenta* | | X |
| *Cheumatopsyche pettiti* | | X | *Pycnopsyche scabripennis* | | X |
| *Cheumatopsyche vannotei* | | X | Leptoceridae | | |
| *Diplectrona modesta* | X | X | *Mystacides sepulchralis* | | X |
| *Hydropsyche betteni* | | X | *Oecetis inconspicua* | | X |
| *Hydropsyche bronta* | | X | *Setodes* | | X |
| *Hydropsyche morosa* | | X | *Triaenodes baris* | | X |
| *Hydropsyche slossonae* | | X | *Triaenodes flavescens* | | X |
| *Hydropsyche sparna* | | X | Molannidae | | |
| Hydroptilidae | | | *Molanna blenda* | X | X |
| *Hydroptila consimilis* | | X | Lepidostomatidae | | |
| *Leucotrichia pictipes* | | X | *Lepidostoma serratum* | X | X |
| Phryganeidae | | | *Lepidostoma sommermanae* | X | X |
| *Ptilostomis ocellifera* | | X | Brachycentridae | | |
| Limnephilidae | | | *Brachycentrus* | | X |
| *Frenesia difficilis* | X | X | *Micrasema charonis* | | X |
| *Frenesia missa* | X | X | Beraeidae | | |
| *Hydatophylax argus* | | X | *Beraea nigritta* | X | |
| *Ironoquia punctatissima* | X | X | Odontoceridae | | |
| *Limnephilus submonilifer* | | X | *Psilotreta frontalis* | | X |
| *Pycnopsyche gentilis* | X | X | *Psilotreta rufa* | X | X |
| *Pycnopsyche guttifer* | | X | | | |

Table 2. Aquatic insect species that have been collected in the headwaters (HW) or in the second- and third-order sections of the White Clay Creek (WCC).

| Insects | HW | WCC | Insects | HW | WCC |
|---|---|---|---|---|---|
| Rhyacophilidae | | | Dixidae | | X |
| *Rhyacophila brunnea* | X | | Ceratopogonidae | | |
| *Rhyacophila carolina* | X | X | *Bezzia grp.* | | X |
| *Rhyacophila invaria* | | X | *Culicoides* | | X |
| Polycentropodidae | | | *Probezzia* | | X |
| *Neureclipsis* | | X | Chironomidae | | |
| *Nyctiophylax denningi* | | X | *Ablabesmyia* | | X |
| *Nyctiophylax moestus* | | X | nr. *Apsectrocladius* | | X |
| *Polycentropus cinereus* | | X | *Bethbilbeckia* | X | |
| *Polycentropus confusus* | | X | *Boreoheptagyia* | | X |
| *Phylocentropus lucidius* | X | X | *Brillia* | | X |
| Sericostomatidae | | | *Cardiocladius* | | X |
| *Agarodes griseus* | X | | *Chaetocladius* | | X |
| Goeridae | | | *Chasmatonotus* | | X |
| *Goera calcarata* | | X | *Chironomus* | | X |
| Uenoidae | | | | | |
| *Neophylax mitchelli* | | X | | | |
| *Neophylax oligius* | | X | | | |
| MEGALOPTERA | | | | | |
| Sialidae | | | | | |
| *Sialis* | | X | | | |
| Ptychopteridae | | X | | | |
| *Bittacomorpha* | X | | | | |
| *Ptychoptera* | X | | | | |

Below: An example of the mayfly *Baetis tricaudatus*, one of hundreds of insect species that contribute to the diversity of fauna in headwater streams. © David H. Funk, Stroud Water Research Center.

Table 2. Aquatic insect species that have been collected in the headwaters (HW) or in the second- and third-order sections of the White Clay Creek (WCC).

| Insects | HW | WCC | Insects | HW | WCC |
|---|---|---|---|---|---|
| *Cladotanytarsus* | | X | *Natarsia* | | X |
| *Clinotanypus* | | X | *Odontomesa* | X | X |
| *Coelotanypus* | | X | *Orthocladius* | | X |
| *Conchapelopia* | | X | *Orthoclad sp. #2* (Funk) | | X |
| *Corynoneura* | | X | *Pagastia* | | X |
| *Cricotopus* | | X | *Parachaetocladius/Pseudorthocladius* | | X |
| *Cryptochironomus* | | X | *Paracladopelma* | | X |
| *Cryptotendipes* | | X | *Parakiefferiella* | | X |
| *Diamesa* | | X | *Paralauterborniella* | | X |
| *Dicrotendipes* | | X | *Parametriocnemus* | | X |
| *Diplocladius* | | X | *Paratanytarsus* | | X |
| *Doncricotopus* | | X | *Paratendipes* | | X |
| *Eukiefferiella* | | X | *Pentaneura* | | X |
| *Glyptotendipes* | | X | *Phaenopsectra* | | X |
| *Harnischia* | | X | *Polypedilum* | | X |
| *Heterotrissocladius* | X | X | *Potthastia gaedii grp.* | | X |
| *Hydrobaenus* | | X | *Procladius* | | X |
| *Larsia* | | X | *Prodiamesa* | | X |
| *Limnophyes* | | X | *Psectrocladius* | | X |
| *Metriocnemus* | | X | *Psectrotanypus* | | X |
| *Micropsectra* | | X | *Pseudochironomus* | | X |
| *Microtendipes* | | X | *Rheocricotopus* | | X |
| *Nanocladius* | | X | *Rheotanytarsus* | | X |

Table 2. Aquatic insect species that have been collected in the headwaters (HW) or in the second- and third-order sections of the White Clay Creek (WCC).

| Insects | HW | WCC | Insects | HW | WCC |
|---|---|---|---|---|---|
| *Smittia* | | X | Tabanidae | | |
| *Sublettea* | | X | *Chrysops* | | X |
| *Smittia* | | X | *Tabanus* | | X |
| *Stenochironomus* | | X | Dolichopodidae | | X |
| *Stictochironomus* | | X | Empididae | | |
| *Stilocladius* | | X | *Hemerodromia* | | X |
| *Symbiocladius* | | X | *Chelifera* | | X |
| *Symposiocladius* | | X | *Clinocera* | | X |
| *Synorthocladius* | | X | COLEOPTERA | | |
| *Tanypus* | | X | Curculionidae | | X |
| *Tanytarsus* | | X | Haliplidae | | X |
| *Thienemanniella* | | X | Dytiscidae | | |
| *Thienemannimyia grp.* | | X | *Agabus obtusatus* | | X |
| *Tribelos* | | X | *Ilybius* | | X |
| *Trissopelopia* | | X | Gyrinidae | | X |
| *Tvetenia* | | X | Hydrophilidae | | X |
| *Xylotopus par* | | X | *Cymbiodyta* | X | |
| *Zavrelia* | | X | Scirtidae | | |
| *Zavrelimyia* | | X | *Cyphon* | X | |
| Stratiomyidae | | X | *Microcara explanata* | X | |
| *Oxycera* | X | | *Prionocyphon* | X | |
| Athericidae | | | | | |
| *Atherix variegata* | | X | | | |

Table 2. Aquatic insect species that have been collected in the headwaters (HW) or in the second- and third-order sections of the White Clay Creek (WCC).

| Insects | HW | WCC |
|---|---|---|
| Dryopidae | | |
| *Helichus fastigiatus* | | X |
| *Helichus basalis* | | X |
| Elmidae | | |
| *Ancyronyx variegata* | | X |
| *Dubiraphia bivittata* | | X |
| *Dubiraphia vittata* | | X |
| *Dubiraphia quadrinotata* | | X |
| *Macronychus glabratus* | | X |
| *Microcylloepus* | | X |
| *Optioservus immunis* | | X |
| *Optioservus ovalis* | | X |
| *Oulimnius latiusculus* | | X |
| *Stenelmis crenata* | | X |
| Psephenidae | | |
| *Ectopria nervosa* | X | X |
| *Psephenus herricki* | | X |
| Ptilodactylidae | | |
| *Anchytarsus bicolor* | | X |
| *Paralichas trivittus* | X | |

Table 3. Number of species for each major aquatic insect order collected in the headwaters of the East Branch of White Clay Creek in southeastern Chester County, Pennsylvania.

| | |
|---|---|
| Plecoptera | 19 |
| Odonata | 14 |
| Ephemeroptera | 52 |
| Hemiptera | 9 |
| Trichoptera | 55 |
| Megaloptera | 5 |
| Lepidoptera | 1 |
| Diptera | 118 |
| Coleoptera | 25 |
| Total | 298 |

Table 4. Aquatic insect species collected in the headwaters of White Clay Creek, southeastern Chester County, Pennsylvania. Taxa with an "X" are found exclusively in the headwaters and have not been collected downstream in second- or third-order sections.

| | |
|---|---|
| PLECOPTERA | |
| Peltoperlidae | |
| *Tallaperla maria* | |
| Nemouridae | |
| *Soyedina carolinensis* | |
| Leuctridae | |
| *Leuctra variabilis* | |
| ODONATA | |
| Gomphidae | |
| *Lanthus parvulus* | |

Table 4. (continued)

| | |
|---|---|
| EPHEMEROPTERA | |
| Ephemerellidae | |
| *Eurylophella funeralis* | |
| Leptophlebiidae | |
| *Paraleptophlebia debilis* | |
| Heptageniidae | |
| *Stenacron carolina* | |
| *Stenonema meririvulanum* | |
| TRICHOPTERA | |
| Philopotamidae | |
| *Wormaldia moesta* | X |
| Hydropsychidae | |
| *Diplectrona modesta* | |
| Limnephilidae | |
| *Frenesia difficilis* | |
| *Frenesia missa* | |
| *Ironoquia punctatissima* | |
| *Pycnopsyche gentilis* | |
| Molannidae | |
| *Molanna blenda* | |
| Lepidostomatidae | |
| *Lepidostoma serratum* | |
| *Lepidostoma sommermanae* | |
| Beraeidae | |
| *Beraea nigritta* | X |
| Odontoceridae | |

Table 4 (continued)

| | | | |
|---|---|---|---|
| *Psilotreta rufa* | | *Odontomesa* | |
| Rhyacophilidae | | Stratiomyidae | |
| *Rhyacophila brunnea* | X | *Oxycera* | X |
| *Rhyacophila carolina* | | COLEOPTERA | |
| Polycentropodidae | | Hydrophilidae | |
| *Phylocentropus lucidius* | | *Cymbiodyta* | X |
| Sericostomatidae | | Scirtidae | |
| *Agarodes griseus* | X | *Cyphon* | X |
| MEGALOPTERA | | *Microcara explanata* | X |
| Corydalidae | | *Prionocyphon* | X |
| *Chauliodes pectinicornis* | | Psephenidae | |
| *Nigronia fasciatus* | | *Ectopria nervosa* | |
| Psychodidae | | Ptilodactylidae | |
| *Threticus bicolor* | X | *Paralichas trivittus* | X |
| Tipulidae | | | |
| *Molophilus* | X | | |
| *Ormosia* | X | | |
| *Pilaria* | X | | |
| *Pedicia* | X | | |
| *Tipula collaris* | X | | |
| Ptychopteridae | | | |
| *Bittacomorpha* | X | | |
| *Ptychoptera* | X | | |
| Chironomidae | | | |
| *Bethbilbeckia* | X | | |
| *Heterotrissocladius* | | | |

Table 5. Average macroinvertebrate densities (individuals/$m^2$) among 10 spring seeps, two second-order stream sites, and four third-order stream sites.

| Site | Insect | Noninsect | Total | Percent insects |
|---|---|---|---|---|
| Spring seeps | 10,600.5 | 5,083.0 | 16,707.0 | 67.5 |
| Second-order streams | 13,835.9 | 3,237.2 | 17,073.0 | 81.0 |
| Third-order streams | 14,152.5 | 1,987.1 | 16,139.6 | 87.7 |

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