Water quality in White Clay Creek Watershed from 1991 to 2008

Stream Watch Report
by the
Stroud Water Research Center
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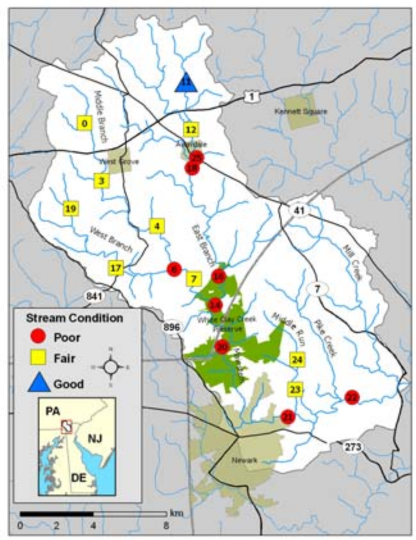
Executive Summary

The White Clay Creek watershed, located in Chester County, Pennsylvania and New Castle County, Delaware, is a valuable source of drinking water (i.e., used by 130,000 people) and possesses outstanding scenic, wildlife, recreational and cultural value. It was the first watershed in its entirety (280 km^2) to be designated as a National Wild and Scenic River.

The Stream Watch Program was initiated back in 1991 because little was known about current stream conditions in the White Clay Creek (WCC) watershed and because of concerns about rapid land development in the area. The goals of this study were to evaluate water quality in WCC and its tributaries using aquatic macroinvertebrates, and make data available to encourage efforts to improve and/or protect water quality in WCC. Aquatic macroinvertebrates (insects and non-insects such as worms and mollusks) are a cost-effective, commonly used, and widely accepted tool in water quality monitoring programs. Macroinvertebrate sampling occurred for ~9-15 yrs from 1991 to 2008 at 18 sites located throughout the WCC watershed.



Classifications of sites in WCC watershed.

Rating Water Quality

The Macroinvertebrate Aggregated Index for Streams (MAIS) uses the presence and relative abundances of certain macroinvertebrates, combined with knowledge of their ability to withstand pollution to come up with a water quality "score" for each site. This MAIS score is used to classify streams on a continuum from Good (macroinvertebrate assemblages characteristic of clean, healthy streams) to Fair (experiencing moderate environmental stress) to Poor (experiencing severe environmental stress). *Of the 18 long-term monitored sites, only one (Site 11) was classified as Good, 9 sites were classified as Fair, and 8 sites were classified as Poor. All headwater sites (Sites 11, 0, 19) rated better water quality than downstream locations and all sites on the Lower Mainstem were Poor indicating degraded water quality.* MAIS scores were comparable to other indexes devised to classify Virginia and Maryland streams.

Stream Watch results agreed with the assessment by the states (PA DEP and DNREC): water quality in WCC is impaired at numerous locations.

Land use and stream condition

The exact cause(s) of degradation at various locations in WCC are not known, but often stream degradation can be linked to the human uses of water and land. The overall watershed is a combination of forests (22%), agriculture (51%), and development (13%). Correlation coefficients indicated that *MAIS scores decreased with increasing development and decreasing pastures*. These results suggest that a dominance of pastures in the watershed are potentially beneficial to water conditions perhaps as an indirect effect of fewer people in the watershed and less intensive farming practices (e.g., hay fields require less fertilizers and tilling than row crops). There is evidence that suggests that as the number of people increase in the watershed there is a change from farms to single family homes (i.e., low intensity development) that results in a decrease in stream conditions.

Multivariate analyses found that the best stream conditions (high MAIS scores) occurred in the headwaters (Sites 11, 19, 0), but as the watershed becomes larger (moving downstream) water conditions became more degraded corresponding to an increase in impervious surfaces (e.g., parking lots and roads), and developed areas (e.g., buildings). *Poor water quality conditions in the lower half of WCC should not be attributed solely to changes in land use because stream condition is Poor in the East and Middle Branches (Sites 6 and 18), including sites downstream in the forested State Parks (Sites 16, 14 and 20), before it ever reaches the heavily populated and developed area of Newark on the Lower Mainstem (Sites 21 and 22).*

The East, West and Middle Branches of WCC

Multivariate analysis indicated water quality in the upper reaches (East, Middle and West Branches of WCC) decreased as development, impervious surfaces, and population density increased.

In 2005, a multi-site survey was done on the East Branch in and around the borough of Avondale. *Macroinvertebrates indicated that the Avondale Waste Water Treatment Plant (WWTP) on the west fork appeared to be a major contributor to stream degradation.* Trout Run, a tributary below the plant, was also in very poor condition. USGS data suggest water quality directly below the plant improved between 1992 and 1997, but then degraded from 1997 to 2004. Upgrades to the WWTP in 2006 do not appear to have measurably improved conditions downstream of the plant (based on 2008 results) but further sampling and time may be required to have an accurate assessment.

The highest quality site (11) and Site 12, ~3.9 km downstream, are located on the section of the East Branch of WCC that has been classified as "Exceptional Value" by the state of PA. Unfortunately, only *Site 11, and not Site 12, appears to have a macroinvertebrate assemblage that is comparable to other EV streams in the region*.

White Clay Creek versus other streams in the region

A comparison of WCC to sites in the neighboring Schuylkill watershed indicated fewer Good sites and more Poor sites in WCC even though both watersheds have comparable land use. Many of the WCC sites compared to the worst, most highly disturbed sites in the Schuylkill.

Overall, sites in the WCC and Schuylkill watersheds indicated that more forests and less agriculture in the watershed resulted in higher water quality. Although, sites in WCC have less forest and more crop and pasture land than most Schuylkill sites. *In the Schuylkill watershed there is a clear relationship between forest or agriculture and water quality, but this pattern is less clear for the WCC watershed. Contrary to expectation, some of the best sites in WCC have the highest percentage of agriculture and lowest forest.* The relationship between population density and MAIS also differs between WCC and Schuylkill: at similar population densities WCC sites are more degraded than Schuylkill sites. To understand the influence of land use on stream conditions in WCC may require additional land variables (e.g., more specific details about land and water use within the riparian zone) then those available for this study.

Water quality over time

Within each site, water quality varied over time but *most sites did not exhibit a trend of improving or degrading conditions since 1991*. Only Site 7 below the Middle and West Branches and Site 21 on the Lower Mainstem show signs of possible improvement.

Long-term datasets from four USGS sites suggest that water quality in the upper WCC has improved since 1972. The trend of improved water conditions was also observed for some long-term sites in the Schuylkill watershed. Comparison of USGS long-term data for WCC and sites considered some of the best in the Schuylkill watershed indicated conditions in the East Branch of WCC and Valley Creek are not as good as those in French and Pickering Creeks. Presently, sites on the upper WCC are comparable to conditions observed on French and Pickering Creeks in the 1970's and 80's. *Overall, results suggest water quality in WCC has improved significantly since 1972, but the change since 1994 is less dramatic, if at all.*

Next Steps

Most of the sites monitored within the White Clay received a Fair or Poor water quality rating. While a growing population and associated development within the watershed are likely contributing to the low water quality ratings, determining the exact cause of pollution at each site is difficult and would require more study. Despite these issues, the White Clay watershed still maintains an abundance of plants and wildlife and offers wonderful opportunities for recreation including fishing and hiking.

Introduction

The White Clay Creek watershed (107 square miles or 280 km^2) is located in Chester County, PA and New Castle County, DE, and flows into the Christina River near Newport, Delaware, which in turn, flows into the Delaware River near Wilmington. The White Clay Creek (WCC) is composed of three main branches in PA (East, Middle, and West) and three main tributaries in Delaware (Middle Run, Pike Creek, and Mill Creek). In 2000 Federal legislation designated WCC and its tributaries as a National Wild and Scenic River signifying it as possessing outstanding scenic, wildlife, recreational and cultural value. That marked the first time an entire watershed - rather than just a section of river - had been designated. Approximately 17% of the watershed is protected open space including the WCC Preserve (PA) and WCC State Park (DE). A variety of habitats provide a rich diversity of fish and wildlife: 21 species of fish, 33 species small mammals, 27 species of reptiles and amphibians, and over 90 species of breeding birds. It is also a cultural and historic location that was originally settled by the Lenape Native Americans and presently has 38 properties on the National Register of Historic Places. In addition, nearly 130,000 people get their drinking water from the WCC and the Cockeysville aquifer that underlies portions of the watershed.

The White Clay Watershed Association's (WCWA) Stream Watch Program was initiated by a WCWA volunteers and the Stroud Water Research Center, and later joined by the Delaware Nature Society, because of concerns of rapid land development in the WCC watershed. Aquatic macroinvertebrates (insects and non-insects such as worms and mollusks) were chosen for biological monitoring because they have been shown to be cost-effective, commonly used, and a widely accepted tool in water quality monitoring programs (Rosenberg and Resh 1993). Macroinvertebrates are advantageous in evaluating water quality because they have relatively diverse assemblages (100-200 species) and as a group are a sensitive measure of environmental change and stress. Their limited mobility and relatively long life spans (a few months to a year) make the presence or conspicuous absence at a site a meaningful record of environmental quality during the recent past, including short-term infrequent events that might be missed by periodic water sampling. Macroinvertebrate sampling started in 1991 and has continued through 2008 with 15 of the last 18 years sampled. A total of 18 sites were monitored: 12 sites in PA were sampled ~15 yrs (1991-2008), three sites in DE were sampled ~9 yrs (1995-2008), and three sites were sampled infrequently. The goals of this project were to:

1) evaluate water quality in White Clay Creek and its tributaries using aquatic macroinvertebrates, and
2) make data available to local education outreach and community groups in order to encourage efforts to assess, improve, and/or protect water quality in White Clay Creek.

Methods

Sample Collection and Processing

Macroinvertebrate sampling occurred at 18 sites located throughout the White Clay Creek watershed (Figure 1). For most sites, sampling occurred annually from 1991 to 2008 in March or April (no samples were taken in 2002, 2006, or 2007). Samples were taken in riffle habitat using a Surber sampler (250-um mesh, 0.093m^2). This is a quantitative method of determining the numbers and kinds of macroinvertebrates found on the stream bottom. To dislodge attached organisms rocks within the sampler were scrubbed using a brush and sediments were disturbed. Four samples were taken at each location, except in 1991 and 1992 when two samples were taken. Samples were rinsed through a 1-mm mesh sieve, transferred to a labeled jar, and preserved with 95% ethanol. Eight sites on the East Branch in the Avondale area were sampled in October 2005 by Avon Grove High School student, Dylan Kee, under the direction of the Stroud Center. Data was collected and processed in comparable way to other Stream Watch data with the exception of two composite samples (sensu Kratzer et al. 2006) instead of four individual samples and samples were processed with a 0.25-mm and 1-mm mesh sieve. In addition, Trout Run (Site 25), a tributary that joins the East Branch in Avondale, was sampled a single time in March 2005.

In the laboratory, a microscope was used to remove ≥200 organisms from detritus material and these individuals were identified usually to family (except in 1991-1993 when many taxa were identified to order), counted, and recorded. In years when samples contained many individuals, only a portion of each sample (e.g., 50%) was processed. Sampling procedures were designed and described in a matter that volunteers with minimal training could collect and process the samples. These protocols are available by contacting the education department at the Stroud Center.

Water chemistry was examined in 1994-1997, 2003-2005, and 2008 (i.e., 8 of the 15 years). Nitrate, ammonium, and soluble reactive phosphorus (SRP) were measured in all 8 years, but other variables were sampled less often (Table 1; Appendix 1).

Land Use

Sampling sites were located with a handheld Garmin 60CS GPS unit and geographic data was mapped with ArcMap (version 9, Environmental Systems Research Institute, Redlands, CA). Watershed boundaries were obtained from the Delaware Valley Regional Planning Commission and a Delaware topoquad obtained from U.S. Geological Survey. Some additional digitizing was done using 7.5 minute digital topoquads. Data layers (land use/cover, imperviousness, and canopy cover) were obtained from the 2001 National Land Cover Data (http://www.epa.gov/mrlc/nlcd-2001.html) at a resolution of 30-m. Population data (1990 and 2000 Census data) were obtained from the National Historic Geographic Information System (http://www.nhgis.org/). Data layer of PA Department of Environmental Protection (PA DEP) impaired sites for 2010 was obtained from www.pasda.psu.edu (accessed 28 Sept 2010).

Data analysis

Certain macroinvertebrates are sensitive to pollution, while others are highly tolerant of it. The number and diversity (richness) of pollution-sensitive (e.g., mayflies, stoneflies, caddisflies) and pollution-tolerant macroinvertebrates (e.g., midges, black flies, worms) can be used to describe water quality or stream conditions. Because the macroinvertebrate samples were collected from a known area of stream bottom the data could be summarized as a density (individuals/m^2) for individual families or groups of families. Not all macroinvertebrates were identified to the family level because of specimen size, damage, or taxonomic limitations. Thus, our estimates of richness may slightly underestimate actual richness. From 1991 to 1993 macroinvertebrates were, in part, only identified to order because volunteers were still developing identification skills. Beside density of certain macroinvertebrate groups, water quality conditions can also be described by various metrics that are commonly used in water quality monitoring programs. Metrics take in to account diversity (richness) and/or composition (percentages) of certain macroinvertebrate groups. Many metrics can be combined to create an index, a single value that rates stream condition for that site. We examined the data using three indexes (MAIS, MDIBI, VASOS) designed for streams in this region.

Density

The quantitative sampling method allowed macroinvertebrate counts to be expressed as a density (e.g., individuals/m^2) that was used to compare across sites and years. We examined densities of pollution-sensitive taxa [e.g., many Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies)] and pollution-tolerant taxa [e.g., many Diptera (true flies), Odonata (dragonflies, damselflies), Coleoptera (beetles)]. In response to moderate exposure to pollution, a decrease in density of pollution-sensitive taxa accompanied by an increase in density of pollution-tolerant taxa would be predicted. Densities of Ephemeroptera, Plecoptera, and Trichoptera (EPT) are commonly pooled together and analyzed as a group to assess changes in water/habitat quality in streams and rivers. Species in this group are generally more pollution-sensitive than other taxa; thus, a decrease in EPT density would be predicted in response to moderate exposure to pollution. All density data were natural logarithm transformed, a standard procedure to correct for the clumped spatial dispersion of invertebrate populations in rivers (Elliott 1977).

MAIS Index

To classify stream condition using the macroinvertebrate data, we calculated a Macroinvertebrate Aggregated Index for Streams (MAIS) that uses family-level identification that integrates 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 Maryland (51 sites), Pennsylvania (53 sites), Virginia (126 sites) and West Virginia (200 sites). It summarizes the values of 10 metrics: Ephemeroptera Richness, EPT Richness, Intolerant Taxa Richness, % Ephemeroptera, % EPT, % 5 Dominant Taxa, Simpson Diversity, Hilsenhoff's Biotic Index (HBI), % Scrapers, and % 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 might be 11-12 taxa at the highest scoring Good sites, but only 1-3 taxa at Poor sites.

MDIBI Index

Maryland Index of Biotic Integrity (MDIBI) was developed for use by trained students or volunteers. It uses family-level identifications to calculate seven metrics: Total Richness, EPT Richness, Ephemeroptera Richness, Diptera Richness, % Ephemeroptera, Intolerant Richness, and Beck's Biotic Index (Stribling et al. 1998; non-coastal plain method). Values for the individual metrics are transformed into a score of 1, 3 or 5, and then combined into a MDIBI score. MDIBI scores are predicted to decrease in response to a decrease in water/habitat quality. Streams were classified based on MDIBI scores using the modified scale: 21-28 Very Good (Non-impacted), 14-20.9 Good (Somewhat impacted), 7-13.9 Fair (Moderately Impacted), and 0-6.9 Poor (Severely impacted).

VASOS Index

The Virginia Save Our Streams (VASOS) Multimetric Index protocol developed for inexperienced volunteers uses a combination of family- and order-level identifications to calculate six metrics: % EP and most T, % Hydropsychid Caddisflies, % Lunged Snails, % Coleoptera, % Tolerant Taxa, and % Non-Insects (http://www.vasos.org). Values for the individual metrics are transformed into a score of 0, 1 and 2, and then combined into a VASOS score. VASOS scores are predicted to decrease in response to a decrease in water/habitat quality. Streams are classified based on VASOS scores as follows: 9-12 Acceptable ecological condition, 7.1-8.9 Ecological conditions cannot be determined at this time (Gray Zone), and 0-7 Unacceptable ecological condition.

Multivariate Analyses

Non-metric Multidimensional Scaling (NMS) was used to examine how macroinvertebrate assemblages differed among sites. NMS ordinations were done with all sites and with the eight sites in the three Upper Branches using $\log_{10}(x+1)$ transformed averaged (1997-2008) densities of common taxa (i.e., taxa present in 2 or more sites) identified to family or higher (PC-ORD, version 4.41, MjM Software, Gleneden Beach, OR). Conditions for the NMS were Sorenson distance, step length set at 0.2, and 51 and 220 iterations for ordinations using all the sites and sites in the Upper Branches, respectively. Monte Carlo test determined 2 axes were optimal for both NMS ordinations. The final instability was 0.00001, and final stress was 7.64 and 0.63 for all the sites and the sites in the Upper Branches, respectively. To improve interpretation ordinations were rotated and a second matrix of macroinvertebrates or land use variables was overlay. Cut off r^2 was set at 0.50 (for macroinvertebrates) and 0.35 (for land use variables) for the ordination including all sites and 0.35 for the ordination on the Upper Branch sites. An NMS using relative abundances of common taxa was also completed: 2 axes solution, 3.59 final stress, 0.00001 final instability, and cut off r^2 of 0.4.

Results & Discussion

Rating Water Quality

WCC MAIS scores

Benthic (i.e., bottom dwelling) macroinvertebrates are a widely accepted tool used to evaluate water quality. The Macroinvertebrate Aggregated Index for Streams (MAIS) uses the presence and relative abundances of certain macroinvertebrates, combined with knowledge of their ability to withstand pollution to come up with a water quality "score" for each site. This MAIS score is used to classify streams on a continuum from Good (macroinvertebrate assemblages characteristic of clean, healthy streams) to Fair (experiencing moderate environmental stress) to Poor (experiencing severe environmental stress). Of the 18 sites, 17 were considered to have moderately (Fair) to highly (Poor) degraded water quality (Figure 1).

All but one site in the upper WCC was in the Fair and/or Poor category and all sites on the Lower Mainstem were Poor indicating degraded water and/or habitat quality throughout much of the WCC watershed (Figure 1). Site 11, on the upper East Branch, was the only location classified as Good water quality, 9 sites were Fair (Sites 12, 0, 3, 4, 7, 19, 17, 24, 23) and 8 sites were Poor (Sites 25, 18, 16, 6, 14, 20, 21, 22) (Figure 2). Low MAIS scores generally reflect the loss of 50-75% of the pollution-sensitive taxa (e.g., mayflies, stoneflies and caddisflies) and an increase in pollution-tolerant taxa (e.g., worms and midge larvae). Characteristics of the individual sites, e.g., MAIS score, dominant macroinvertebrates, water chemistry, and land use, are reported in Appendix 1. Unfortunately, 7 of the 9 sites classified as Fair were closer to Poor than Good. All headwater sites (Sites 11, 0, 19) scored higher water quality than downstream locations. The highest MAIS score occurred on the East Branch at Site 11 and the lowest MAIS score was at Site 25 on Trout Run, a tributary on the East Branch (Figure 3).

Comparison of water quality indexes

There are many variables to consider when monitoring a stream such as collection method (e.g., a defined sample area versus a random collection of many habitats), processing method (e.g., in the field versus a microscope), identification level (e.g., volunteers identifying to a higher level like family versus an expert naming a taxa to species), number of individuals examined (e.g., 100-300), analysis method (what indexes are use to evaluate the data), etc. Because of these factors we wanted to examine how different indexes compared using the same dataset. We choose three commonly used indexes for this region of the U.S. that implemented family-level identifications: MAIS, Maryland Indices of Biotic Integrity (MDIBI), and Virginia Save Our Stream (VASOS). MAIS is the primary index used by the Stroud Center because we have worked with it for >10 years and feel it works well for streams in southeastern PA, while MDIBI and VASOS provide perspective of other regional methods (Figure 4). Overall, the indexes were comparable for most streams (Appendix 2). MAIS and MDIBI gave the same rating for 16 of the 18 streams (Appendix 3). Both indexes rated Poor sites similarly, but MDIBI rated three streams as Good versus only one by MAIS. VASOS rated 14 of the 18 streams the same as the MAIS. In contrast, VASOS rated more sites as Poor compared to MAIS.

Assessment of WCC by Pennsylvania and Delaware

States are required by the Federal Clean Water Act to compile a list of impaired waters, commonly referred to as the 303(d) list. Stream reaches on the 303(d) list may be required to develop a Total Maximum Daily Load (TMDL) for pollutants of concern. A TMDL (based on levels of nutrients, dissolved oxygen, bacteria, pesticides, or zinc) sets a limit on the amount of a pollutant that can be discharged into a water body and still meet federal water quality standards. Once a TMDL is determined an implementation plan is designed that outlines the means to reduce the pollutant so the stream is brought into compliance.

The 2010 report by PA Department of Environmental Protection (PA DEP) indicated that 11 of the 13 sites in the PA area of WCC, were considered impaired for aquatic life use and required a TMDL (ALU; PA DEP 2010). This included Site 11, the best site in this study, although we were not able to determine why section was impaired (Figure 5). Sites 12 and 7 were the only sites PA DEP classified as unimpaired and indicated as Fair by this study. Their method for classifying a stream as attaining or having impaired aquatic life use involves mostly genus-level identifications of macroinvertebrates used in an Index of Biotic Integrity (IBI) devised for PA streams (PA DEP 2009). The most common factor the PA DEP attributed to impairment was agricultural sources causing nutrient addition and siltation, and occasionally organic enrichment/low dissolved oxygen. Delaware Department of Natural Resources and Environmental Control (DNREC) identified the mainstem of WCC and it tributaries (Middle, Pike and Mill Creeks) as impaired, indicating non-point sources were likely affecting the nutrients, bacteria, habitat, and biology of the stream (DNREC 2010). There were few differences between Stream Watch and PA DEP or DNREC in their assessment of WCC, with the overall consensus being that water quality conditions in the watershed are degraded.

Land use and stream condition

The exact cause(s) of degradation at various locations in WCC are not known, but often stream degradation can be linked to the human uses of water and land. Land use is variable in the watershed but mainly rural (agriculture) in PA and mostly suburbanized (homes and industry) in DE (Figure 6, Appendix 4). The watershed in its entirety is a combination of forests (22%), agriculture (51%), and development (13%). Agriculture is primarily cultivated crops (12%) and pasture/hay fields (39%). Development also varies from low intensity (e.g., single family homes) to high intensity (e.g., apartment complexes, row houses and commercial/industrial buildings) with more low (9%) and medium (3%) development than high (<1%). The remaining land is categorized as open developed space (e.g., grass lawns, golf courses; 9%), wetlands (3%), and barren land (e.g., rock, sand, clay; 1%). Another important land use variable is impervious surfaces (e.g., parking lots, roofs and road; 6%), which is a component of other land use categories (e.g., development). Land use varies among sites with a range in the amount of forests (e.g., from 10% at Site 25 to 26% at Site 23), agriculture (e.g., from 49% at Site 25 to 81% at Site 19), and development (e.g., from <1% at Site 11 to 16% at Site 25). Population density can also be used to help describe the impact on the watershed. Densities (measured in 2000 census) among sites ranged from 33 people/km^2 at Site 11 to 468 people/km^2 at Site 24.

There was a significant relationship ($p < 0.05$) between MAIS scores and eight land use variables (Table 2). MAIS scores decreased when the amount of development (open space, high, medium, and low/med/high categories of intensity), barren land, evergreen forests, and impervious surfaces increased in the watershed. Four of these variables (barren land, development high and medium, and evergreen forests) each averaged ≤1% of the watersheds; impervious surfaces averaged 2% of the watersheds, while open space and development (all categories combined) averaged 5% (Table 2, Appendix 4). In contrast, the overall dominant land use was pasture/hay fields (~50% of most watersheds) and this variable was positively related to MAIS: sites with high MAIS scores had greater proportions of pasture in their watershed. Significant correlations do not imply causation but a potential existence of causal connection. For example, these results suggest that certain farms (e.g., those with unplowed fields) and open pastures are potentially beneficial to water conditions perhaps as an indirect effect of fewer people in the watershed and crops (e.g., hay) that require minimal disturbance [e.g., negligible fertilizer, herbicide, fungicide, and insecticide use; less tilling than row crops (e.g., corn, soybeans)]. Although not quantified by this study, Chester County, PA has an abundance of horse farms that likely have less impact than farms characterized by dairy cows, beef cattle, or row crops. Contrary, pastures in the lower mainstem were less dominant while development increased. An increase in development, predominately low intensity (ranged from 0.2 to 13% of the watershed among all the sites) occurred in conjunction with degrading water conditions (Table 2, Appendix 4).

Multivariate analysis (e.g., NMS) is a method where macroinvertebrate assemblages and land use characteristics can be analyzed together. NMS results, shown in Figure 7, indicated best water quality (high MAIS rating) occurred in the most upstream or headwater sites (11, 19, 0) on the three main Branches. Certain macroinvertebrates characterized good conditions (e.g., mayflies [Heptageniidae, Baetidae], caddisflies [Philopotamidae, Ueniodae, Glossosomatidae, Polycentropidae], and others [Psephenidae, Ceratopogonidae]). As the watershed becomes larger (moving downstream) stream conditions became more degraded (a decrease in MAIS score) corresponding to an increase in impervious surfaces (e.g., roofs, parking lots, roads) and associated developed areas (e.g., buildings; Figure 7). Sites on the Lower Mainstem lacked the pollution-sensitive insect groups listed above. In contrast, Sites 18 and 16, on the East Branch, had an abundance of round worms (Nematoda), a group considered tolerant to pollution. It is important to realize stream conditions are Poor in the East and Middle Branches (Sites 6 and 18), including sites downstream in the forested State Parks (Sites 16, 14 and 20), before it ever reaches the heavily populated and developed area of Newark on the Lower Mainstem (Sites 21 and 22), so Poor conditions in the lower half of WCC should not be attributed solely to local changes in land use downstream. An NMS using relative abundances (not shown) indicated the model accounted for about the same amount of variability (98%) as the NMS using densities and had similar sites grouping (i.e., headwater sites [11, 0, 19] grouped together and were opposite of those on the Lower Mainstem), which suggests patterns were not a function of density alone.

The East, West and Middle Branches of WCC

To better understand what was occurring in the upper reaches (East, Middle and West Branches) of WCC a separate multivariate analysis was done (Figure 8). Similar to the NMS with all sites (Figure 7), a decrease in water quality was associated with an increase in developed and impervious surfaces in the watershed, as well as, an increase in human population. The best water quality (highest MAIS) was found in the headwaters (most upstream sites) and water quality degraded as it went downstream. Sites 18 (East) and 4 (Middle) are both downstream from waste water treatment plants but they have different macroinvertebrate communities suggesting the quality or quantity of waste water effluent may vary or that additional factors (e.g., stream habitat, storm water, industrial waste) are influencing macroinvertebrates at these sites.

When you compare the best sites (11 and 19) to the worst sites (4 and 18) on the East, West, and Middle Branches there is a six point decrease in the MAIS scores (12 vs. 6), twice as many people (75 vs. 145 people/km^2), three times more developed area (1 vs. 3% of the watershed), and two times more impervious surfaces (0.7 vs. 1.7%). Not surprising, there was a negative relationship between MAIS and population density, i.e., as the number of people increased the water quality decreased (Figure 9). Water quality also became more degraded as the amount of developed land increased.

Water quality near the borough of Avondale

A multi-site survey of the East Branch in and around the borough of Avondale was conducted by a high school student (with the assistance of the Stroud Center) in October 2005 (Figure 10). Macroinvertebrates indicated that the Avondale Waste Water Treatment Plant (WWTP) on the west fork of the East Branch appeared to be a major contributor to stream degradation (Figure 11). All sites upstream of the WWTP scored Fair (ranged from 9.5 to 12.2), although the west fork (D) above the WWTP appeared to be experiencing a decrease in water quality. Immediately downstream of the WWTP the MAIS score was Poor (4.0). The addition of the east fork (MAIS ≥12) temporarily raised the MAIS score to 6.4, but the addition of Trout Run (Site 25), a poor water quality stream resulted in a MAIS score ≤5.0 at the two sampling locations south of the borough.

The above results, like the Stream Watch study, used a 1-mm sieve to process samples, but the Avondale survey also examined the macroinvertebrates retained by a finer mesh (0.25-mm) that captured even the tiniest of invertebrates. The fine sieve indicated that the decrease in water conditions upstream of the WWTP on the west fork (D) was greater than with the coarser (1-mm) sieve (Appendix 5), which further supports the idea that factors other than WWTP and Trout Run are contributing to degrading conditions in the area of Avondale.

Prior surveys by PA DEP that compared above and below the WWTP reported the plant caused slight impact (Spring 1991), more severe impact (Fall 1992), no impact (Spring 1997), and slight impact (Summer 2002 and Fall 2004) (see Weihrer 2005). Their results suggest water quality improved between 1992 and 1997, but then degraded from 1997 to 2004 (Weihrer 2005). In contrast, water quality for Trout Run did not fluctuate among years because it has always been shown to be in poor condition (Boyer 1997). The decrease in water quality (below the plant) may be an indication population growth in the watershed is putting greater demand on the WWTP. The Avondale plant was scheduled for upgrades in secondary treatment from modified activated sludge to oxidation ditch technology in late 2005 to early 2006 with permitted discharge increasing (300,000 to 500,000 gal/d of effluent) after the expansion (Weihrer 2005). Preliminary findings from a PA DEP survey in the fall of 2008 (taken at Site G or Site 18, below the WWTP and Trout Run; unpublished, Assessment ID 60032) and findings from this study in 2008 (Site 18; Appendix 1, 7a) suggest conditions are still degraded below the WWTP. Further sampling is needed to assess if the upgrades have measurably improved water quality; optimal sampling locations for this would be directly above and below the WWTP (but above Trout Run) as done in earlier PA DEP surveys.

Exceptional value status

East Branch of WCC from its source to the northern border of Avondale Borough (approximately 28 km of stream length) has been classified as "Exceptional Value" (EV) by the PA Department of Environmental Protection; Site 11, the best site in this study, and Site 12, ~3.9 km downstream, are located on this segment of stream. Only the best streams in the state receive this highest protection of water quality. Site 11, and not Site 12, presently appears to have a macroinvertebrate assemblage that is comparable to other EV streams in southeastern PA (Figure 12). Most EV streams had an average MAIS score >13 (Good) including Site 11. French and Hay were exceptions, with a MAIS rating of Fair (≈11), and Site 12 only averaged 7.5. The decrease in MAIS score from Site 11 to Site 12 reflects an increase in tolerant taxa (e.g., oligochaetes and chironomids) and a loss of EPT. A comparison of Site 11 vs. Site 12 indicated on average densities were 200 vs. 3000 oligochaetes/m^2 and 4000 vs. 10,000 chironomids/m^2, respectively. Typically EPT abundance was 33% lower and total richness decreased by five taxa from Site 11 to Site 12 (Appendix 1). Visible land use between Site 11 and Site 12 include the stream flowing through a golf course and past several mushroom and agricultural farms (i.e., cow, crops, orchards, and pastures).

White Clay Creek versus other streams in the region

To get a perspective on how WCC compares to other streams in southeastern PA we compared these study results to 150 sites (sampled anywhere from 1-14 yrs from 1996-2009) located in the Schuylkill River basin. The Schuylkill River sites were chosen for comparison because of their close proximity to the WCC, the amount of macroinvertebrate data available, and the similarity in land use between the watersheds. Land use in the Schuylkill vs. WCC is comparable with a mixture of agriculture (40 vs. 51%), forests (41 vs. 22%), and urbanization (13 vs. 13%). In addition, both watersheds have a similar history in urban and suburban developments (i.e., dating to late 1600's - early 1700's), although present population density is lower in the WCC watershed. Overall, compared to the Schuylkill basin, the WCC watershed had fewer Good sites (6 vs. 21%), more Poor sites (44 vs. 25%) and a similar number of Fair sites (50 vs. 51%) (Figure 13). A Poor rating signals a loss of diversity (e.g., ≤3 families pollution-sensitive Ephemeroptera, Plecoptera and Trichoptera [EPT]) and a decrease in abundance of pollution-sensitive taxa (e.g., <15% of the total are EPT). Sites that rated Poor in the Schuylkill are highly disturbed because they are extremely urbanized (e.g., Wissahickon Creek), receive runoff from point sources and agricultural non-point sources, have active dams (e.g., Tulpehocken Creek), or receive acid mine drainage (AMD) from anthracite coal mining (e.g., headwaters of the Main Schuylkill, West Branch of the Schuylkill and Little Schuylkill). In contrast, degraded sites in the WCC are likely the result of point (e.g., treated waste water effluent) and non-point (e.g., agricultural runoff) sources in the Upper Branches in PA, as well as, urbanization in the Lower Mainstem in DE.

Analysis of WCC and Schuylkill sites (excluding 12 AMD sites) was done to better understand the relationship between land use and stream degradation. Across WCC and Schuylkill sites there was a positive relationship between the amount of forest in the watershed and MAIS scores and a negative relationship between agriculture (e.g., pasture and crops) and MAIS (Figure 14). These relationships indicated higher water quality was associated with more forests and less agriculture in the watershed. The benefits of trees to stream health are well documented, especially when the forest occurs along the stream and acts as a buffer to activities in the uplands (Lowrance et al. 1995, Sweeney et al. 2004). Conspicuously, sites in WCC have lower amounts of forest, higher amounts of agriculture, and lower water quality than most Schuylkill sites; even at Site 11, which had the highest MAIS score in this study (Figure 14).

The relationship between land use (i.e., forest and agriculture) and water quality (MAIS) is obvious for the Schuylkill, but this pattern is less clear for the WCC watershed (Figure 14). For example, contrary to expectation some of the best water quality sites (Sites 0, 11, 19) in WCC have the highest percentage of agriculture and lowest forest. In addition, water quality actually appears to improve as the amount of pastures and crops increases in the watershed. In WCC, agriculture ($R^2 = 0.44$) is a stronger prediction of stream condition than forest ($R^2 = 0.03$; Figure 14). Percentage of forest varied little (11-27%) among the Stream Watch sites; in contrast, forest cover for the Schuylkill sites ranged from 3-99% (Appendix 4).

One form of agriculture that is more prevalent in the upper WCC than the Schuylkill watershed is the mushroom industry. PA is the leader in mushroom production in the United States, and Chester County accounts for 81% of PA mushroom farms (e.g., Kennett Square is known as the Mushroom Capital of the World). This type of farming typically involves extensive fertilizers and composting (i.e., spent mushroom substrate) and the by-products (e.g., nutrients) can make their way into nearby streams through runoff (Kaplan et al. 1995, Guo and Chorover 2004). Historically there was heavy pesticide usage with the industry but now a steam pasteurized method is used sanitize 'new' compost to remove problem pests. Nevertheless, spent compost has been spread on fields throughout the region resulting in residual pesticides in the soil. It is difficult to quantify the impact mushroom farming has had on streams in WCC, but certainly toxic levels of insecticides [e.g., diazinon (used to control the mushroom flies but no longer sold for mushroom use since 2002), 4,4'-DDT and other breakdown products of DDT (banned in 1972 in the US), heptachlor (limited in its use)] associated but not limited to the mushroom industry have been reported in the WCC (Boyer 1992, 1997). One of the TMDLs on the East Branch (near Avondale) is for pesticides (PA 2010), with the likely source being attributed to the mushroom industry (US EPA 2007). The use of pesticides in mushroom growing process has decreased greatly in recent years, but because many of the compounds have a long half life their persistence and residual effects may require extended periods (and no additional pesticides) before there is a measurable improvement in stream condition.

The relationship between population density and MAIS also differs between the WCC and Schuylkill watersheds at a number of sites. Water quality is much more degraded in the WCC watershed compared to the Schuylkill for a given population density (Figure 14). Typically more people in the watershed has a greater negative impact on the water quality, but this conclusion was not consistent with what was found in WCC since some of the better rated sites (23 and 24) had the highest density of people (Figure 14, Appendix 1). Population density in WCC correlated positively to low intensity development and negatively to pasture and crops: this may be interpreted that as the number of people increased in the watershed there was a change from farms to single family homes (Appendix 6). If you exclude Sites 23 and 24 there is a significant relationship ($p < 0.001$) for the remaining sites between MAIS and density of people: more people resulted in poorer water quality (Appendix 6).

Land use variables are complicated because they can be difficult to quantify. For example, population density or agriculture may have less of an impact on water quality if they occur enough distance from the stream and there is an intact riparian buffer that helps to minimize impacts from reaching the stream. Another difficulty was the GIS data layer (i.e., land use/cover, imperviousness, and canopy cover) used in this study was at a somewhat course resolution (30 m) because we needed data layers that spanned both PA and DE, and were collected in a similar and consistent manner (NLDC 2001). It is important to understand that how the GIS information is collected can affect interpretation. For example, a study on the WCC watershed near Newark, DE reported impervious surfaces that ranged from 3 to 44% of the watershed (Kauffman et al. 2009); much higher than 1.7-5.4% that we found. To better understand the influence of land use on stream conditions in WCC may require examining additional land variables [e.g., number and size of operational mushroom facilities, number and size of farms differentiated by use (e.g., working dairy vs. agricultural vs. horse)] or variables from this study be measured on a finer scale than is currently available (e.g., examine population density within 50-m, 100-m, etc riparian buffer).

Water quality over time

Stream Watch data

The abundance of macroinvertebrate species within a community often differs year-to-year. This difference is referred to as annual variation, and the cumulative affect can be evident in the MAIS scores (Figure 15). Annual variation may be related to natural phenomena (e.g., droughts or floods) or human activities (e.g., toxic spills), but most of it is often unexplained. Examination of multiple years of data indicated many Stream Watch sites ranged from Good to Fair or from Fair to Poor. In most instances, a site that was classified Good was never Poor and a site that was Poor was never Good. Sites 19, 0, and 7 were an exception to this rule because they had at least one year that rated Good, Fair and Poor. This high variability among years emphasizes the importance of having multi-year studies to correctly characterize conditions. If only one or a few years of data are available, it is important to be conservative in the use of stream classifications because annual variation may have influenced that classification. Of all sites sampled in more than one year, only Site 11 was never classified as Poor. In contrast, Sites 16 and 21 rated Poor in all the years they were sampled.

Within each site, water quality varied over time but most sites exhibited no trend of improving or degrading stream condition since 1991 when the study started (Figure 16; Appendix 7a-d). Regressions of MAIS over time suggest Site 7 below the Middle and West Branches ($p = 0.12$) and Site 21 on the Lower Mainstem ($p = 0.06$) are locations where water quality may be improving (Figure 17). There has been no change at Sites 6 and 17 upstream of Site 7, which suggests improvements at Site 7 may be local. Site 7 had MAIS scores that were highly variable; during the 10 years (1994-2005) examined they ranged from 1.5 in 1997 to 13.6 in 2003. Additional sampling would help clarify if this variability is due to unstable conditions that are typical of this site or if an actual improvement in water quality is occurring. Even with potential improvements at Site 21, conditions are still Poor (MAIS = 5.9 in 2000), but this site should be reexamined in the future because the analysis is based on only 5 years of data (1995-2000) instead of 10-12 years like most sites.

Additional assessments of WCC by USGS in partnership with CCWRA

Chester County Water Resources Authority (CCWRA) had a cooperative water-resources program with the U.S. Geological Survey (USGS) to measure, describe, and manage water-resources in the County. USGS has annually sampled macroinvertebrates at four locations (labeled USGS 28, 29, 30, and 58) in the PA portion of WCC watershed as far back as 1972, with the exception of USGS 58 which was sampled starting in 1998

(Figure 18; Reif 2002). A comparison of their data to the Stream Watch data (i.e., sites that were in close proximity to theirs and collected in the same year) indicates the USGS MAIS scores were consistently higher than the Stream Watch ones (Figure 19). This likely reflects seasonal variation in the macroinvertebrate assemblages being exhibited in the MAIS score; we sampled in late winter/early spring (March/April) and USGS sampled in autumn (Oct/Nov). In autumn there tended to be greater total richness and more EPT taxa than in the winter/spring, which resulted in higher MAIS scores (Appendix 8). In addition, there were more Trichoptera (i.e., Hydropsychidae and Glossosomatidae) and fewer chironomids in autumn compared to the winter/spring (data not shown). A 2007 study done on 11 streams in Bucks County also observed a similar relationship between MAIS scores and season [i.e., higher MAIS scores occurred in the summer/autumn (Sep) versus the spring (Apr)], and a stronger relationship between land cover and macroinvertebrates occurred in spring versus autumn (SWRC unpublished data). To a lesser extent, MAIS scores may have been influenced by differences in methods (e.g., sieve mesh-size [1-mm vs. 500-μm], sampling gear [Surber vs. Lium or Hess], processing [subsampling vs. whole sample], personnel, and number of samples [4 Surbers vs. a composite of 3 Hesses]) (Andrew Reif, USGS, personal communication, May 15, 2010).

Long-term datasets from USGS suggest that water quality has gotten better since 1972 for WCC sites in PA: data ranging from 1972 to 2009 indicates improvement at three of the four locations ($p < 0.05$; Figure 20; USGS 28, 29, 30). For USGS 28 on the East Branch total richness has increased from 8 to 17 taxa/200 individuals, this translate into a MAIS score that went from a low of 5.1 (Poor) to a high of 14.5 (Good). The Middle (USGS 29) and West (USGS 30) Branches also have had an improvement in water conditions since the early 1970s. Site 58, below the Middle and West Branches, was the only site not to show a significant increase in MAIS, but this site was only sampled starting in 1998 and had started (and ended) with the highest overall water quality rating (based on MAIS and richness), therefore it had less room for improvement.

The trend of improved water conditions based on richness metrics was also observed for some long-term sites in the Schuylkill watershed: French (USGS 15), Pickering (USGS 5), and Valley (USGS 50/52) Creeks (Figure 20; Reif 2004). French and Valley have been designated as an EV streams and Pickering as High Quality (HQ). USGS 28 is also part of the EV section of the East Branch of WCC, yet comparisons among streams would suggest conditions in the East Branch (USGS 28), as well as Valley, are not as good as French and Pickering. For example, total richness from 2000 to 2005 for French and Pickering averaged 26 and 20 taxa/200 individuals, respectively, whereas during the same time period for Valley and the East Branch total richness was 12 and 15 taxa/200 individuals, respectively (Figure 20). Perhaps more significant, the portion of the total richness that were sensitive to pollution (e.g., individuals that have a TV $\leq$5) was also higher in French and Pickering (69% of the total richness were sensitive taxa) than Valley (43%) and East Branch (49%). Presently, sites on WCC (USGS 28, 29, 30 and 58) are comparable to conditions observed on French and Pickering Creeks in the 1970's and 80's.

After much improvement between 1970's to mid-1990's there has been minimal or no change since mid 1990's. MAIS scores in recent years (1994-2009) indicate data from the USGS sites 28 and 58 and the corresponding Stream Watch Sites 12 and 7 have changed little, but there were several trends that were nearly significant ($p < 0.15$) (Figure 21). Conditions are possibly improving at USGS 28 on the East Branch (but not at the nearby Stream Watch Site 12), and below the West and Middle Branches at USGS 58 and Stream Watch Site 7 (Figure 17). Sampling at USGS 29 and 30 stopped in 1997 so we were limited in our ability to make comparisons to our Sites 4 and 17, respectively (e.g., only three years of data overlapped). Overall the USGS and our results suggest water quality in WCC has improved significantly since 1972, but changes, if any, are occurring at a less dramatic rate since the mid 1990's (Figure 21).

Synopsis

Macroinvertebrates were sampled at 18 sites located throughout the WCC watershed for the most part annually from 1991 to 2008 (Figure 1). In addition, several sites in the Avondale area were sampled in 2005. The macroinvertebrate data were used to calculate a Macroinvertebrate Aggregated Index for Streams (MAIS) that integrated various types of information into a single number that classified streams as Good, Fair, or Poor. Of the 18 long-term monitored sites, only one (Site 11) was classified as Good, 9 sites were Fair (Sites 12, 0, 3, 4, 7, 19, 17, 24, 23) and 8 sites were Poor (Sites 25, 18, 16, 6, 14, 20, 21, 22) (Figure 2). The most upstream sites (Sites 11, 0, 19) scored higher than sites downstream on the same branches. All three branches of the upper White Clay had sites in the Fair and/or Poor category and all sites on the Lower Mainstem were Poor indicating degraded water or habitat quality. PA DEP and DNREC also consider water quality in WCC as impaired (based on their 303 (d) list).

The exact cause(s) of degradation at various locations in WCC are not known, but often stream degradation can be linked to the human uses of water and land. Land use is variable in the watershed but mainly rural (agriculture) in PA and mostly suburbanized (homes and industry) in DE. As the watershed becomes larger (moving downstream) water conditions become more degraded corresponding to an increase in impervious surfaces (parking lots and roads), and developed areas (buildings). It is important to recognize that water conditions are Poor in the Upper Branches in PA before it ever reaches the Lower Mainstem. Therefore, Poor conditions in the lower half of WCC should not be attributed solely to local land use changes or an increase in population density. Data from sites in the East, West and Middle Branches showed that as the number of people and the amount of developed land in the watershed increased the water quality decreased.

Sites on the East Branch suggest that water quality degrades in the vicinity of Avondale. Land use changes and point source discharges that occur in this area include the increased population density of the borough, a golf course, the WWTP, and other non-point sources (i.e., residential areas and agriculture, including mushroom facilities). The East Branch remains poor south of Avondale and even with the addition of the West and Middle Branches, which were mainly rated as Fair, the main channel remains Poor. The large forested areas in the state parks in PA and DE also do little to improve the water quality of the Lower Mainstem through Delaware. Apparently in this case, large forests do not correct stream degradation that begins upstream. Further studies may want to ascertain the specific influences that are negatively impacting the East Branch and propose suggestions for their remediation or prevention.

Compared to 150 sites in the nearby Schuylkill River basin the WCC watershed has fewer Good sites and more Poor sites. The lower water quality in the WCC compared to the Schuylkill watershed appears to be related in part, to the lower amounts of forest and higher amounts of agriculture in WCC watershed. Compared to long-term data (1972-2009) for EV or HQ streams in the Schuylkill watershed, water quality in the upper WCC watershed was lower than some creeks (French and Pickering), but comparable to others (Valley). Within each site water quality varied over time, but there were no trends in our data or data from four USGS sites indicating conditions have improved or become more degraded from 1994 to 2009; although, the USGS sites showed that water quality has markedly improved since 1972.

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References

Boyer, M.R. 1992. Aquatic biology investigation: UNT East Branch White Clay Creek., PA DEP SE Regional office, Conshohocken, PA.

Boyer, M.R. 1997. Aquatic Biology Investigation - East Branch White Clay Creek. Case: Avondale STP/Non-Point Sources. PA DEP Report.

DNREC (Delaware Department of Natural Resources and Environmental Control). 2010. State of Delaware 2010 Combined Watershed Assessment Report (305(b)) and determination for the Clean Water Act Section 303(d) List of Waters Needing TMDLs. <http://www.wr.dnrec.delaware.gov/Information/OtherInfo /Pages/WatershedAssessment305band303dReports.aspx> Accessed 29 Sept 2010.

Elliott, J.M. 1977. Some methods for the statistical analysis of samples of benthic invertebrates, 2nd Edition. Freshwater Biological Assoc. Sci. Publ. No. 25. 156 pp.

Guo, M. and J. Chorover. 2004. Solute release from weathering of spent mushroom substrate under controlled conditions. Compost Science & Utilization 12: 225-234.

Kaplan, L.A., L.J. Standley, and J.D. Newbold. 1995. Impact on water quality of high and low density applications of spent mushroom substrate to agricultural lands. Compost Science and Utilization 3: 55-63.

Kauffman, G.J., A.C. Belden, K.J. Vonck, and A.R. Homsey. 2009. Link between impervious cover and base flow in the White Clay Creek Wild and Scenic watershed in Delaware. Journal of Hydrologic Engineering 14:324-334.

Kratzer, E.B., J.K. Jackson, D.B. Arscott, A.K. Aufdenkampe, C.L. Dow, L.A. Kaplan, J.D. Newbold, and B.W. Sweeney 2006. Macroinvertebrate distribution in relation to land use and water chemistry in New York City drinking-water-supply watersheds. Journal of the North American Benthological Society 25: 954-976.

Lowrance, R., L.S. Altier, J.D. Newbold, R.R. Schnabel, P.M. Groffman, J.M. Denver, D.L. Correll, J.W. Gilliam, J.L. Robinson, R.B. Brinsfield, K.W. Staver, W.C. Lucas, and A.H. Todd. 1995. Water quality functions of riparian forest buffer systems in the Chesapeake Bay Watershed. Chesapeake Bay Program Technology Transfer Report. U.S. Environmental Protection Agency 903-R-95-004 CBP/TRS 134/95.

PA DEP (Pennsylvania Department of Environmental Protection). 2009. An Index of Biotic Integrity for Wadeable Freestone Riffle-Run Streams in Pennsylvania <http://www.depweb.state.pa.us/portal/server.pt/community/water_quality_standards/10556/2009_assessment_methodology/666876> Accessed 30 September 2010.

PA DEP (Pennsylvania Department of Environmental Protection). 2010. 2010 Pennsylvania Integrated Water Quality Monitoring and Assessment Report Clean Water Act Section 305(b) Report and 303(d) List <http://www.portal.state.pa.us/portal/server.pt/community/water_quality_standards/10556/integrated_water_quality_report_-_2010/682562> Accessed 28 August 2010.

Reif, A.G. 2002. Assessment of stream quality using biological indices at selected sites in the Red Clay and White Clay Creek Basins, Chester County, Pennsylvania, 1981-97. USGS Fact Sheet FS-118-02.

Reif, A.G. 2004. Assessment of water chemistry, habitat, and benthic macroinvertebrates at selected stream-quality monitoring sites in Chester County, Pennsylvania, 1998-2000**:** 84.

Rosenberg, D.M. and V.H. Resh (editors). 1993. Freshwater Biomonitoring and Benthic Macroinvertebrates. Routledge, Chapman and Hall, New York.

Smith, E.P. and J. Voshell. 1997. Studies of Benthic Macroinvertebrates and Fish in Streams within EPA Region 3 for Development of Biological Indicators of Ecological Condition. Part 1. Benthic Macroinvertebrates. Final report for Cooperative Agreement CF821462010. U.S. Environmental Protection Agency, Washington, D.C.

Stribling, J.B., B.K. Jessup, J.S. White, D. Boward, and M. Hurd. 1998. Development of a Benthic index of Biotic Integrity for Maryland Streams, Chesapeake Bay and Watershed Programs. Report no. CBWP-EA-98-3**.** 62 pp.

"Stroud Water Research Center: Schuylkill Project." *Stroud Water Research Center: Dedicated to the Study of Streams and Rivers*. Web. 1 June 2010. <http://www.stroudcenter.org/schuylkill/index.htm>.

Sweeney, B.W., T.L. Bott, J.K. Jackson, L.A. Kaplan, J.D. Newbold, L.J. Standley, W.C. Hession, and R.J. Horwitz. 2004. Riparian deforestation, stream narrowing, and loss of stream ecosystem services. Proceedings of the National Academy of Sciences of the United States of America 101: 14132-14137.

US EPA (Untied States Environmental Protection Agency). 2007. Decision rationale Total Maximum Daily Loads East Branch White Clay Creek Watershed for pesticides affected segments Chester County, Pennsylvania. A report prepared by PA DEP for US EPA. <http://www.epa.gov/reg3wapd/tmdl/pa_tmdl/EBrWhiteClayCreek/index.html> Accessed 20Oct 2010.

Weihrer, K.A. 2005. Aquatic Biology Investigation – UNT to East Branch White Clay Creek Chester County, Avondale Borough. Case: Avondale STP. PA DEP Report.

Table 1. Schedule of when water chemistry variables were measured. Water chemistry samples were collected in 8 of the 15 years and only at sites when macroinvertebrate sampling occurred.

Year	Nitrate	Ammonium	Total Phosphorus	Soluble Reactive Phosphorus	Sulfate	Alkalinity	pH	Conductivity	Dissolved Organic Carbon
1994	x	x		x				x	x
1995	x	x		x					
1996	x	x		x		x	x	x	x
1997	x	x		x			x	x	x
2003	x	x	x	x	x	x	x	x	
2004	x	x	x	x	x	x	x	x	
2005	x	x	x	x	x	x	x	x	
2008	x	x	x	x	x	x	x	x	

Table 2. Correlation coefficients (r) for MAIS (1993-2008 average) and land use variables. Land use averages are based on all the sites (n = 18). All variables were measured as a percentage of the watershed except population variables, which were based on the 2000 census (see methods for details). Developed includes areas with a mixture of some constructed materials and vegetation. Categories are open space (<20% of total cover is impervious surfaces; e.g., lawns), low intensity (20-49% impervious surfaces; e.g., single family homes), medium intensity (50-79% impervious surfaces, e.g., single family homes), and high intensity (80-100% impervious surfaces, e.g., apartment complexes, row houses and commercial/industrial buildings).

Land use category	Average	r	p
Developed, open space	5	-0.71	0.001
Barren land (Rock/Sand/Clay)	<1	-0.68	0.002
Pasture/Hay	51	0.65	0.003
Developed, high intensity	<1	-0.65	0.003
Developed, medium intensity	1	-0.65	0.004
Evergreen forest	<1	-0.61	0.008
Impervious surfaces	2	-0.59	0.01
Developed, low, med & high intensity	5	-0.50	0.04
% Population change from 1990 to 2000	30	-0.46	0.06
Mixed forest	<1	-0.38	0.12
Cultivated crops	19	0.33	0.18
Developed, low intensity	3	-0.33	0.18
Emergent herbaceous wetlands	<1	-0.31	0.21
Population density (people/km^2)	185	-0.30	0.23
Woody wetlands	1	-0.30	0.22
Canopy	17	-0.23	0.37
Open water	<1	-0.22	0.37
Forest (deciduous, evergreen, mixed)	18	-0.14	0.58
Deciduous forest	18	-0.11	0.65

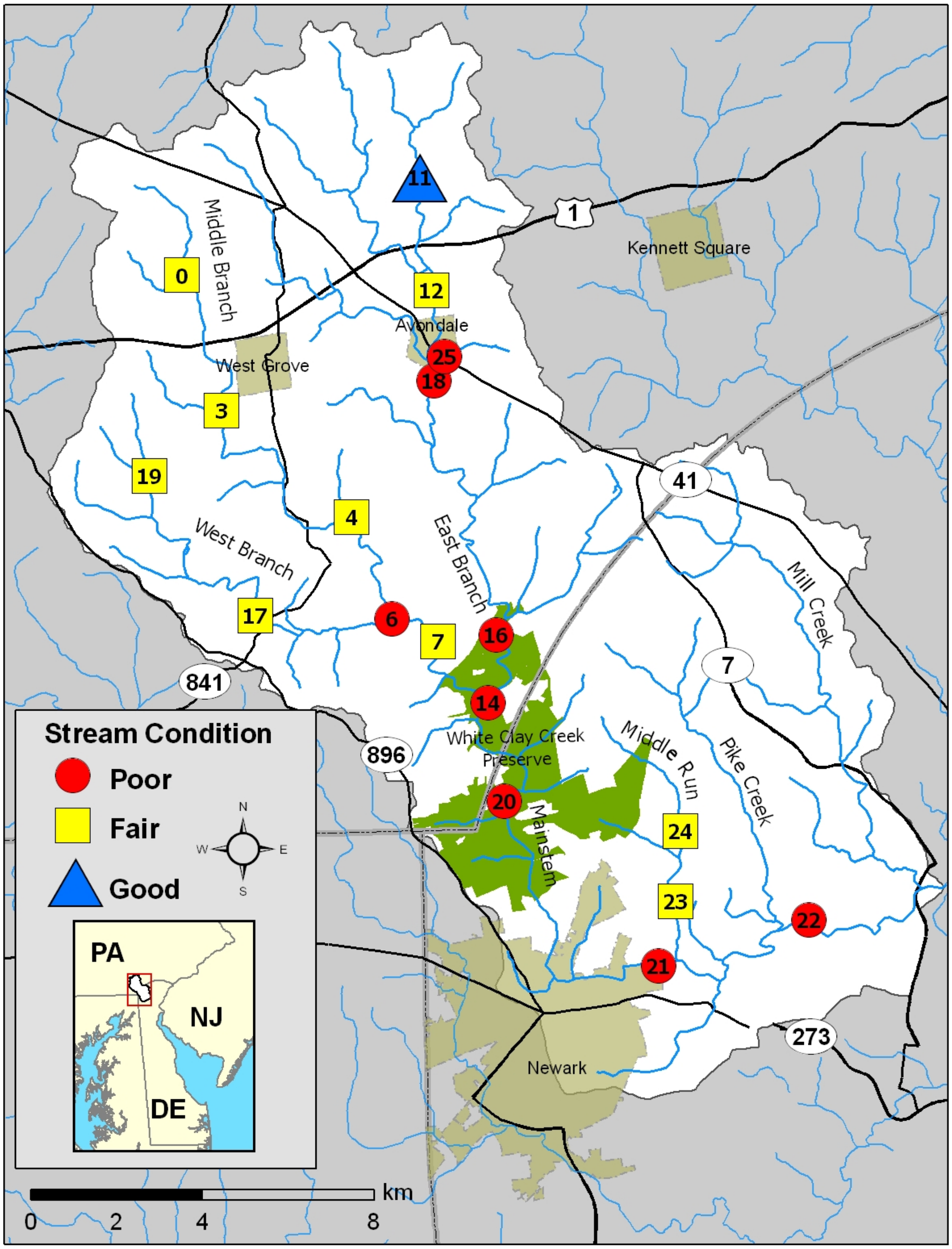


Figure 1. Watershed Map showing location of sites sampled in the East, Middle, and West Branches, Middle Run, and the Lower Mainstem of the White Clay Creek watershed from 1991-2008. Macroinvertebrates were used to rate water quality as Good, Fair, and Poor.

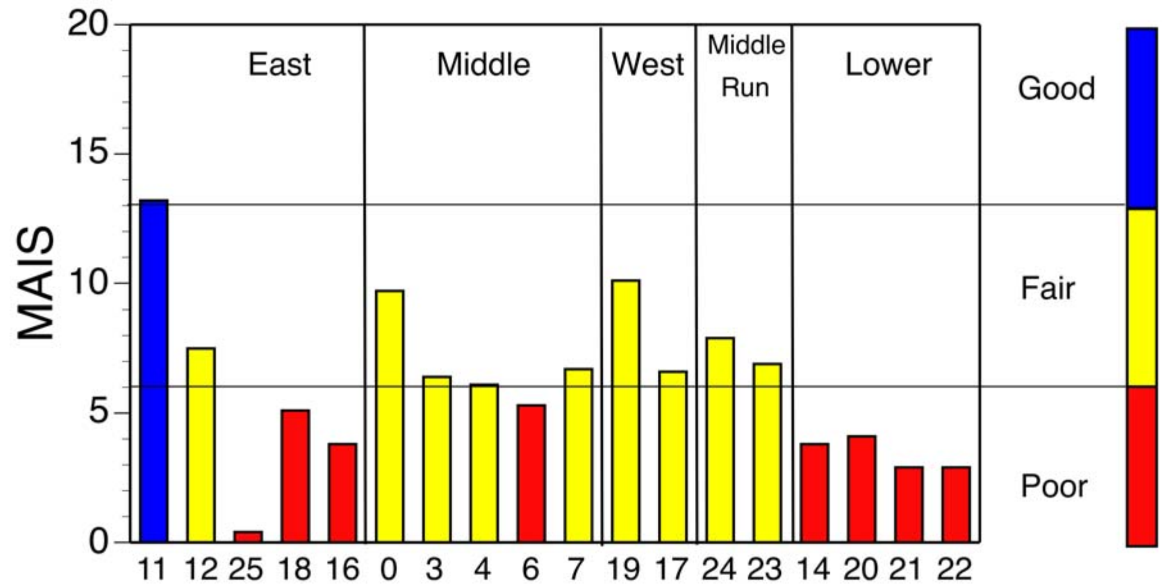


Figure 2. Average MAIS scores based on 1-12 years of data taken between 1994-2008. Sites are in order from upstream to downstream within each branch of the White Clay Creek.

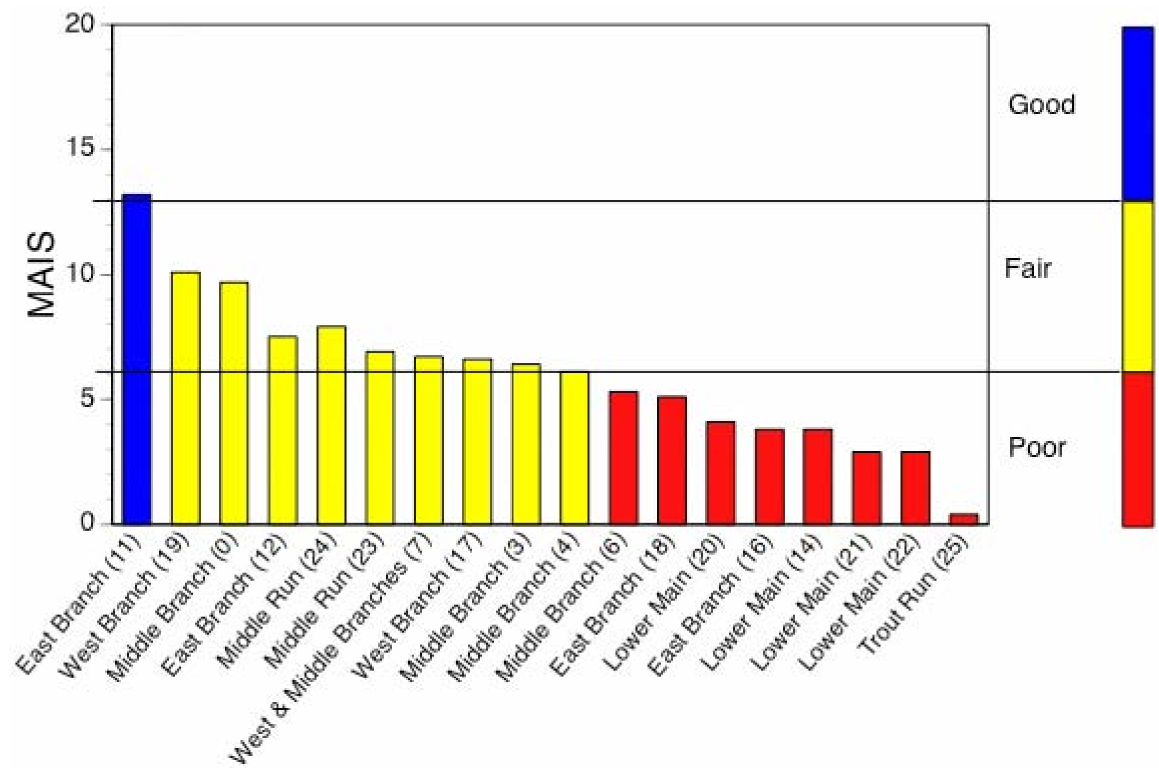


Figure 3. Average MAIS scores based on 1-12 years of data taken between 1994-2008. Sites are in order from best to worst based on MAIS score.

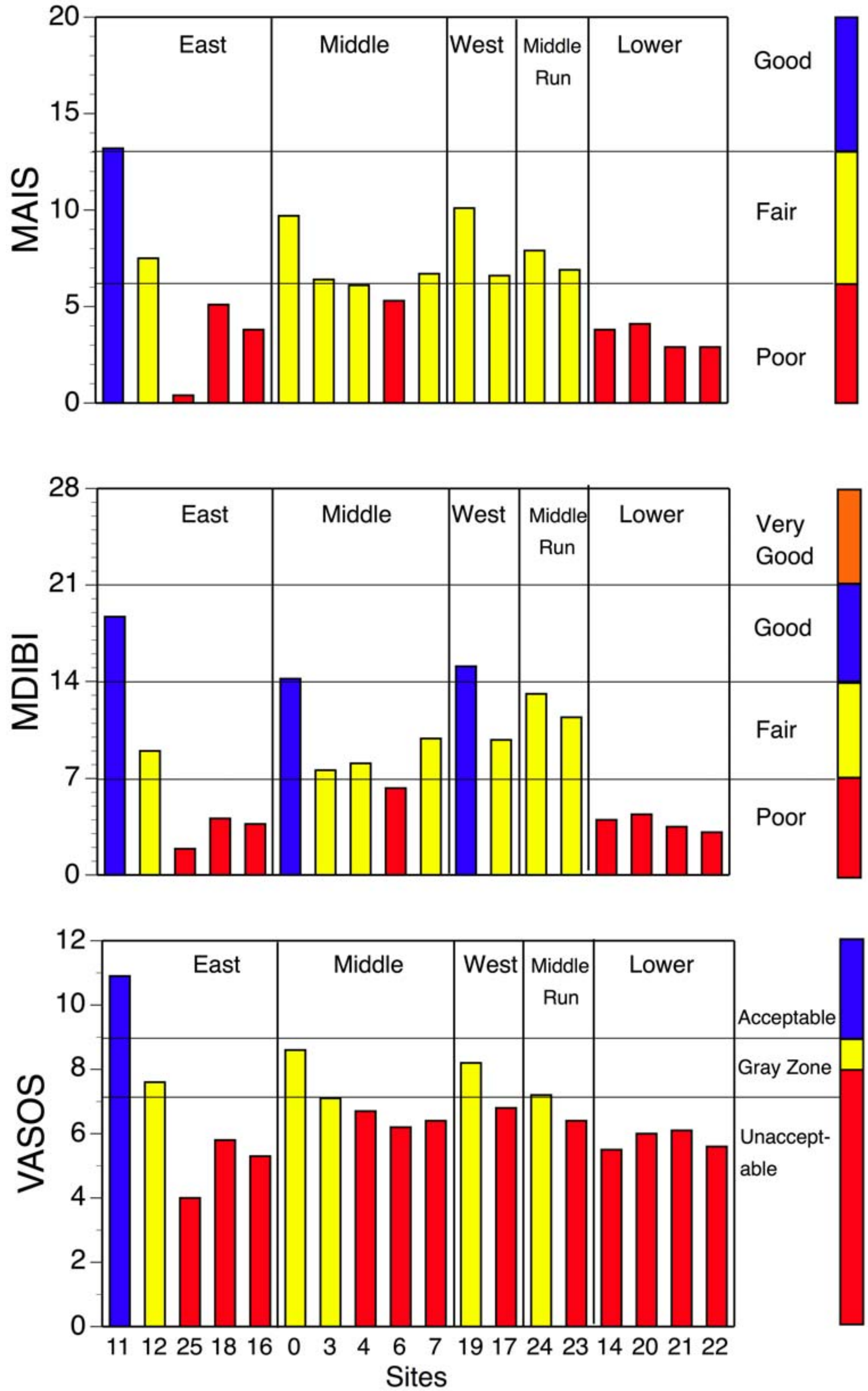


Figure 4. Macroinvertebrate Indexes used to evaluate sites in the WCC: Macroinvertebrate Aggregated Index for Streams (MAIS), Maryland Indices of Biotic Integrity (MDIBI), and Virginia Save Our Stream (VASOS).

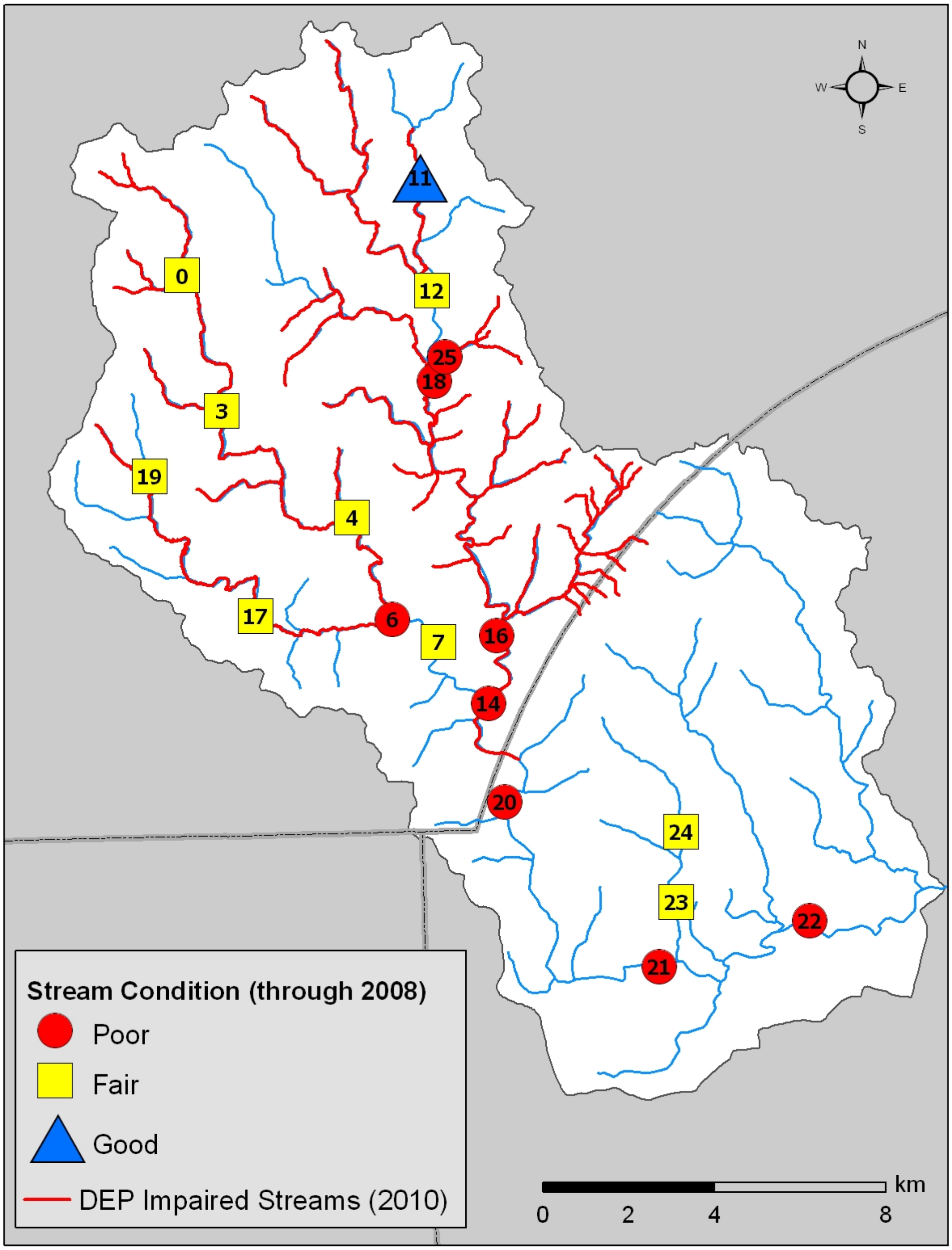


Figure 5. Map of stream reaches designated as impaired by the PA DEP (2010). Poor, Fair and Good classifications are based on Stream Watch data. Not shown on map is that the WCC watershed (mainstem, Middle, Pike, and Mill Creeks) in Delaware is also considered impaired (DNREC 2010).

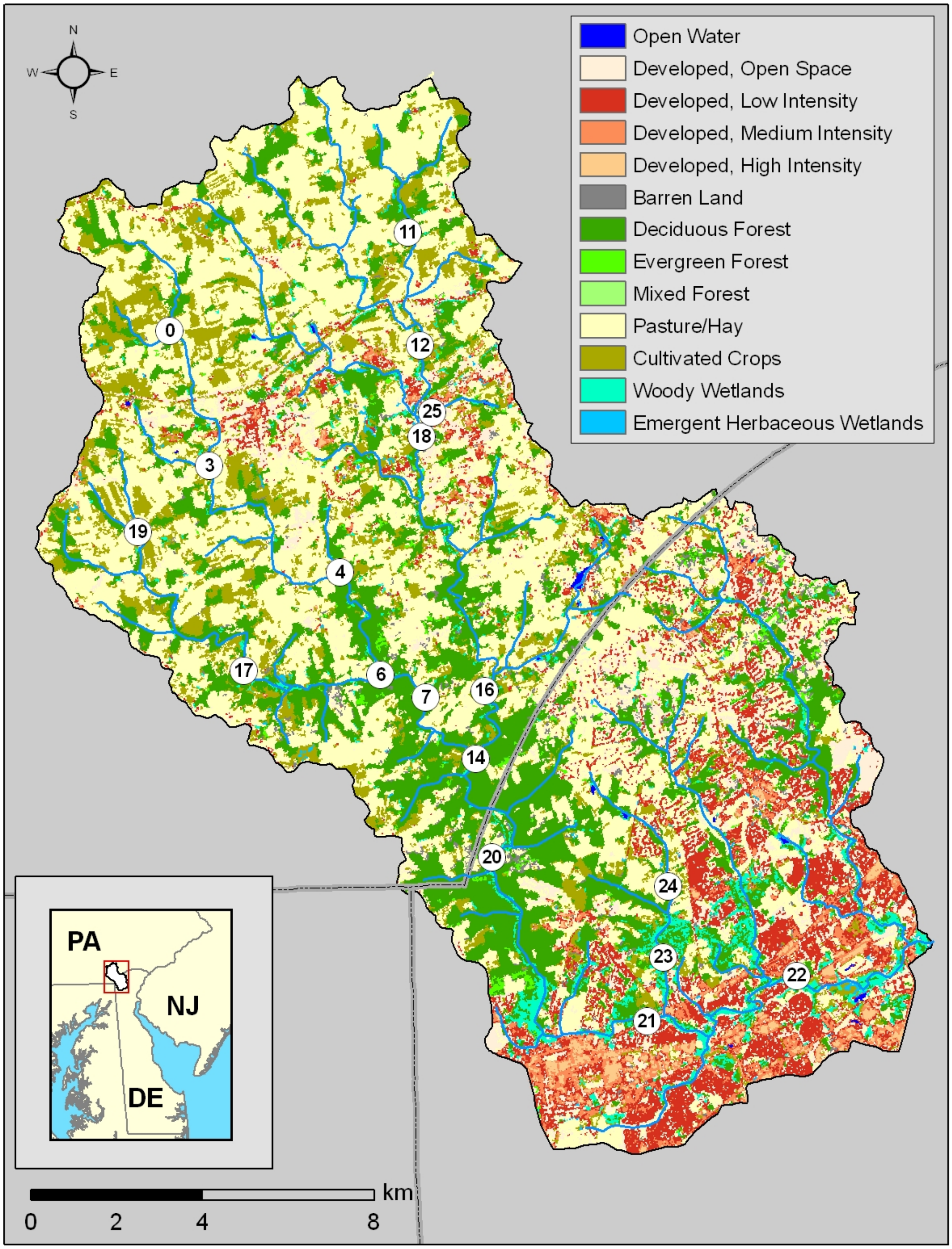


Figure 6. Map of land use and location of sites sampled in the WCC watershed.

A

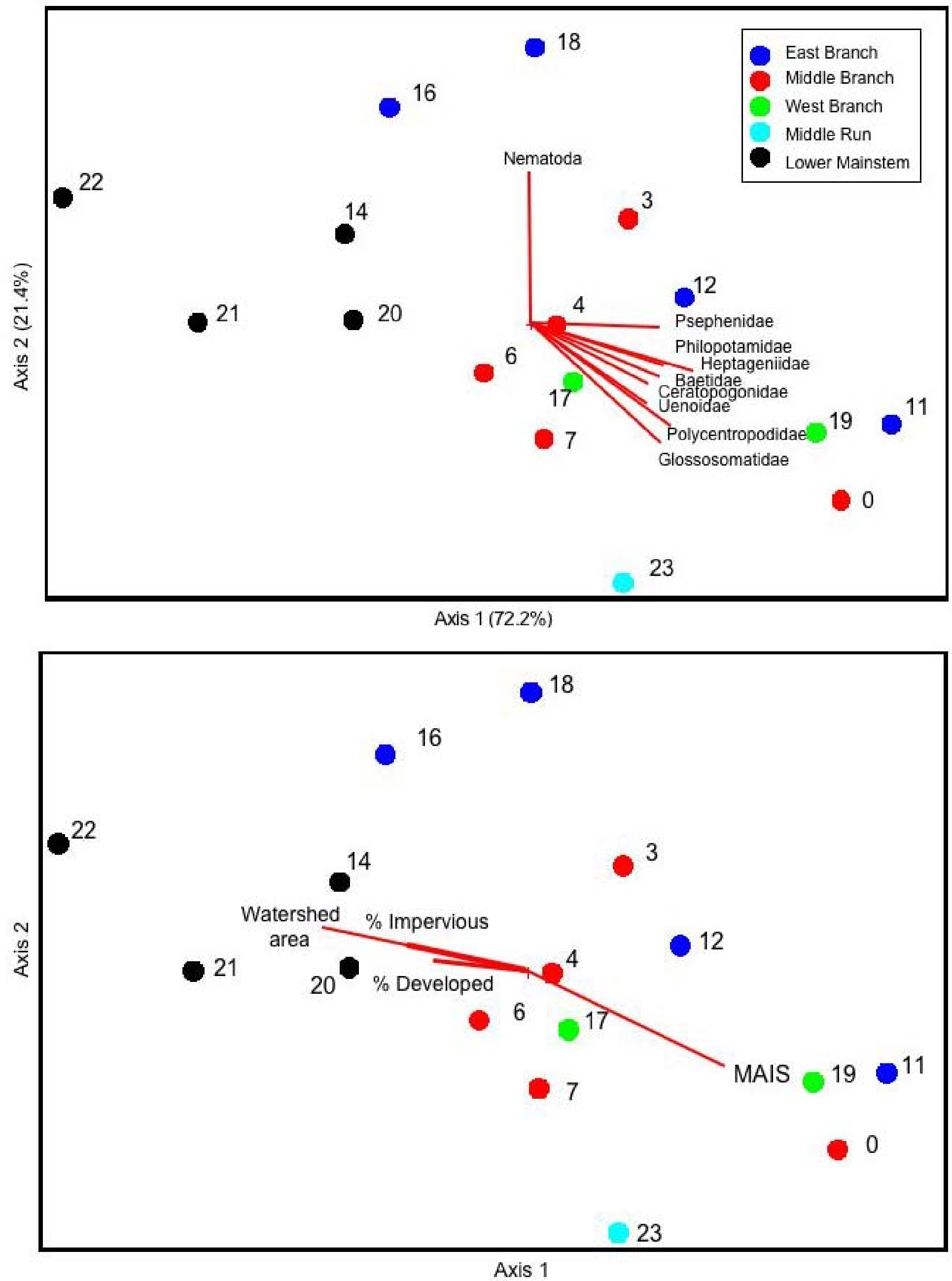


Figure 7. Non-metric Multidimensional Scaling on common macroinvertebrates densities averaged from 1997-2008 from all sites. Sites are indicated as points, where the closer the points than the more similar their macroinvertebrate assemblages. To help explain patterns among sites additional data was added, which are indicated as vectors (lines). Vectors are shown for (A) macroinvertebrate groups or (B) land use variables. The longer the length of the vector the more variation is explained by that variable. For example, sites in the Lower Mainstem (14, 20, 21, 22) are characterized by large amounts of impervious surfaces and development.

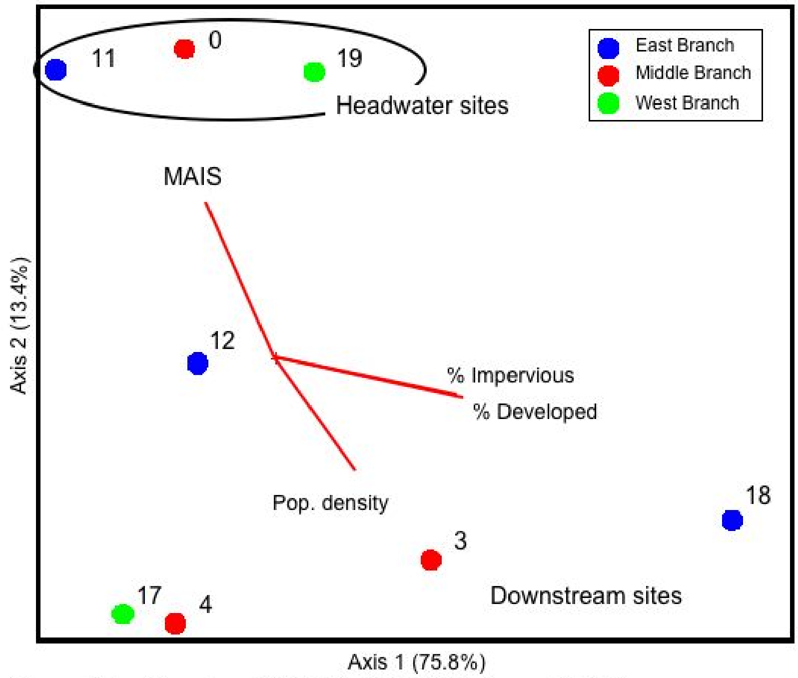


Figure 8. Multivariate analyses (NMS) on common macroinvertebrates densities averaged from 1997-2008 for eight sites from the Upper Branches. Sites (points) that are close together have more similar macroinvertebrate communities. Vectors (lines) indicate land use variables that help explain patterns among sites.

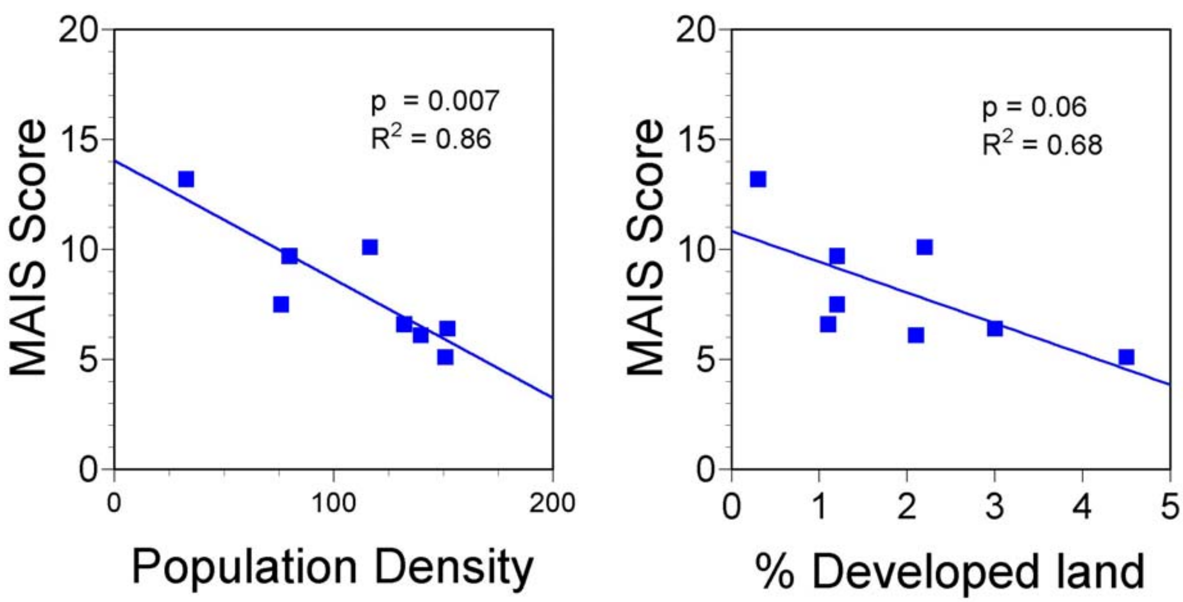
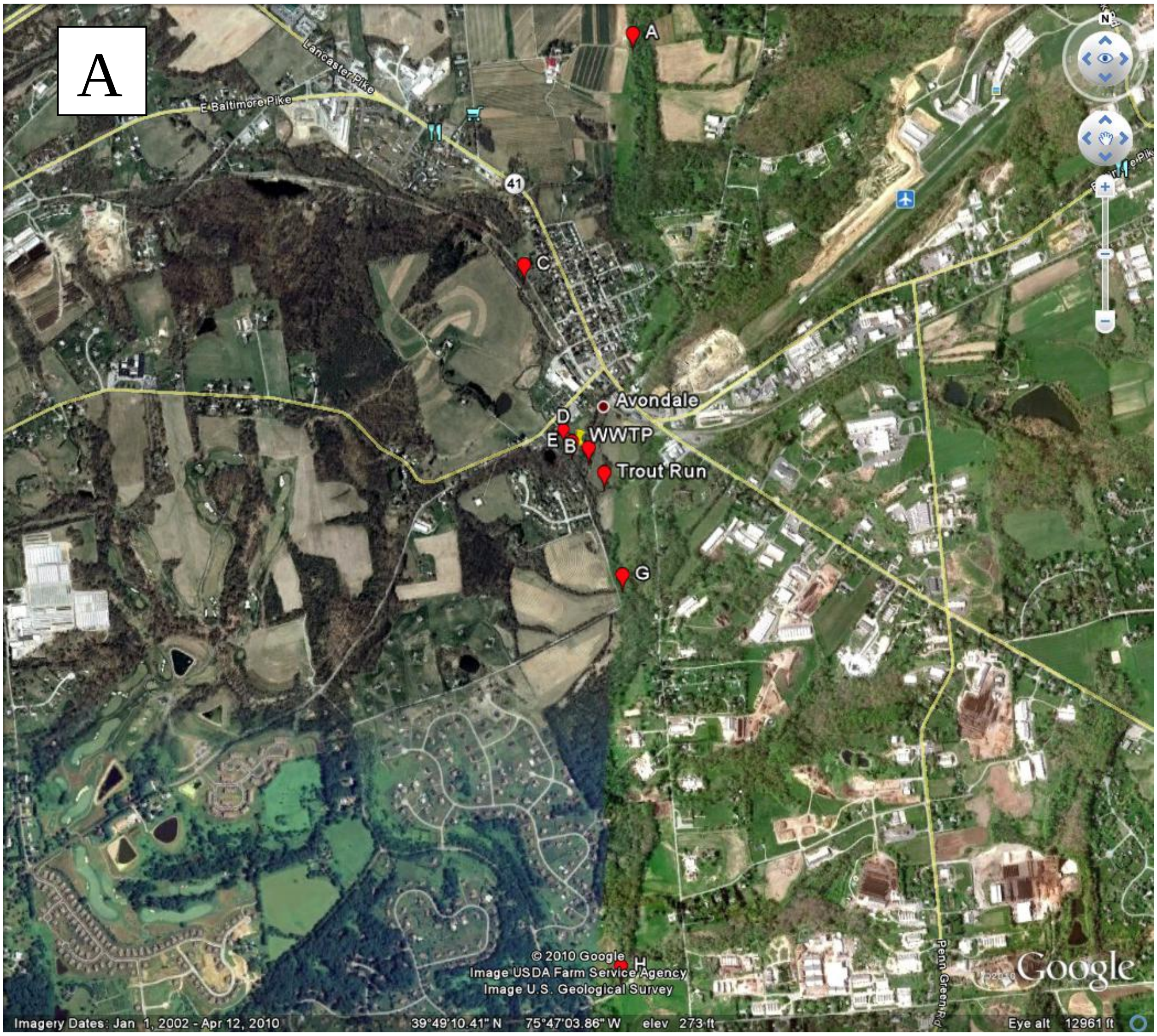


Figure 9. Using sites in the three Upper Branches, regressions shown between MAIS (means from 1994-2008) and population density (people/km^2 in 2000) and % developed land (e.g., buildings).



B

Figure 10. A) Map of sampling sites in and near the borough of Avondale. B) Close-up of sites near the Waste Water Treatment Plant (WWTP).

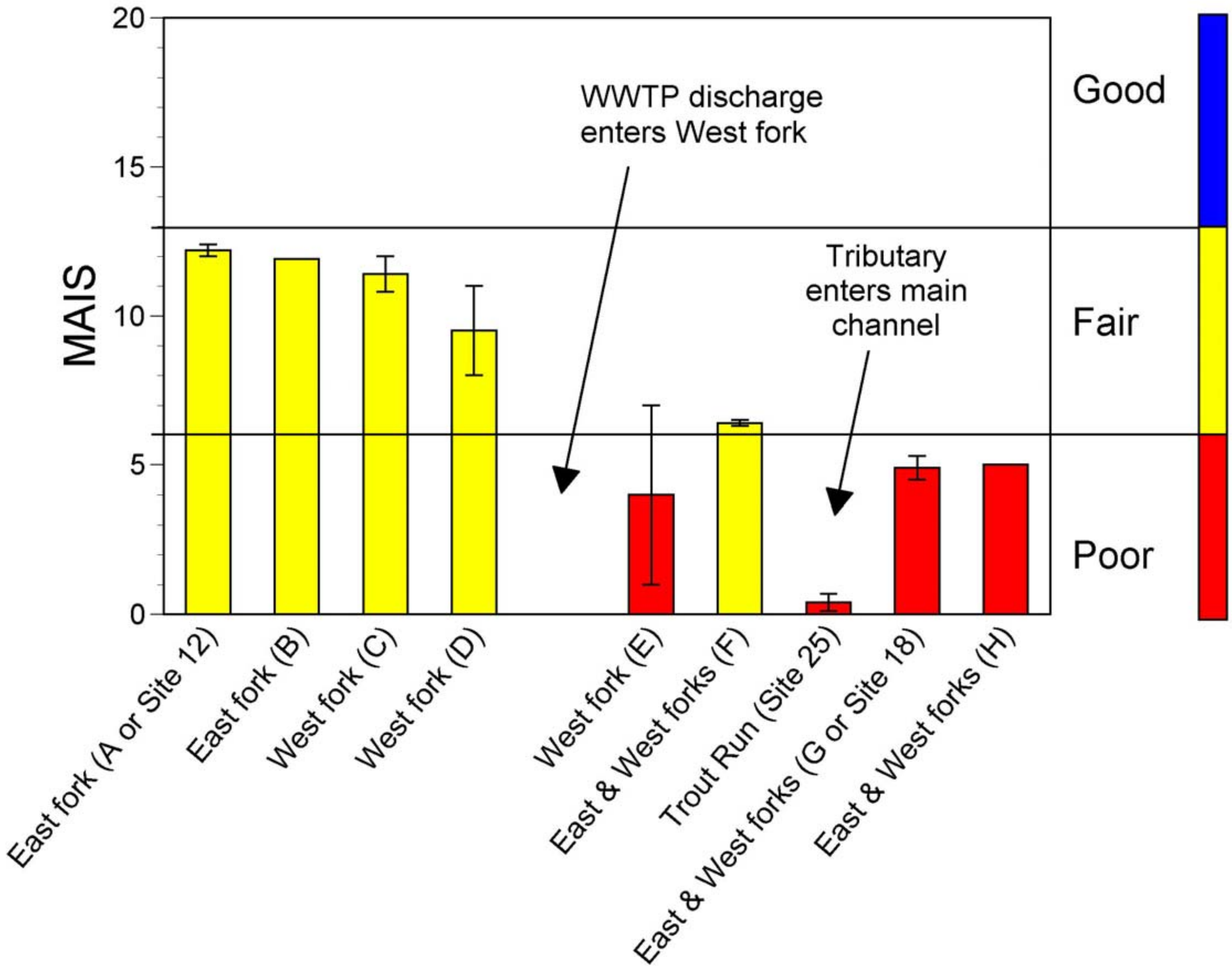


Figure 11. MAIS scores from sites sampled in the borough of Avondale in October 2005.

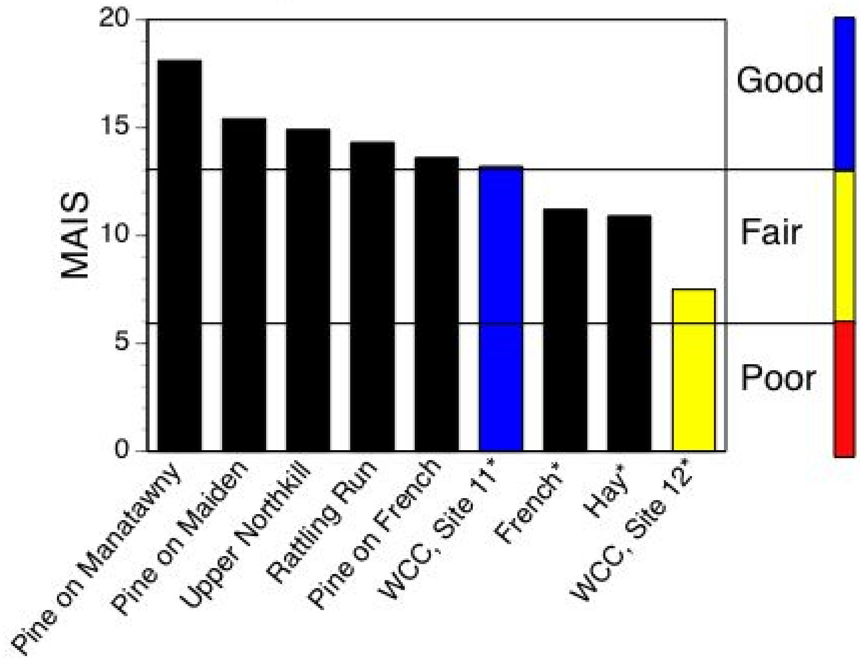


Figure 12. MAIS scores shown for Sites 11 and 12 on WCC and seven Exceptional Value streams in the Schuylkill watershed. Asterisks indicate 12-year mean otherwise streams were sampled in 2008 and 2009. Samples were processed with a 1-mm sieve for WCC sites and 500-mm sieve for all other sites.

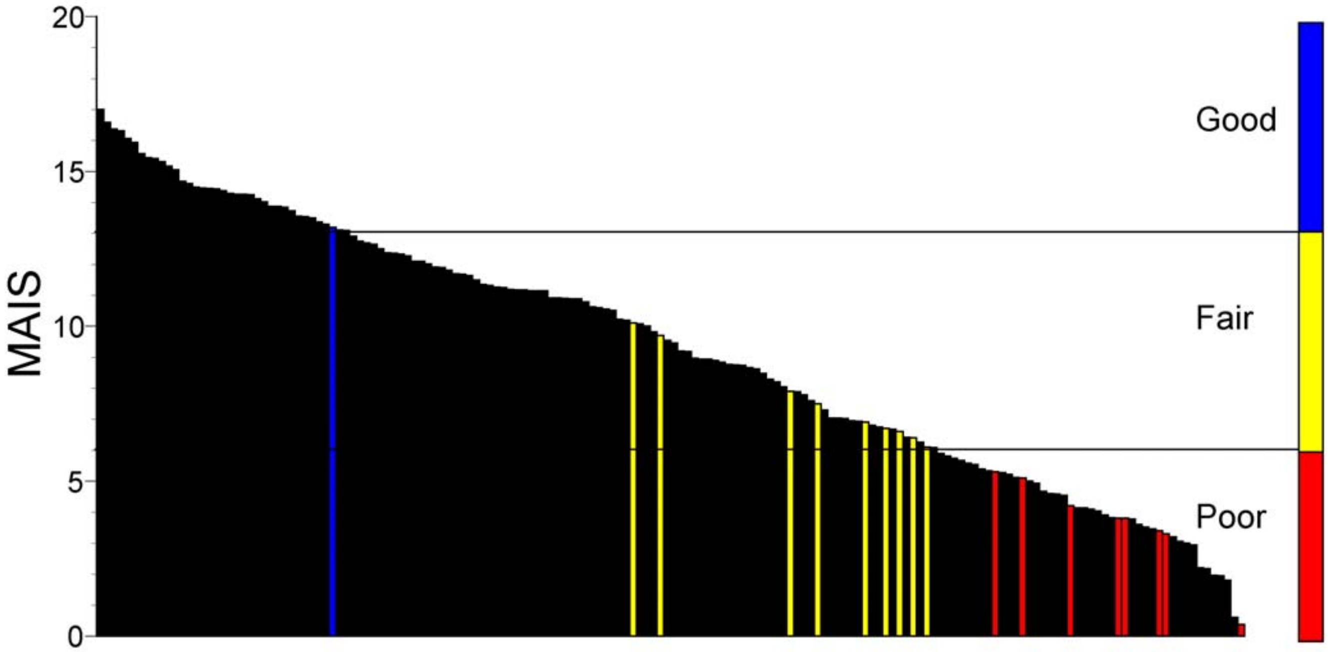


Figure 13. MAIS scores for WCC (1-12 yrs data) and 150 sites in the Schuylkill watershed (1-14 yr data from 1996-2009). Highlighted bars are Stream Watch sites.

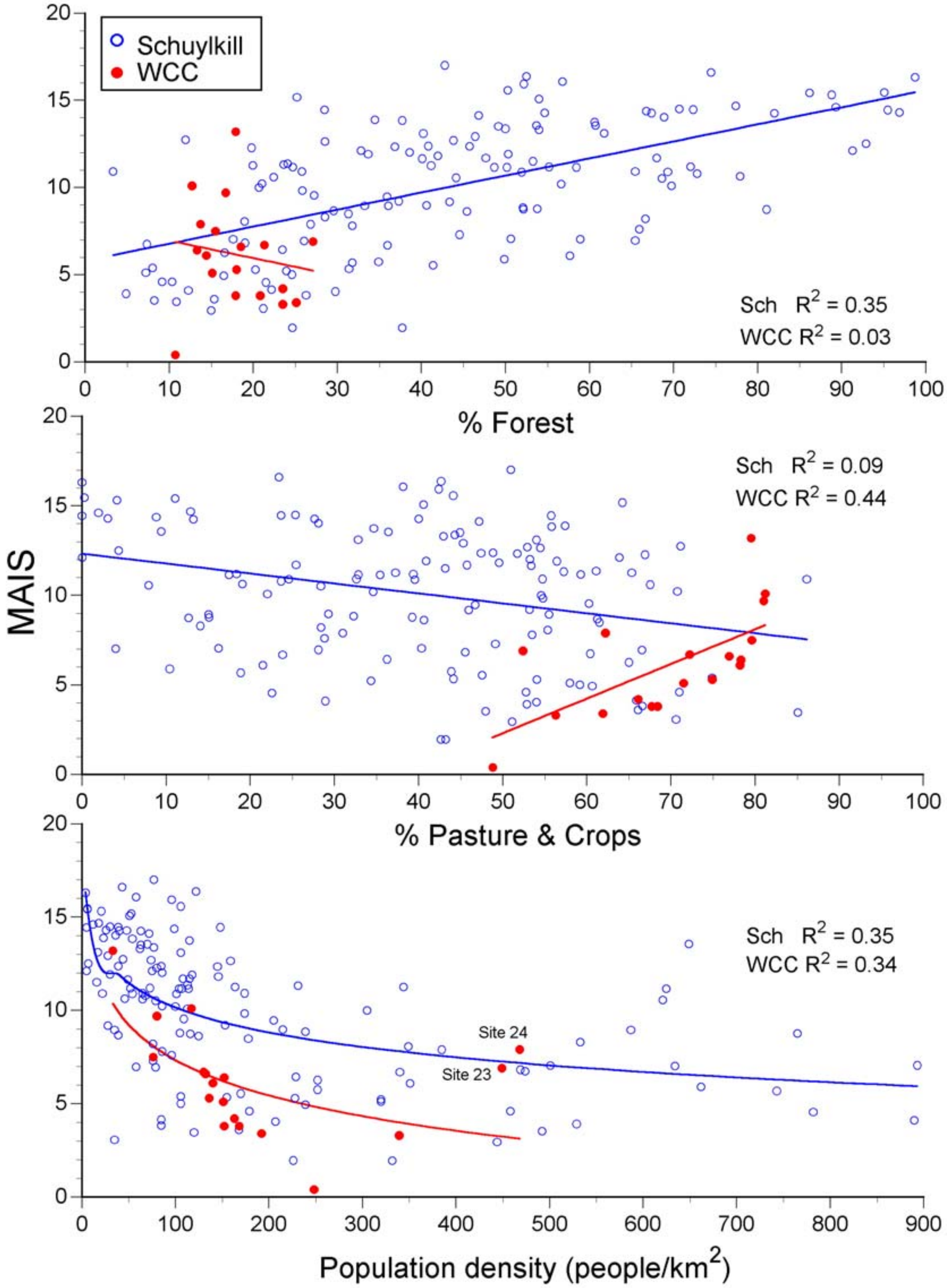


Figure 14. Land use and MAIS scores for Stream Watch sites (1-12 yrs of data) in WCC and 138 sites in the Schuylkill watershed (1-14 yrs of data). R^2 show the strength of the relationship between the MAIS scores and land use variable for Schuylkill (Sch) and WCC sites (i.e., the closer to 1.0 the stronger the relationship). Schuylkill samples were collected using a Hess sampler (500-um, n = 3-5) and WCC samples were collected with a Surber sampler (1-mm, n = 2-4).

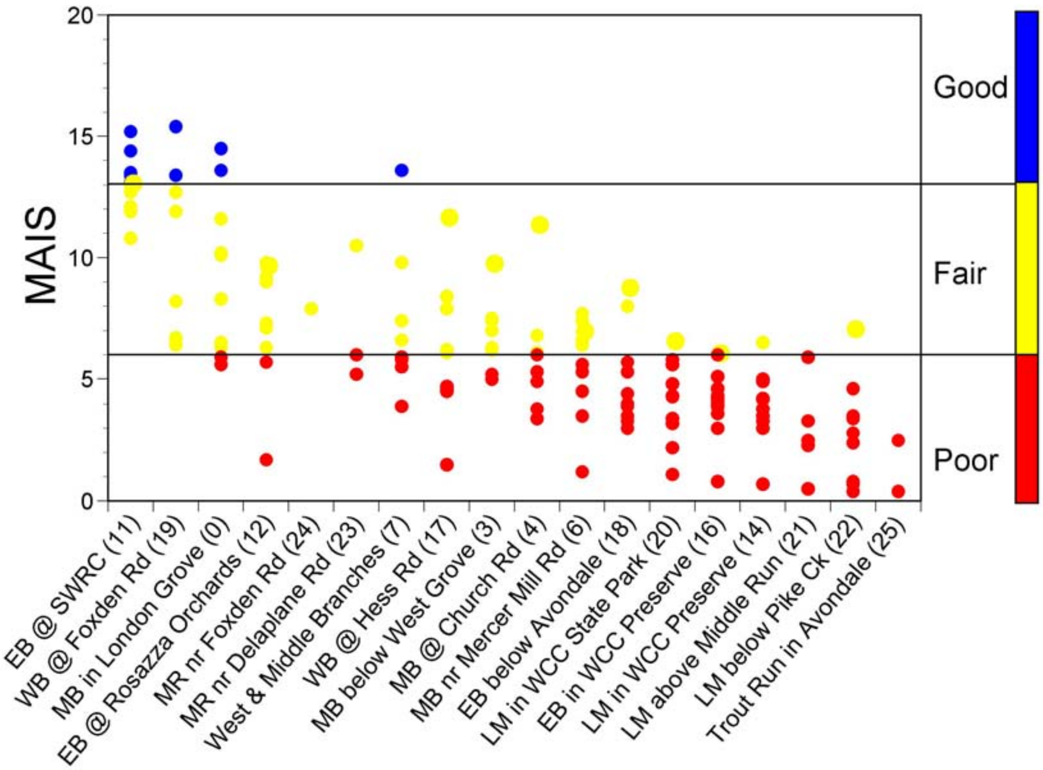


Figure 15. Graph indicating range of MAIS scores among years (1994-2008) for sites on WCC. Site names are abbreviated as East Branch (EB), West Branch (WB), Middle Branch (MB), Middle Run (MR), and Lower Mainstem (LM).

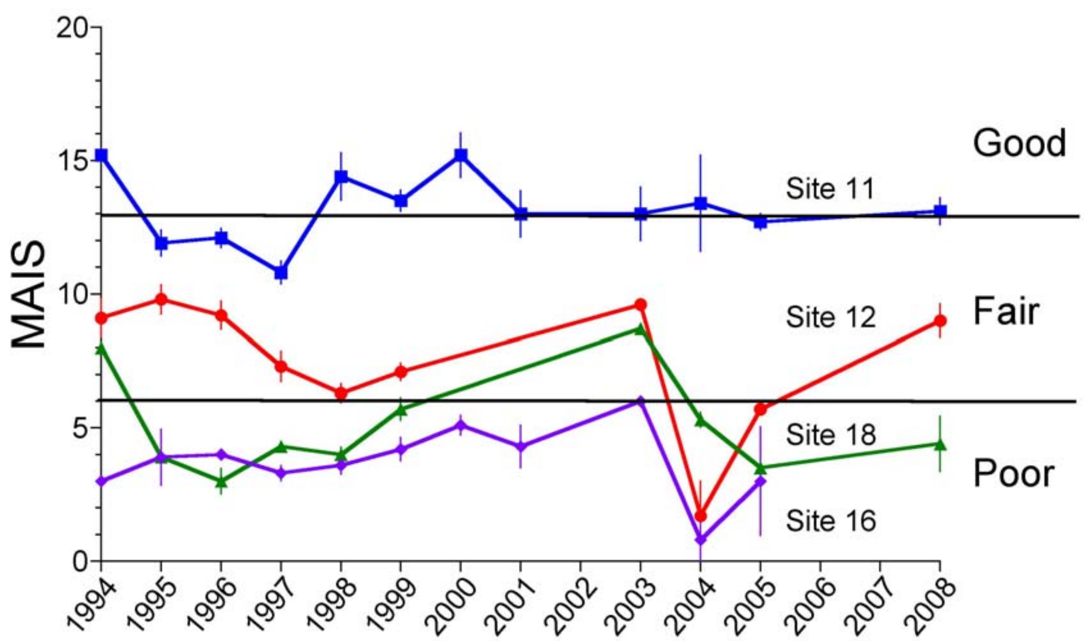


Figure 16. Example of variability in MAIS scores over the study for four sites on the East Branch (see Appendix 3 for other sites and related information).

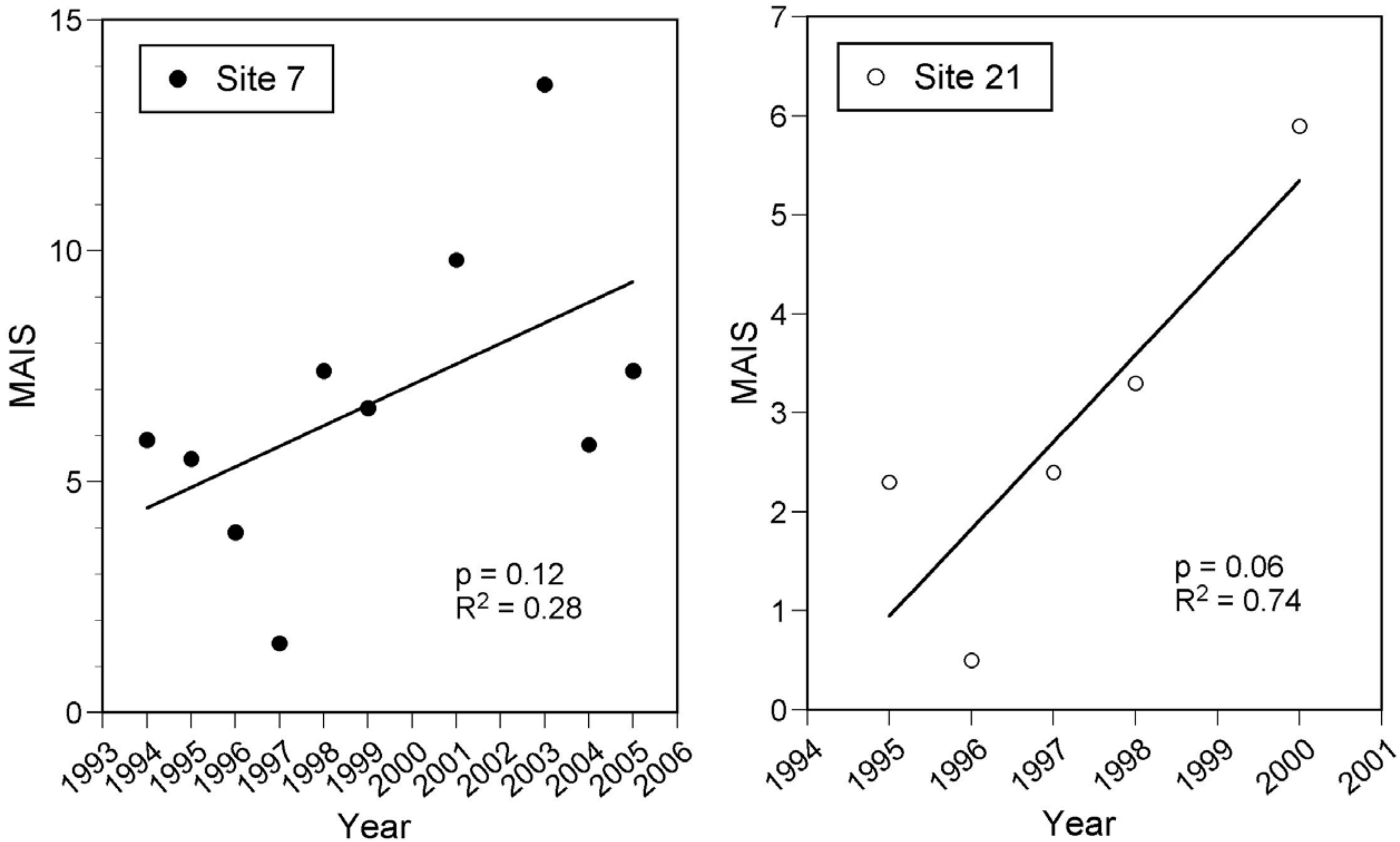


Figure 17. MAIS scores for Site 7 below the West and Middle Branches and Site 21 on the Lower Mainstem suggest water quality may be improving at these locations.

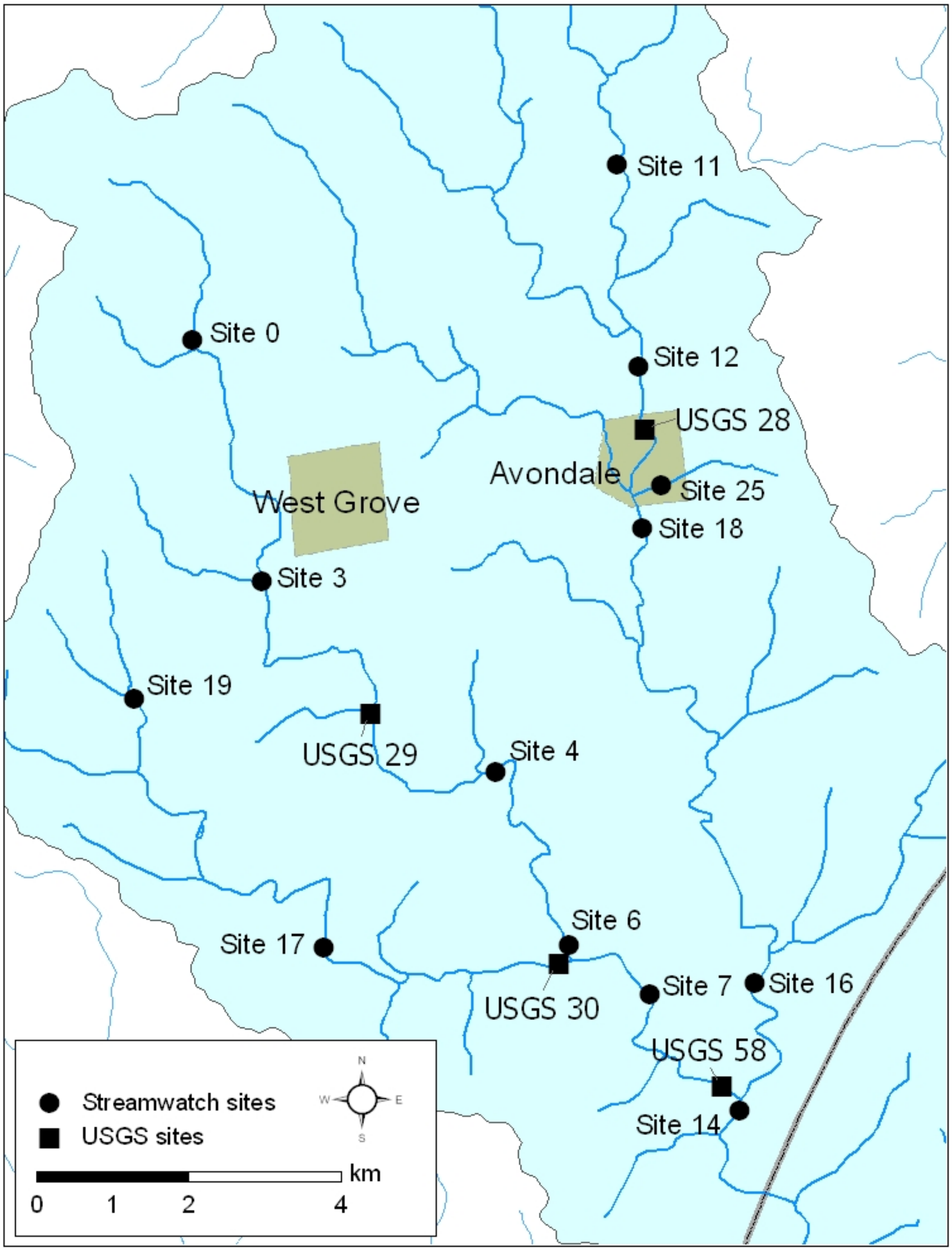


Figure 18. Locations of Stream Watch sites and USGS sites in the upper WCC.

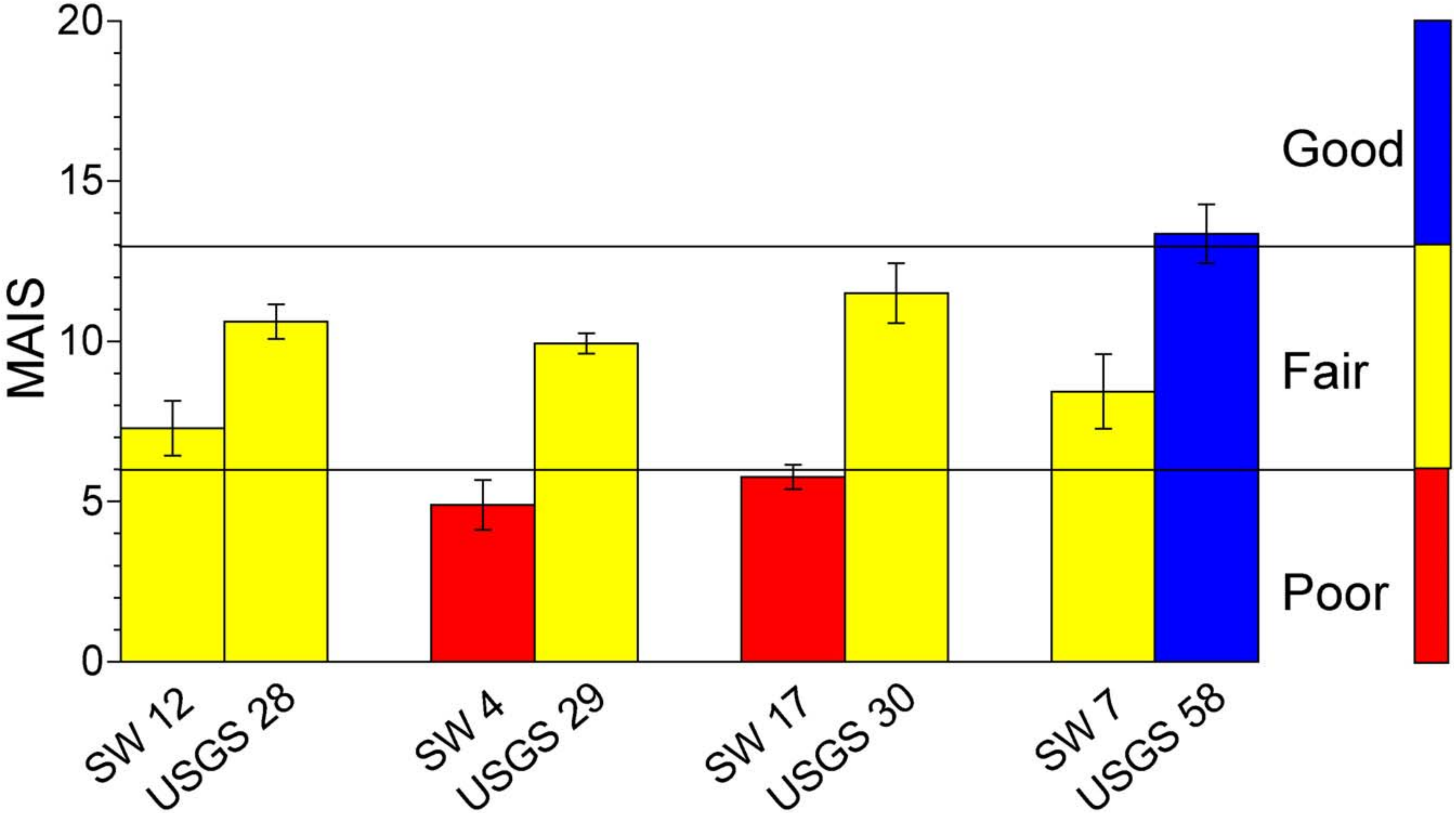


Figure 19. Average MAIS values for Stream Watch (SW) and USGS data. Sites that were located near one another in the watershed are paired together on graph. Only years were both sites were sampled are shown. Sampling occurred between 1994-2008, but number of years sampled differed: USGS 28/SW 12, n = 9; USGS 29/SW 4 and USGS 30/SW 17, n = 3; USGS 58/SW 7, n = 6.

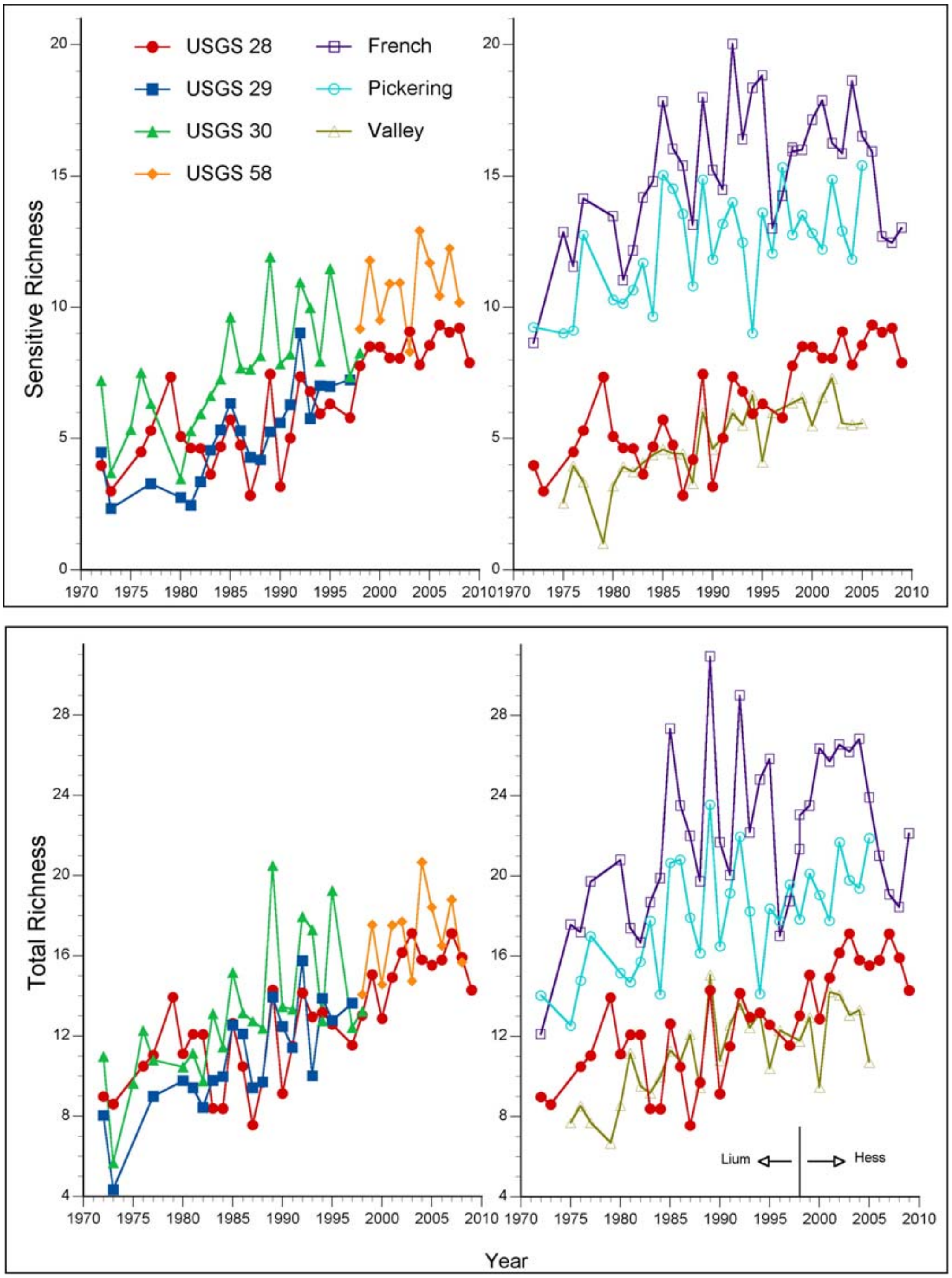


Figure 20. USGS data for four sites in WCC (USGS 28, 29, 30 and 58) and three sites in the Schuylkill watershed; French (USGS 15), Pickering (USGS 5), and Valley (USGS 50/52). Richness measures are based on number of families/200 individuals. Sensitive richness was based on families whose tolerance value ≤5. Collection method was initially Lium but changed to Hess in 1998.

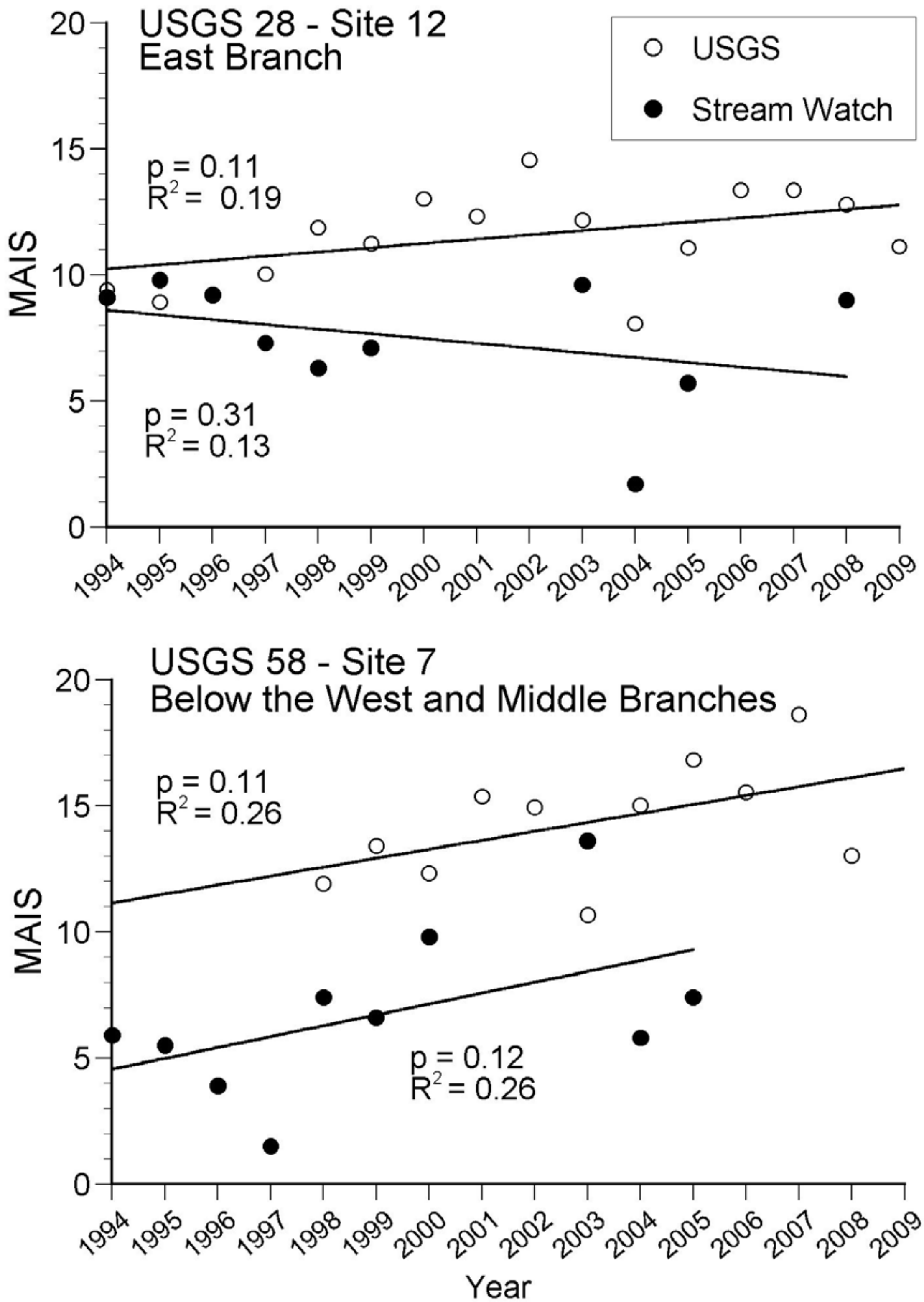


Figure 21. MAIS scores reported in recent years for this study and by the USGS. Sites located near each other are shown on same graph.

Appendix 1. Descriptions of location, land use, water chemistry, and macroinvertebrates for 18 sites in the White Clay Creek watershed.

East Branch of White Clay Creek: Site 11

Site 11 is located upstream of Spencer Rd at the Stroud Water Research Center, Avondale, PA. This section of the stream was awarded Exceptional Value status by the PA Department of Environmental Protection in 1984 and is considered the study reference site. The stream at this location has an intact riparian forest, low human density and most fields in pasture/hay. Measurements of nitrogen (nitrate and ammonium) and phosphorus (soluble reactive and total phosphorus) were low compared to other sites in WCC, suggesting minimal impacts from agriculture or residential septic tanks. There are no known point sources upstream of this location, but some mushroom businesses do exist in the watershed.

Densities at this location were generally the highest observed in the study and averaged 16,000 individuals/m^2 (Appendix 3a). Density was highly variable among years and ranged from a low of 2400 individuals/m^2 in 1994 to a high of 43,200 individuals/m^2 in 1999. Even though density varied, % EPT was notably high most years and ranged from 29% to 83% for the 15 years sampled. Half of the Total Richness (16 taxa/200 individuals) on average was composed of EPT taxa, a group of taxa considered sensitive to degradation. Site 11 was the only location to be categorized as Good water quality based on the MAIS score. The MAIS score averaged 13.2 and ranged from 10.8 (Fair) to 15.2 (Good). Density and metric scores suggest that the macroinvertebrate community at this site was relatively stable during the study.

Location	
Site Number	11
Description	Upstream of Spencer Rd at the Stroud Water Research Center, Avondale
Lat Long (hr min sec)	39°51.579’ N, -75°47.059’ W
Land Use	
Watershed area above site (km^2)	7
Population density in 2000 (#/km^2)	33
% Population increase from 1990 to 2000	13
Percent pasture/hay	62
Percent cultivated crops	18
Percent forest	17
Chemistry (see Table 1 for sampling schedule)	
Nitrate (mg/L)	3.65
Ammonium (mg/L)	0.01
Total phosphorus (mg/L)	0.016
Soluble reactive phosphorus (mg/L)	0.036
Sulfate (mg/L)	17.78
Alkalinity (mg/L $CaCo_3$)	58.00
pH	7.79
Conductivity (µmhos)	200
Dissolved organic carbon (mg/L)	1.70
Macroinvertebrate Data	
Years sampled	1991-2001, 2003-2005, 2008
MAIS score	13.2
MAIS score rating	Good
1st most abundant	Ephemerellidae (spiny crawler mayflies)
2nd most abundant	Chironomidae (midges)
3rd most abundant	Hydropsychidae (common netspinner caddisflies)
4th most abundant	Elmidae (riffle beetles)
5th most abundant	Simuliidae (black flies)

East Branch of White Clay Creek: Site 12

Site 12 is located at Rosazza Orchards off of Glen Willow Rd north of Avondale, PA. Land use is very similar to Site 11 (e.g., mostly pasture/hay fields, with some cultivated crops and intact forest), but population density was doubled at Site 12. Although phosphorus levels were similar between Sites 12 and 11, nitrate, alkalinity and conductivity were higher at Site 12. Known potential pollution (e.g., fertilizers, pesticides and sedimentation) sources upstream of this location consist of a golf course, mushroom houses, and agriculture and livestock farming.

Total macroinvertebrate density ranged from 9100 individuals/m^2 to 44,700 individuals/m^2. Chironomid midges, a pollution-tolerant group, on average made up half of the total numbers. Total Richness was lower (11 taxa/200 individuals) compared to Site 11 (16 taxa/200 individuals), considered the best site. EPT Richness (4 taxa/200 individuals) was also not abundant at this site. % EPT averaged 22%, much lower than the 55% upstream at Site 11. MAIS score study average was 7.5, which classifies this site on the low end of the Fair category. Eight of the 10 years rated this site as Fair: in 2004 and 2005 Site 12 was rated Poor. The long-term trend for water quality at this site appears to be unchanged since the study started.

Location	
Site Number	12
Description	At Rosazza Orchards off of Glen Willow Rd north of Avondale
Lat Long (hr min sec)	39°50.146’ N, -75°46.915’ W
Land Use	
Watershed area above site (km^2)	28
Population density in 2000 (#/km^2)	76
% Population increase from 1990 to 2000	35
Percent pasture/hay	64
Percent cultivated crops	16
Percent forest	15
Chemistry (see Table 1 for sampling schedule)	
Nitrate (mg/L)	4.64
Ammonium (mg/L)	0.03
Total phosphorus (mg/L)	0.021
Soluble reactive phosphorus (mg/L)	0.038
Sulfate (mg/L)	27.25
Alkalinity (mg/L $CaCo_3$)	91.03
pH	8.03
Conductivity (µmhos)	315
Dissolved organic carbon (mg/L)	1.99
Macroinvertebrate Data	
Years sampled	1991-1999, 2003-2005, 2008
MAIS score	7.5
MAIS score rating	Fair
1st most abundant	Chironomidae (midges)
2nd most abundant	Oligochaeta (aquatic earthworms)
3rd most abundant	Hydropsychidae (common netspinner caddisflies)
4th most abundant	Elmidae (riffle beetles)
5th most abundant	Ephemerellidae (spiny crawler mayflies)

East Branch of White Clay Creek: Site 25

Trout Run is a small tributary that enters the East Branch of White Clay Creek below the town of Avondale and its sewage treatment plant. This was the smallest stream sampled. Compared to other sampling locations in this study this site had the smallest forest area and the greatest proportion of impervious surfaces (paved roads and parking lots made up 9% of the landscape) and developed open space in the watershed. As of 2000, population density in this watershed was high compared to the other sites, with the density doubling within a 10-year period. Several mushroom operations have existed on Trout Run for many decades. DEP has reported diazinon and DDT (insecticides) in this stream (Boyer 1997).

Trout Run was only sampled in 2005. Three locations within ≈300 m reach were sampled and their averages were combined. It was the worst site in the study. Total Density was 40,700 individuals/m^2 and EPT taxa made <0.1% of this total. Most (99%) of the taxa were oligochaetes (61% of the total) and chironomid midges (38% of the total). Total Richness was only 4 taxa/200 individuals.

Location	
Site Number	25
Description	Trout Run, a tributary upstream of Site 18 near Route 41 in Avondale
Lat Long (degree & decimal minutes)	39°49.280' N, -75°46.897' W
Land Use	
Watershed area above site (km^2)	3
Population density in 2000 (#/km^2)	248
% Population increase from 1990 to 2000	56
Percent pasture/hay	32
Percent cultivated crops	17
Percent forest	10
Chemistry (see Table 1 for sampling schedule)	
Nitrate (mg/L)	n/a
Ammonium (mg/L)	n/a
Total phosphorus (mg/L)	n/a
Soluble reactive phosphorus (mg/L)	n/a
Sulfate (mg/L)	n/a
Alkalinity (mg/L $CaCo_3$)	n/a
pH	n/a
Conductivity (µmhos)	n/a
Dissolved organic carbon (mg/L)	n/a
Macroinvertebrate Data	
Years sampled	2005
MAIS score	0.4
MAIS score rating	Poor
1st most abundant	Oligochaeta (aquatic worms)
2nd most abundant	Chironomidae (midges)
3rd most abundant	Simuliidae (black flies)
4th most abundant	Empididae (dance flies)
5th most abundant	Ephemerellidae (spiny crawler mayflies)

East Branch of White Clay Creek: Site 18

Site 18 is located along Indian Run Road below the Avondale waste water treatment plant (WWTP) outfall and Trout Run tributary where Site 25 is located. Similar to sites upstream, pasture/hay fields are the predominant land cover. Cultivated crops and forest are also common features in the watershed. Human populations are at moderate densities compared to other study sites and about five times the number of people compares to Site 11 located upstream in the headwaters. Nitrate, sulfate, alkalinity and conductivity are all elevated compared to other sites in the White Clay Creek watershed, presumably reflecting the effluent from the WWTP suggesting an impact from the treatment facility (Boyer 1997).

Total macroinvertebrate density ranged from 860 individuals/m^2 to 35,900 individuals/m^2. Oligochaetes and chironomid midges, taxa both tolerant to degradation, made up approximately 81% of the total numbers. The % EPT was relatively low (range of <1% to 7%), especially when compared to the reference Site 11 (29-83%). MAIS scores ranged from 3.0 (Poor) to 8.7 (Fair) and averaged 5.1 (Poor). 1994 and 2003 were the only years the site was considered Fair, in 2003 Total Richness and % EPT were high and in 1994 EPT Richness was high. Macroinvertebrate data from 1991 through 2008 suggest water quality at this location is variable and never above Fair.

Location	
Site Number	18
Description	Below the Avondale sewage treatment outfall along Indian Run Road
Lat Long (hr min sec)	39°48.983’ N, -75°46.933’ W
Land Use	
Watershed area above site (km^2)	50
Population density in 2000 (#/km^2)	151
% Population increase from 1990 to 2000	33
Percent pasture/hay	54
Percent cultivated crops	17
Percent forest	15
Chemistry (see Table 1 for sampling schedule)	
Nitrate (mg/L)	4.76
Ammonium (mg/L)	0.05
Total phosphorus (mg/L)	0.051
Soluble reactive phosphorus (mg/L)	0.089
Sulfate (mg/L)	35.90
Alkalinity (mg/L $CaCo_3$)	107.12
pH	8.05
Conductivity (µmhos)	382
Dissolved organic carbon (mg/L)	2.75
Macroinvertebrate Data	
Years sampled	1991-1999, 2003-2005, 2008
MAIS score	5.1
MAIS score rating	Poor
1st most abundant	Chironomidae (midges)
2nd most abundant	Oligochaeta (aquatic worms)
3rd most abundant	Elmidae (riffle beetles)
4th most abundant	Empididae (dance flies)
5th most abundant	Tipulidae (crane flies)

East Branch of White Clay Creek: Site 16

Site 16 is situated on the White Clay Creek Preserve, downstream from Good Hope Road and the bridge on Broad Run. Land cover is mostly pasture with some forests and agriculture. The number of people living in the watershed has nearly doubled from 1990 to 2000, but as of 2000 it was still at a density comparable to the study average. Like other sites on the East Branch, alkalinity and conductivity are high compared to the West, Middle, and Lower reaches.

Total macroinvertebrate density averaged 8200 individuals/m^2 between 1991 and 2005. This site was considered Poor on all of the 11 sample dates, with an average MAIS score of 3.8. EPT Richness (2 taxa/200 individuals) and % EPT (9%) were extremely low compared to the reference Site 11. Macroinvertebrates characterized this as one of the most degraded sites and show no improvement since 1991.

Location	
Site Number	16
Description	On the White Clay Creek Preserve, downstream from Good Hope Road and the bridge on Broad Run
Lat Long (hr min sec)	39°45.764' N, -75°45.998' W
Land Use	
Watershed area above site (km^2)	83
Population density in 2000 (#/km^2)	168
% Population increase from 1990 to 2000	41
Percent pasture/hay	52
Percent cultivated crops	16
Percent forest	17
Chemistry (see Table 1 for sampling schedule)	
Nitrate (mg/L)	4.54
Ammonium (mg/L)	0.03
Total phosphorus (mg/L)	0.094
Soluble reactive phosphorus (mg/L)	0.085
Sulfate (mg/L)	38.80
Alkalinity (mg/L $CaCo_3$)	92.38
pH	8.39
Conductivity (µmhos)	352
Dissolved organic carbon (mg/L)	3.10
Macroinvertebrate data	
Years sampled	1991-2001, 2003-2005
MAIS score	3.8
MAIS score rating	Poor
1st most abundant	Chironomidae (midges)
2nd most abundant	Oligochaeta (aquatic worms)
3rd most abundant	Hydropsychidae (common netspinner caddisflies)
4th most abundant	Tipulidae (crane flies)
5th most abundant	Elmidae (riffle beetles)

Middle Branch of White Clay Creek: Site 0

Site 0 is located above Tice Road in London Grove Township, PA. This is the most upstream site on the Middle Branch so the watershed is only 7 km^2. Land use is predominantly uncultivated fields with some forests and active farming. The human population has remained relatively low. At present there are no known point sources above this site. Most water chemistry variables are comparable to the study wide average with the exception of nitrate and ammonium levels, which were high.

Macroinvertebrate density average 13,000 individuals/m^2 and composed anywhere from 60% EPT in 1991 to <10% EPT in 1996, 2004 and 2005. Taxa richness although lower than the reference Site 11 was still relatively high compared to downstream sites. Total Richness and EPT Richness averaged 15 and 7 taxa/200 individuals, respectively. Water quality based on the MAIS score was highly variable and ranged from Good in 1998 and 2003, to Poor in 2005 and averaged Fair (9.7). This is the third best site in this study. There appears to be no obvious trend of conditions at this site improving or degrading based on this study.

Location	
Site Number	0
Description	Above Tice Road in London Grove Township
Lat Long (hr min sec)	39°50.411' N, -75°51.006' W
Land Use	
Watershed area above site (km^2)	7
Population density in 2000 (#/km^2)	80
% Population increase from 1990 to 2000	32
Percent pasture/hay	55
Percent cultivated crops	26
Percent forest	17
Chemistry (see Table 1 for sampling schedule)	
Nitrate (mg/L)	6.08
Ammonium (mg/L)	0.10
Total phosphorus (mg/L)	0.015
Soluble reactive phosphorus (mg/L)	0.019
Sulfate (mg/L)	10.65
Alkalinity (mg/L $CaCo_3$)	23.71
pH	7.52
Conductivity (µmhos)	175
Dissolved organic carbon (mg/L)	2.38
Macroinvertebrate data	
Years sampled	1991-2000, 2003-2005, 2008
MAIS score	9.7
MAIS score rating	Fair
1st most abundant	Chironomidae (midges)
2nd most abundant	Simuliidae (black flies)
3rd most abundant	Hydropsychidae (common netspinner caddisflies)
4th most abundant	Elmidae (riffle beetles)
5th most abundant	Ephemerellidae (spiny crawler mayflies)

Middle Branch of White Clay Creek: Site 3

Site 3 is found south of West Grove, PA directly upstream of State Road. Most land use in the watershed is in pastures and crops. The number of people living in the watershed in 2000 was typical of the average study density. Phosphorus levels were high (e.g., total phosphorus >6x higher than the study-wide average, especially in 1995 and 2003-2005) and nitrogen (study-wide average is 4.44 mg/L) at this site, while other water chemistry variables were comparable to most study sites. Sampling occurred downstream from the waste water treatment plant in West Grove.

Total macroinvertebrate density ranged from 2600 individuals/m^2 to 22,000 individuals/m^2. EPT density was relatively low compared to the reference Site 11 and only averaged 1100 individuals/m^2. % EPT ranged from 1% to 42% and averaged 15% from 1991 to 2008. Total Richness and EPT Richness seemed on average slightly higher in recent years compared to when the study started. Total Richness ranged from 7 taxa/200 individuals in 1997 to 16 taxa in 2003 and EPT Richness ranged from 1 taxa/200 individuals in 1997 to 6 taxa in 2003. MAIS scores for this site were Poor (range of 3.8-5.2) for three of the years and Fair (range of 6.2-9.7) for seven of the years. The average MAIS score was 6.4 placing it in the lower range of the Fair category near the 6.0 line separating Fair and Poor..

Location	
Site Number	3
Description	Upstream from State Road south of West Grove
Lat Long (hr min sec)	39°48.694' N, -75°50.414' W
Land Use	
Watershed area above site (km^2)	19
Population density in 2000 (#/km^2)	152
% Population increase from 1990 to 2000	27
Percent pasture/hay	52
Percent cultivated crops	27
Percent forest	13
Chemistry (see Table 1 for sampling schedule)	
Nitrate (mg/L)	5.75
Ammonium (mg/L)	0.07
Total phosphorus (mg/L)	0.245
Soluble reactive phosphorus (mg/L)	0.222
Sulfate (mg/L)	16.73
Alkalinity (mg/L $CaCo_3$)	44.19
pH	7.64
Conductivity (µmhos)	232
Dissolved organic carbon (mg/L)	2.18
Macroinvertebrate data	
Years sampled	1991-1999, 2003-2005, 2008
MAIS score	6.4
MAIS score rating	Fair
1st most abundant	Chironomidae (midges)
2nd most abundant	Oligochaeta (aquatic worms)
3rd most abundant	Elmidae (riffle beetles)
4th most abundant	Hydropsychidae (common netspinner caddisflies)
5th most abundant	Tipulidae (crane flies)

Middle Branch of White Clay Creek: Site 4

Site 4 is found at Church Hill Road near Creek Road in PA and is downstream of the discharge from the West Grove sewage treatment facility like Site 3. Like most study sites uncultivated fields, row crops, and forests make up >90% of the landscape in the watershed. Density of people in the area is also at a level typically of most sites in this study. Phosphorus levels are much lower at this site compared to Sire 3 immediately upstream suggesting a localized problem upstream. Other water chemistry variables measured do not indicate any obvious impacts (e.g., waste water effluent).

Total macroinvertebrate and EPT density averaged 10,900 individuals/m^2 and 700 individuals/m^2, respectively. EPT taxa made on average only 11% of the total numbers but up to 41% of the Total Richness (an average of 5 EPT taxa and 11 total taxa/200 individuals). The average MAIS score (6.1) for Site 4 was in the lower end of the Fair category (Poor ≤6.0). Scores ranged from a low of 3.4 (Poor) in 1995 to a high of 11.3 (Fair) in 2003. Although the MAIS score was the highest in 2003, the following 2 years were extremely low (4.9 and 5.3) and in the Poor category suggesting no long-term improvement at this site.

Location	
Site Number	4
Description	At Church Hill Road near Creek Road
Lat Long (hr min sec)	39°47.303’ N, -75°48.318’ W
Land Use	
Watershed area above site (km^2)	31
Population density in 2000 (#/km^2)	140
% Population increase from 1990 to 2000	31
Percent pasture/hay	55
Percent cultivated crops	24
Percent forest	14
Chemistry (see Table 1 for sampling schedule)	
Nitrate (mg/L)	4.98
Ammonium (mg/L)	0.02
Total phosphorus (mg/L)	0.078
Soluble reactive phosphorus (mg/L)	0.080
Sulfate (mg/L)	19.97
Alkalinity (mg/L $CaCo_3$)	38.22
pH	7.94
Conductivity (µmhos)	209
Dissolved organic carbon (mg/L)	2.21
Macroinvertebrate data	
Years sampled	1991-1999, 2003-2005
MAIS score	6.1
MAIS score rating	Fair/Poor
1st most abundant	Chironomidae (midges)
2nd most abundant	Tipulidae (crane flies)
3rd most abundant	Hydropsychidae (common netspinner caddisflies)
4th most abundant	Hydroptilidae (microcaddisflies)
5th most abundant	Oligochaeta (aquatic worms)

Middle Branch of White Clay Creek: Site 6

This site is situated upstream from Mercer Mill Road, just upstream of the confluence with the West Branch. The predominant land use in the watershed is pasture/hay fields. Row crop agriculture and forests are also prevalent. The number of people in the watershed is typical of sites in this study. Water chemistry results are similar to the study wide average and indicate no obvious impacts at the time sampling occurred.

Total density averaged 9800 individuals/m^2 and ranged from 800 individuals/m^2 to 26,600 individuals/m^2. Chironomids were the most dominant taxa and usually made 80% of the total density, while EPT (mainly Hydropsychid caddisflies) made approximately 15% of the total. Total Richness ranged from 5-13 taxa/200 individuals and typically 40% of those taxa were EPT. Of the 10 years sampled, half the MAIS scores were considered Fair and half were Poor. The average MAIS score was 5.3 (Poor).

Location	
Site Number	6
Description	Upstream from Mercer Mill Road, near the confluence with the West Branch
Lat Long (degree & decimal minutes)	39°46.001’ N, -75°47.702’ W
Land Use	
Watershed area above site (km^2)	35
Population density in 2000 (#/km^2)	136
% Population increase from 1990 to 2000	30
Percent pasture/hay	53
Percent cultivated crops	22
Percent forest	18
Chemistry (see Table 1 for sampling schedule)	
Nitrate (mg/L)	4.19
Ammonium (mg/L)	0.01
Total phosphorus (mg/L)	0.053
Soluble reactive phosphorus (mg/L)	0.065
Sulfate (mg/L)	19.03
Alkalinity (mg/L $CaCo_3$)	27.9
pH	7.84
Conductivity (µmhos)	190
Dissolved organic carbon (mg/L)	1.99
Macroinvertebrate Data	
Years sampled	1994-1999, 2001, 2003-2005
MAIS score	5.3
MAIS score rating	Poor
1st most abundant	Chironomidae (midges)
2nd most abundant	Hydropsychidae (common netspinner caddisflies)
3rd most abundant	Tipulidae (crane flies)
4th most abundant	Oligochaeta (aquatic worms)
5th most abundant	Simuliidae (black flies)

Below confluences of West & Middle Branches of White Clay Creek: Site 7

Site 7 can be found at North Creek Road downstream from Good Hope Road on the White Clay Creek Preserve, PA. Half of the land in the watershed is in pasture/hay while the other half is predominantly crops and forests. The watershed is not heavily populated and typically of most other sites. Water chemistry variables were also similar to the study wide mean.

Total density and EPT density averaged 8100 individuals/m^2 and 1000 individuals/m^2, respectively. Typically chironomid midges, a group considered pollution-tolerant, make up 75% of the total numbers. Total Richness (11 taxa/200 individuals) and EPT Richness (5 taxa/200 individuals) were lower than the reference Site 11, but higher than the Site 6 upstream on the Middle Branch and similar to Site 17 upstream on the West Branch. The average MAIS score ranked this site as Fair (6.7) and long-term trends suggest conditions may be improving at this location. The average MAIS for 1994-1997 was 4.2 (Poor) and for 2003-2005 it was 8.9 (Fair). Upstream sampling locations (see Site 6 and Site 17) suggest the Middle Branch is contributing more to degraded conditions at Site 7 than the West Branch.

Location	
Site Number Description	7 Downstream from Good Hope Road at North Creek Road
Lat Long (degree & decimal minutes)	39°45.699' N, -75°46.960' W
Land Use	
Watershed area above site (km^2)	64
Population density in 2000 (#/km^2)	130
% Population increase from 1990 to 2000	33
Percent pasture/hay	52
Percent cultivated crops	21
Percent forest	21
Chemistry (see Table 1 for sampling schedule)	
Nitrate (mg/L)	3.92
Ammonium (mg/L)	0.02
Total phosphorus (mg/L)	0.033
Soluble reactive phosphorus (mg/L)	0.050
Sulfate (mg/L)	18.83
Alkalinity (mg/L $CaCo_3$)	28.46
pH	7.87
Conductivity (µmhos)	187
Dissolved organic carbon (mg/L)	1.63
Macroinvertebrate Data	
Years sampled	1994-2000, 2003-2005
MAIS score	6.7
MAIS score rating	Fair
1st most abundant	Chironomidae (midges)
2nd most abundant	Hydropsychidae (common netspinner caddisflies)
3rd most abundant	Tipulidae (crane flies)
4th most abundant	Ephemerellidae (spiny crawler mayflies)
5th most abundant	Oligochaeta (aquatic worms)

West Branch of White Clay Creek: Site 19

Site 19 is the most headwater site on the West Branch located upstream from State Road in New London Township, PA. Similar to the other study sites, this site is dominated by open uncultivated fields. In contrast, Site 19 had the highest amount of row crops (10% more than the 17 site average). Fertilizer application to these agricultural fields may be the reason that nitrate levels were so high, although phosphorus, another potential byproduct of fertilizer, was not.

Macroinvertebrate densities ranged from 2300 individuals/m^2 in 2003 to 25,400 individuals/m^2 in 2008 and average 12,000 individuals/m^2. EPT on average made up 28% of the total numbers and averaged 3300 individuals/m^2. EPT taxa made up approximately 48% of the Total Richness, which average 14 taxa/200 individuals. The average MAIS score was 10.1 or Fair. There was one year (1997) it rated Poor (5.6), 8 years it rated Fair (6.4-12.7), and 2 years (1998 and 2003) it rated Good (13.4-15.4). The high variability in the MAIS score at this site gives no indication whether the macroinvertebrate community is improving or not.

Location	
Site Number	19
Description	Upstream from State Road in New London Township
Lat Long (hr min sec)	39°47.882' N, -75°51.611' W
Land Use	
Watershed area above site (km^2)	4
Population density in 2000 (#/km^2)	117
% Population increase from 1990 to 2000	29
Percent pasture/hay	50
Percent cultivated crops	31
Percent forest	13
Chemistry (see Table 1 for sampling schedule)	
Nitrate (mg/L)	7.11
Ammonium (mg/L)	0.03
Total phosphorus (mg/L)	0.018
Soluble reactive phosphorus (mg/L)	0.050
Sulfate (mg/L)	11.48
Alkalinity (mg/L $CaCo_3$)	27.09
pH	7.41
Conductivity (μmhos)	209
Dissolved organic carbon (mg/L)	2.70
Macroinvertebrate data	
Years sampled	1994-2000, 2003-2004, 2008
MAIS score	10.1
MAIS score rating	Fair
1st most abundant	Chironomidae (midges)
2nd most abundant	Ephemerellidae (spiny crawler mayflies)
3rd most abundant	Elmidae (riffle beetles)
4th most abundant	Hydropsychidae (common netspinner caddisflies)
5th most abundant	Oligochaeta (aquatic worms)

West Branch of White Clay Creek: Site 17

Site 17 is the only other site on the West Branch besides Site 19 and is located at Hess Mill Road upstream of Route 841. Similar to Site 19, pasture/hay fields and cultivated crops are the dominant land use in the watershed. The number of people in the watershed is typical compared to other sites, but with most of the growth occurring more recently. Water chemistry variables were comparable to the study wide average.

Macroinvertebrate densities at Site 17 were particularly low in 1991-1994 and 2003 (<3000 individuals/m^2), and highest in 1995 and 1997 (<16,000 individuals/m^2). Total density averaged 8300 individuals/m^2 and EPT density averaged 890 individuals/m^2. EPT made ≈15% of the total numbers, much lower than the reference Site 11 (56%). Total Richness and EPT Richness averaged 11 and 5 taxa/200 individuals, respectively. MAIS scores ranged from 4.5 (Poor) to 11.6 (Fair) and averaged 6.6 (Fair). The long-term trend for this site was very similar to the upstream location, Site 19, with low MAIS scores in 1996, 1997, 2004, and 2005 and high scores in 1998, 1999 and 2003. In summary there was no predictable pattern indicating whether conditions are improving or degrading for locations on the West Branch, although there is a big drop in MAIS Scores from the upstream Site 19 (10.1) to this site.

Location	
Site Number	17
Description	At Hess Mill Road upstream of Route 841
Lat Long (hr min sec)	39°46.091' N, -75°49.932' W
Land Use	
Watershed area above site (km^2)	15
Population density in 2000 (#/km^2)	132
% Population increase from 1990 to 2000	50
Percent pasture/hay	53
Percent cultivated crops	24
Percent forest	19
Chemistry (see Table 1 for sampling schedule)	
Nitrate (mg/L)	4.93
Ammonium (mg/L)	0.01
Total phosphorus (mg/L)	0.019
Soluble reactive phosphorus (mg/L)	0.036
Sulfate (mg/L)	19.07
Alkalinity (mg/L $CaCo_3$)	28.83
pH	7.71
Conductivity (μmhos)	189
Dissolved organic carbon (mg/L)	2.16
Macroinvertebrate data	
Years sampled	1991-1999, 2003-2005
MAIS score	6.6
MAIS score rating	Fair
1st most abundant	Chironomidae (midges)
2nd most abundant	Hydropsychidae (common netspinner caddisflies)
3rd most abundant	Tipulidae (crane flies)
4th most abundant	Ephemerellidae (spiny crawler mayflies)
5th most abundant	Oligochaeta (aquatic worms)

Tributary on the Lower White Clay Creek: Site 24

Site 24 on Middle Run is directly upstream of Foxden Road. The watershed is the second smallest in the study but has the highest density of people based on 2000 census data. Land use is predominantly pastures with a low amount of row crops but a high number of roads (impervious surfaces made up 5% of the watershed, double the amount found at most sites) and low intensity developed land (13%). Water samples were never taken at this site.

This location on Middle Run was only sampled in 2001. Although a large proportion (45%) of the total numbers (≈3500 individuals/m^2) were chironomids (≈1600 individuals/m^2) there was also an abundance of pollution sensitive taxa such as black flies, riffle beetles, and ephemerellid mayflies (i.e., these three groups made 37% of the total density). The MAIS score was 7.9 (Fair) and similar to scores reported for Site 23, which was located downstream on Middle Run. Conditions on the mainstem of the Lower White Clay Creek are Poor (i.e., in the same year Site 22 had a MAIS score of 2.8), which implies Middle Run is not contributing to this degradation but may actually help enhance conditions on the mainstem.

Location	
Site Number	24
Description	Middle Run upstream of Foxden Road
Lat Long (degree & decimal minutes)	39°43.227' N, -75°43.075' W
Land Use	
Watershed area above site (km^2)	4
Population density in 2000 (#/km^2)	468
% Population increase from 1990 to 2000	20
Percent pasture/hay	50
Percent cultivated crops	12
Percent forest	13
Chemistry	
Nitrate (mg/L)	n/a
Ammonium (mg/L)	n/a
Total phosphorus (mg/L)	n/a
Soluble reactive phosphorus (mg/L)	n/a
Sulfate (mg/L)	n/a
Alkalinity (mg/L $CaCo_3$)	n/a
pH	n/a
Conductivity (µmhos)	n/a
Dissolved organic carbon (mg/L)	n/a
Macroinvertebrate Data	
Years sampled	2001
MAIS score	7.9
MAIS score rating	Fair
1st most abundant	Chironomidae (midges)
2nd most abundant	Simuliidae (black flies)
3rd most abundant	Elmidae (riffle beetles)
4th most abundant	Ephemerellidae (spiny crawler mayflies)
5th most abundant	Empididae (dance flies)

Tributary on the Lower White Clay Creek: Site 23

Site 23 on Middle Run is at the north end of Delaplane Avenue. The stream is accessed by a public walking trail located behind residential homes. This site is also part of the White Clay Creek State Park in DE and is the second most populated watershed in the study; Site 24 upstream on Middle Run is the most populated. Similar to Site 24 the population density in the watershed has been relatively unchanged since the 1990's. In contrast to the site upstream, there is a large amount of forests and woody wetlands (5%) in the watershed. Nitrate, phosphorus and sulfate levels were low compared to other study sites suggesting minimal impacts from residential areas (e.g., lawn fertilizers).

Total density averaged 5800 individuals/m^2 and approximately 80% of the individuals were chironomid midges. Average Total Richness was 13 taxa/200 individuals with 40% of the taxa being EPT. MAIS scores averaged 6.9 (Fair) for the four sample years. MAIS scores suggest water quality is deteriorating at this site: scores went from 10.5 in 2000 to 5.2 in 2005.

Location	
Site Number	23
Description	Middle Run at Delaplane Manor development near the north end of Delaplane Avenue
Lat Long (degree & decimal minutes)	39°42.338' N, -75°43.186' W
Land Use	
Watershed area above site (km^2)	9
Population density in 2000 (#/km^2)	449
% Population increase from 1990 to 2000	2
Percent pasture/hay	40
Percent cultivated crops	13
Percent forest	27
Chemistry (see Table 1 for sampling schedule)	
Nitrate (mg/L)	2.67
Ammonium (mg/L)	0.01
Total phosphorus (mg/L)	0.013
Soluble reactive phosphorus (mg/L)	0.088
Sulfate (mg/L)	13.00
Alkalinity (mg/L $CaCo_3$)	29.21
pH	7.66
Conductivity (µmhos)	187
Dissolved organic carbon (mg/L)	2.36
Macroinvertebrate Data	
Years sampled	2000, 2001, 2003, 2005
MAIS score	6.9
MAIS score rating	Fair
1st most abundant	Chironomidae (midges)
2nd most abundant	Ephemerellidae (spiny crawler mayflies)
3rd most abundant	Empididae (dance flies)
4th most abundant	Tipulidae (crane flies)
5th most abundant	Simuliidae (black flies)

Lower Mainstem of the White Clay Creek: Site 14

Site 14 on the Lower Mainstem is found below the confluence of the East, West, and Middle Branches, downstream of Yeatman Road. Land use was typically of the study average: mostly pasture/hay fields with some row crops and forest. This site is on the White Clay Creek Preserve in PA so a large portion of the stream above the sampling location has an intact riparian forest (a.k.a. a stream buffer) providing a barrier against potential impacts. Water chemistry variables are comparable to the study wide average and indicate no obvious anomalies.

Average total density was 7400 individuals/m^2 and ranged from 145 individuals/m^2 in 1993 to 20,300 individuals/m^2 in 1998. Chironomid midges dominated the samples: on average midges made up to 85% of the total density. The MAIS score averaged 3.8 (Poor) and was more similar to the upstream site on the East Branch (Site 16, MAIS = 3.8) than the upstream site on the Middle/West Branches (Site 7, MAIS = 6.7). This implies that the East Branch contributed to more of the degradation that was measured at Site 14 on the Lower White Clay Creek. Long-term trends suggest no improvement in water quality from 1994 through 2005.

Location	
Site Number	14
Description	Below confluence of the East, West and Middle Branches, downstream of Yeatman Rd in WCC Preserve
Lat Long (degree & decimal minutes)	39°44.910' N, -75°46.168' W
Land Use	
Watershed area above site (km^2)	153
Population density in 2000 (#/km^2)	152
% Population increase from 1990 to 2000	37
Percent pasture/hay	51
Percent cultivated crops	18
Percent forest	20
Chemistry (see Table 1 for sampling schedule)	
Nitrate (mg/L)	3.89
Ammonium (mg/L)	0.01
Total phosphorus (mg/L)	0.033
Soluble reactive phosphorus (mg/L)	0.049
Sulfate (mg/L)	18.37
Alkalinity (mg/L $CaCo_3$)	37.22
pH	8.12
Conductivity (µmhos)	208
Dissolved organic carbon (mg/L)	1.97
Macroinvertebrate Data	
Years sampled	1994-2001, 2003-2005
MAIS score	3.8
MAIS score rating	Poor
1st most abundant	Chironomidae (midges)
2nd most abundant	Tipulidae (crane flies)
3rd most abundant	Hydropsychidae (common netspinner caddisflies)
4th most abundant	Oligochaeta (aquatic worms)
5th most abundant	Empididae (dance flies)

Lower Mainstem of the White Clay Creek: Site 20

Site 20 is located near Creek Road at the Delaware Visitor Center in White Clay Creek State Park. Like most sites in the watershed the main land uses are pasture/hay, crops and forest. Water chemistry variables are comparable to the study wide mean and indicated no obvious problems.

On average 85% of the total density were chironomid midges (7600 midges/m^2 versus 8800 total individuals/m^2). EPT richness was very low, only 2 taxa/200 individuals, at reference Site 11 the average was 8 taxa/200 individuals. Total Richness averaged 8 taxa/200 individuals. The MAIS score averaged 4.1, which rated this site as Poor.

Location	
Site Number	20
Description	At the Delaware Visitor Center near Creek Road in White Clay Creek State Park
Lat Long (degree & decimal minutes)	39°43.658' N, -75°45.946' W
Land Use	
Watershed area above site (km^2)	165
Population density in 2000 (#/km^2)	163
% Population increase from 1990 to 2000	34
Percent pasture/hay	49
Percent cultivated crops	17
Percent forest	23
Chemistry (see Table 1 for sampling schedule)	
Nitrate (mg/L)	3.58
Ammonium (mg/L)	0.01
Total phosphorus (mg/L)	0.038
Soluble reactive phosphorus (mg/L)	0.054
Sulfate (mg/L)	27.87
Alkalinity (mg/L $CaCo_3$)	50.90
pH	8.07
Conductivity (µmhos)	294
Dissolved organic carbon (mg/L)	1.98
Macroinvertebrate Data	
Years sampled	1995-1998, 2000, 2001, 2003-2005
MAIS score	4.1
MAIS score rating	Poor
1st most abundant	Chironomidae (midges)
2nd most abundant	Tipulidae (crane flies)
3rd most abundant	Hydropsychidae (common netspinner caddisflies)
4th most abundant	Oligochaeta (aquatic worms)
5th most abundant	Hydroptilidae (microcaddisflies)

Lower Mainstem of the White Clay Creek: Site 21

Site 21 on the Lower Mainstem is found at Windy Mill Park above Kirkwood Highway, upstream of the confluence with the Middle Run tributary. This is the second largest site sampled in the study. The area immediately near the sampling location is heavily developed and populated, but overall only 10% of the watershed is developed area. The large % forest in the watershed is due to the presence of the White Clay Creek Preserve (PA) and State Park (DE) that borders large portions of the stream. Water chemistry variables examined indicated no obvious problems, but the data is limited to 3 yrs (1995-1997).

Similar to many sites in the Lower White Clay, chironomid midges dominated the samples. Midges made up >85% of the total density and EPT made up ≈13% of the total density (total macroinvertebrate density average 7000 individuals/m^2). Total Richness averaged 6 taxa/200 individuals, with only two of those taxa being EPT. The MAIS score averaged 2.9 and rated Poor in the five years sampled. Only in 2005 did the MAIS score (5.9) approach the Fair category. A regression of MAIS and year suggest conditions are improving at this site.

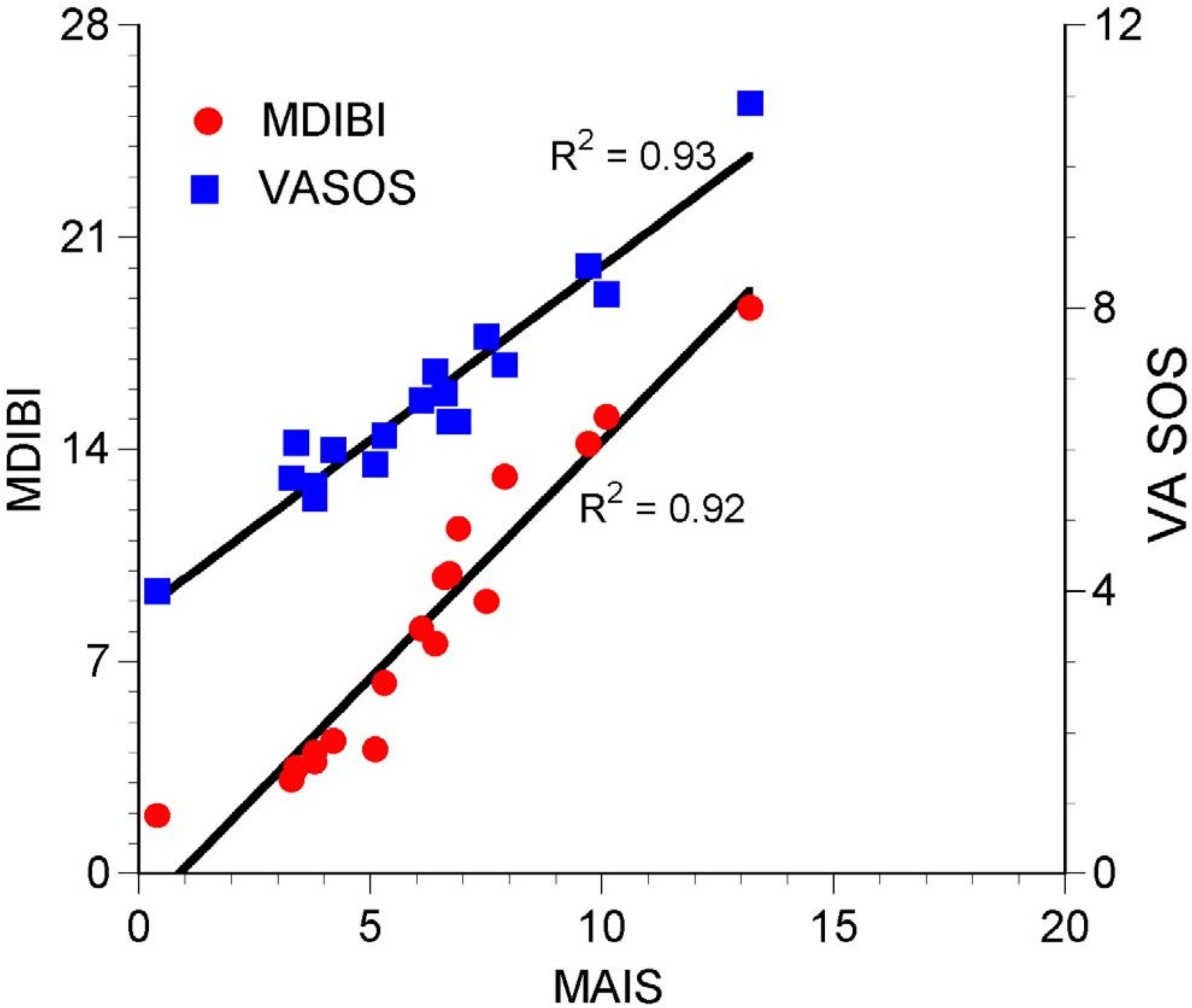
Location	
Site Number	21
Description	At Windy Mill Park above Kirkwood Highway, upstream of Middle Run tributary
Lat Long (degree & decimal minutes)	39°41.530' N, -75°43.484' W
Land Use	
Watershed area above site (km^2)	183
Population density in 2000 (#/km^2)	192
% Population increase from 1990 to 2000	20
Percent pasture/hay	46
Percent cultivated crops	16
Percent forest	24
Chemistry (see Table 1 for sampling schedule)	
Nitrate (mg/L)	3.37
Ammonium (mg/L)	0
Total phosphorus (mg/L)	n/a
Soluble reactive phosphorus (mg/L)	0.014
Sulfate (mg/L)	n/a
Alkalinity (mg/L $CaCo_3$)	13.9
pH	8.00
Conductivity (µmhos)	242
Dissolved organic carbon (mg/L)	2.44
Macroinvertebrate Data	
Years sampled	1995-1998, 2000
MAIS score	2.9
MAIS score rating	Poor
1st most abundant	Chironomidae (midges)
2nd most abundant	Hydropsychidae (common netspinner caddisflies)
3rd most abundant	Hydroptilidae (microcaddisflies)
4th most abundant	Tipulidae (crane flies)
5th most abundant	Empididae (dance flies)

Lower Mainstem of the White Clay Creek: Site 22

Site 22 is at Harmony Brook Park, downstream of Pike Creek. This is the largest sampling location we have on White Clay Creek. The number of people in the watershed is relatively high so it is not surprising the large amount of developed area (16%) and impervious surface (5%). What is beneficial for the stream is the large amount of forest in the watershed (23%). Water chemistry variables indicated no obvious problems.

Total density averaged 6600 individuals/m^2 and ranged from 200 individuals/m^2 in 1996 to 17,000 individuals/m^2 in 2004. Chironomid midges, a group relatively tolerant to pollution, typically made >85% of the total numbers. Total Richness and EPT Richness averaged 7 and 1 taxa/200 individuals, respectively. Of the nine sample dates, MAIS rated eight of them as Poor, only in 2003 (an extremely low density year) was the site considered to have Fair water quality. Sites 22 and 21 (upstream) had the overall lowest MAIS scores for the Lower Mainstem. The MAIS score at Site 22 averaged 2.9 (Poor) and ranged from 0.4 to 7.

Location	
Site Number	22
Description	Harmony Brook Park in Harmony Hills development, downstream of Pike Creek
Lat Long (degree & decimal minutes)	39°42.060’ N, -75°41.012’ W
Land Use	
Watershed area above site (km^2)	225
Population density in 2000 (#/km^2)	339
% Population increase from 1990 to 2000	21
Percent pasture/hay	42
Percent cultivated crops	14
Percent forest	23
Chemistry (see Table 1 for sampling schedule)	
Nitrate (mg/L)	3.12
Ammonium (mg/L)	0.02
Total phosphorus (mg/L)	0.034
Soluble reactive phosphorus (mg/L)	0.049
Sulfate (mg/L)	25.80
Alkalinity (mg/L $CaCo_3$)	56.80
pH	7.97
Conductivity (µmhos)	282
Dissolved organic carbon (mg/L)	2.52
Macroinvertebrate Data	
Years sampled	1995-1998, 2000, 2001, 2003-2005
MAIS score	2.9
MAIS score rating	Poor
1st most abundant	Chironomidae (midges)
2nd most abundant	Hydropsychidae (common netspinner caddisflies)
3rd most abundant	Oligochaeta (aquatic worms)
4th most abundant	Empididae (dance flies)
5th most abundant	Ceratopogonidae (biting midges)



Appendix 2. Relationship between Macroinvertebrate Aggregated Index for Streams (MAIS) and two other indexes; Maryland Indices of Biotic Integrity (MDIBI) and Virginia Save Our Stream (VASOS).

Appendix 3. Macroinvertebrates Indexes used to rate water quality as Good, Fair or Poor for sites in the WCC. Indexes were Macroinvertebrate Aggregated Index for Streams (MAIS), Maryland Indices of Biotic Integrity (MDIBI), and Virginia Save Our Stream (VASOS).

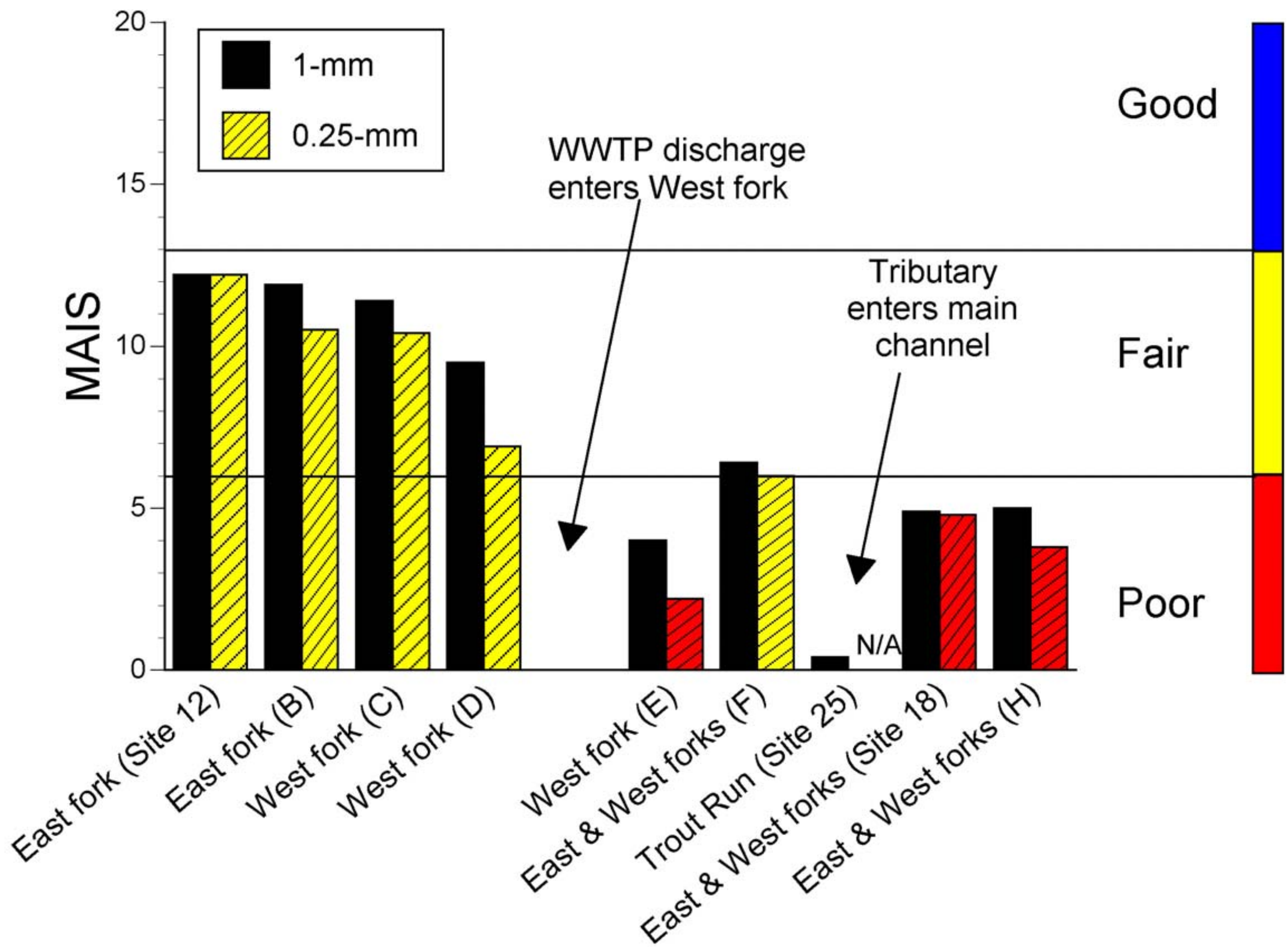
Site	MAIS	MDIBI	VASOS
East Branch			
11	good	good	good
12	fair	fair	fair
25 (tributary)	poor	poor	poor
18	poor	poor	poor
16	poor	poor	poor
Middle Branch			
0	fair	good	fair
3	fair	fair	fair
4	fair	fair	poor
6	poor	poor	poor
7	fair	fair	poor
West Branch			
19	fair	good	fair
17	fair	fair	poor
Middle Run			
24	fair	fair	fair
23	fair	fair	poor
Lower Mainstem			
14	poor	poor	poor
20	poor	poor	poor
21	poor	poor	poor
22	poor	poor	poor

Appendix 4. Land use variables based on 2001 National Land Cover Data. Population data from 1990 and 2000 Census data (see methods). Land cover variables are expressed as a % of the watershed.

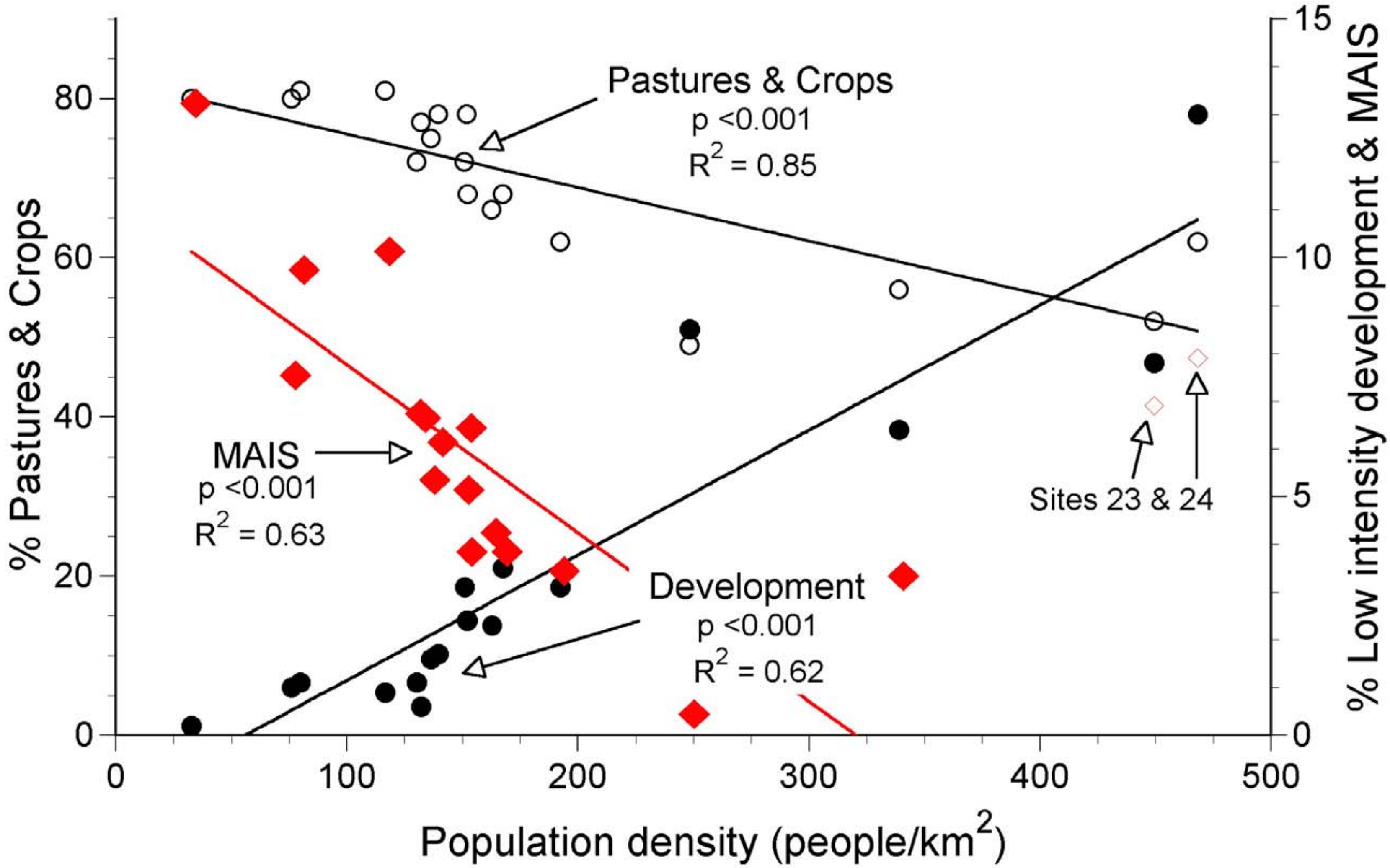
Site	Name	Location	MAIS	Water-shed area (km^2)	Pop. density (people /km^2)	% Pop. change from 1990 to 2000	Pasture /Hay	Crops	Deciduous Forest
11	East Branch	Upstream of Spencer Rd at the Stroud Water Research Center, Avondale	13.2	7	33	13	62	18	17
12	East Branch	At Rosazza Orchards off of Glen Willow Rd north of Avondale	7.5	28	76	35	64	16	15
25	Tributary to East Branch	Trout Run, tributary upstream of Site 18 near Route 41 in Avondale	0.4	3	248	56	32	17	10
18	East Branch	Below the Avondale sewage treatment outfall along Indian Run Road	5.1	50	151	33	54	17	15
16	East Branch	On the White Clay Creek Preserve, downstream from Good Hope Road and the bridge on Broad Run	3.8	83	168	41	52	16	17
0	Middle Branch	Above Tice Road in London Grove Township	9.7	7	80	32	55	26	17
3	Middle Branch	Upstream from State Road south of West Grove	6.4	19	152	27	52	27	13
4	Middle Branch	At Church Hill Road near Creek Road	6.1	31	140	31	55	24	14
6	Middle Branch	Upstream from Mercer Mill Road, near the confluence with the West Branch	5.3	35	136	30	53	22	17
7	Below West and Middle Branches	Downstream from Good Hope Road at North Creek Road	6.7	64	130	33	52	21	21
17	West Branch	At Hess Mill Road upstream of Route 841	6.6	15	132	50	53	24	18
19	West Branch	Upstream from State Road in New London Township	10.1	4	117	29	50	31	13
24	Tributary to the Lower Mainstem	Middle Run upstream of Foxden Road	7.9	4	468	20	50	12	13
23	Tributary to the Lower Mainstem	Middle Run at Delaplane Manor near the north end of Delaplane Road	6.9	9	449	2	40	12	26
14	Lower Mainstem	Below confluence of the East, West and Middle Branches in White Clay Creek Preserve	3.8	153	152	37	51	17	20
20	Lower Mainstem	At the Delaware Visitor Center near Creek Road in White Clay Creek State Park	4.2	165	163	34	49	17	23
21	Lower Mainstem	At Windy Mill Park above Kirkwood Highway, upstream of Middle Run tributary	3.4	183	192	20	46	16	24
22	Lower Mainstem	At Harmony Brook Park, downstream of Pike Creek	3.3	225	339	21	42	14	23
WCC	watershed			269	417	18	51	13	21

Appendix 4. Continued.

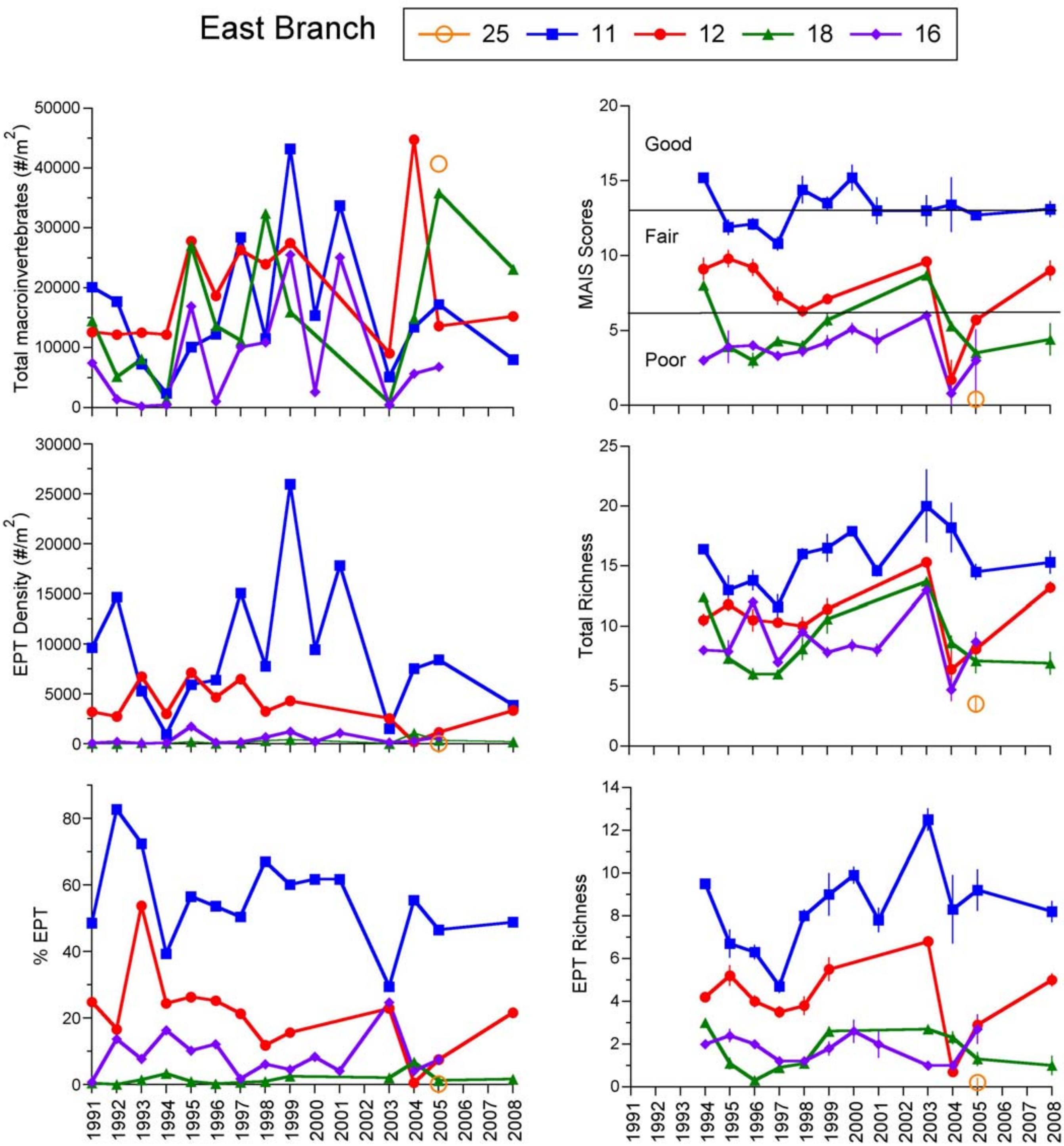
Site	Can-opy	Imperv-ious surfaces	Barr-en land	Ever-green forest	Dev., open space	Dev., low intensity	Dev., med. intensity	Dev., high intensity	Woody wet-lands	Emer. herb. wet-lands	Open water	Mixed forest
11	17	0.1	0.6	0.5	0.6	0.2	0.0	0.0	0.8	0.4	0.00	0.000
12	15	0.7	0.4	0.3	2.1	1.0	0.2	0.1	1.0	0.1	0.00	0.000
25	12	8.7	1.8	0.7	20.3	8.5	6.3	0.9	1.6	0.7	0.39	0.000
18	15	2.3	0.6	0.4	6.5	3.1	1.2	0.2	1.3	0.3	0.07	0.000
16	17	2.6	0.8	0.5	6.7	3.5	1.3	0.2	1.3	0.4	0.17	0.000
0	15	0.5	0.0	0.1	0.9	1.1	0.2	0.0	0.2	0.0	0.00	0.000
3	12	1.5	0.2	0.2	4.7	2.4	0.5	0.0	0.4	0.1	0.08	0.000
4	13	1.1	0.4	0.3	4.2	1.7	0.4	0.0	0.4	0.1	0.05	0.000
6	17	1.0	0.5	0.5	3.9	1.6	0.3	0.0	0.6	0.1	0.04	0.010
7	19	0.8	0.7	0.5	3.0	1.1	0.3	0.1	0.9	0.2	0.02	0.006
17	17	0.7	0.4	0.0	2.1	0.6	0.4	0.1	0.7	0.2	0.00	0.000
19	12	1.4	0.0	0.0	3.2	0.9	1.0	0.3	0.4	0.3	0.00	0.000
24	12	5.4	1.0	0.5	7.3	13.0	0.8	0.0	0.6	0.7	0.71	0.000
23	28	3.5	1.0	0.6	5.6	7.8	0.7	0.1	4.6	0.5	0.34	0.000
14	19	1.8	0.8	0.6	5.0	2.4	0.8	0.2	1.1	0.3	0.10	0.006
20	22	1.7	0.9	0.6	4.8	2.3	0.8	0.1	1.2	0.3	0.09	0.006
21	24	2.4	1.0	0.7	5.3	3.1	1.1	0.4	1.7	0.3	0.09	0.005
22	23	4.6	1.0	0.7	7.0	6.4	2.1	0.7	2.5	0.3	0.09	0.007
WCC	22	6.3	1.2	0.8	9.4	8.9	2.9	1.0	2.7	0.4	0.10	0.011



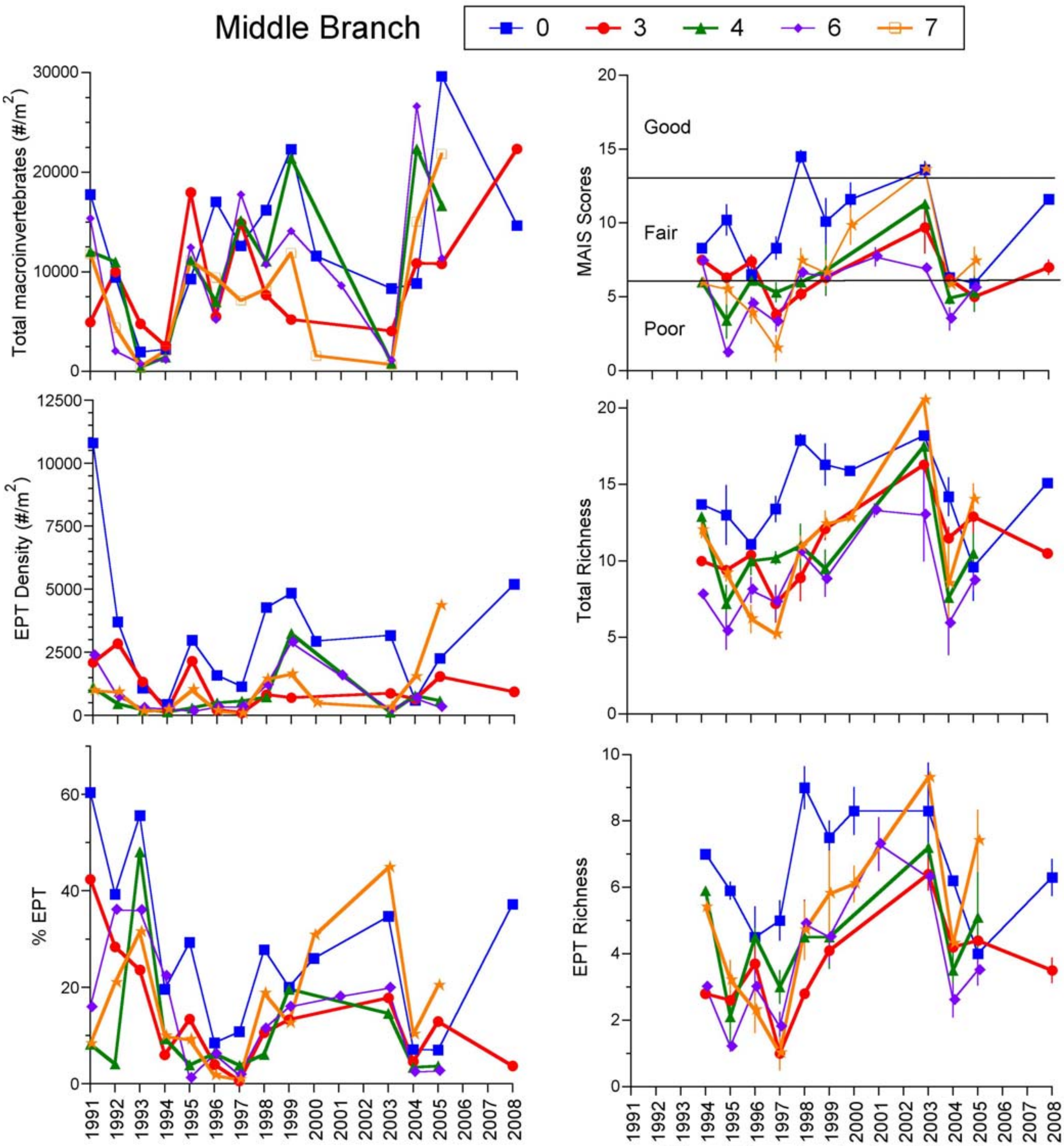
Appendix 5. MAIS scores for sites on the East Branch of White Clay Creek sites near the borough of Avondale in October 2005. MAIS scores were determined with samples processed with a 1-mm mesh (black solid bars) and 0.25-mm mesh (colored bars) sieves.



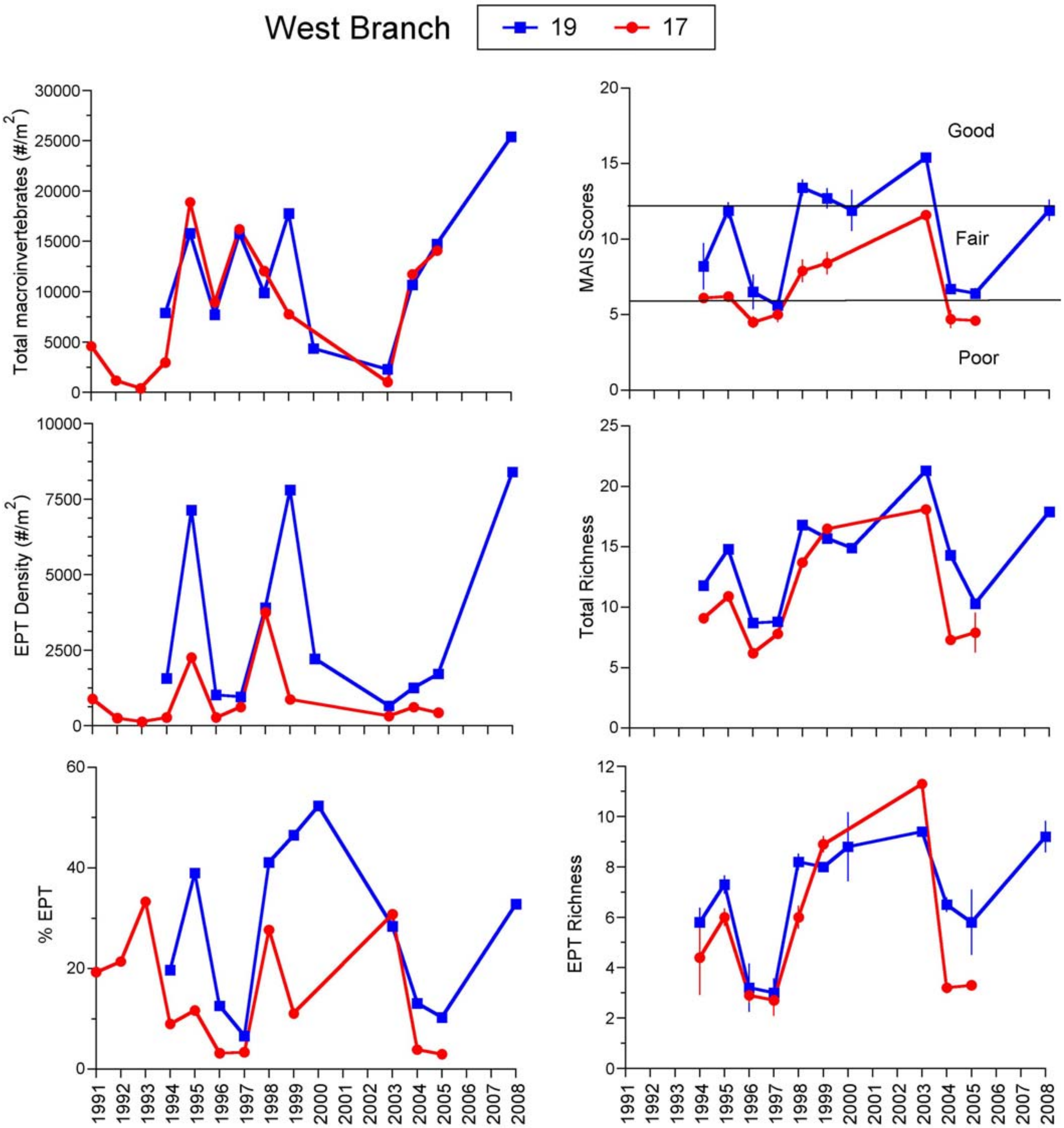
Appendix 6. Relationship between population density (people/km^2) and the percentage of pasture & crops and low intensity development for Stream Watch sites in the WCC watershed. Regression line for MAIS does not include Sites 23 and 24.



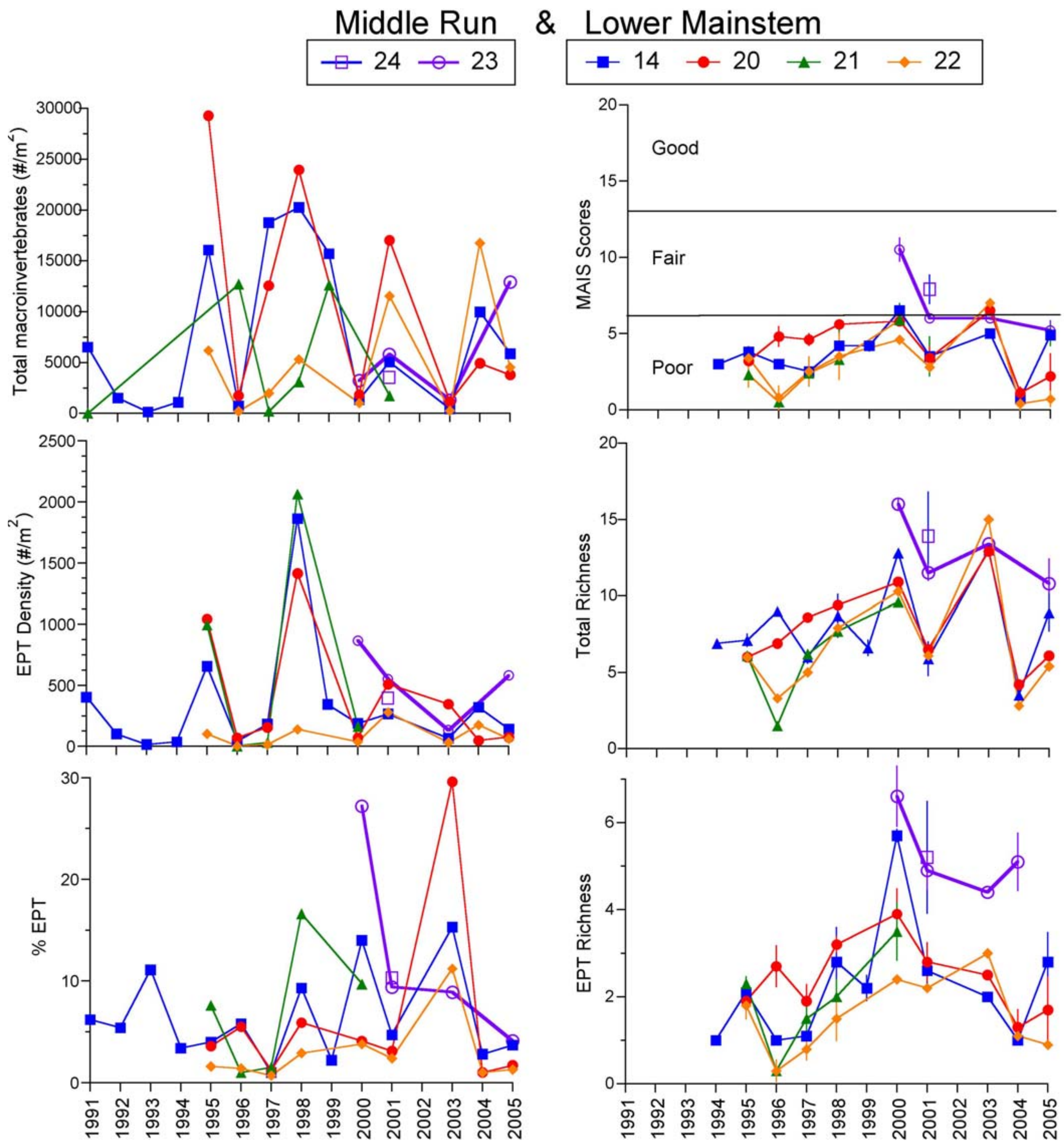
Appendix 7a. Macroinvertebrate characteristics for sites on the East Branch of WCC. Points are means. Metrics (± 1 SE) are based on no. taxa/200 individuals.



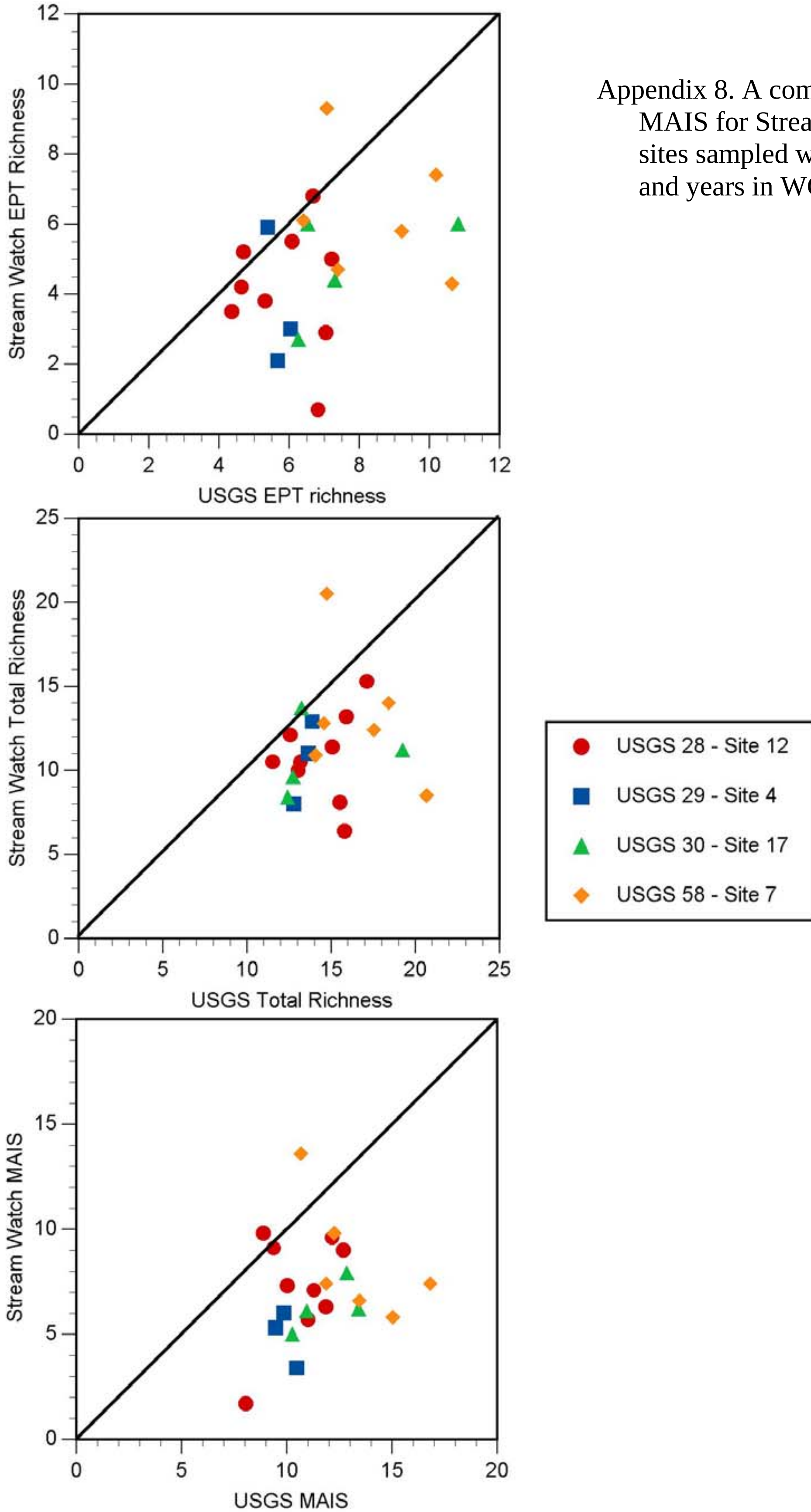
Appendix 7b. Macroinvertebrate characteristics for sites on the Middle Branch of WCC. Points are means. Metrics (± 1 SE) are based on no. taxa/200 individuals.



Appendix 7c. Macroinvertebrate characteristics for sites on the West Branch of WCC. Points are means. Metrics (± 1 SE) are based on no. taxa/200 individuals.



Appendix 7d. Macroinvertebrate characteristics for sites on Middle Run and the Lower Mainstem of WCC. Points are means. Metrics (± 1 SE) are based on no. taxa/200 individuals.



Appendix 8. A comparison richness and MAIS for Stream Watch and USGS sites sampled within the same areas and years in WCC.