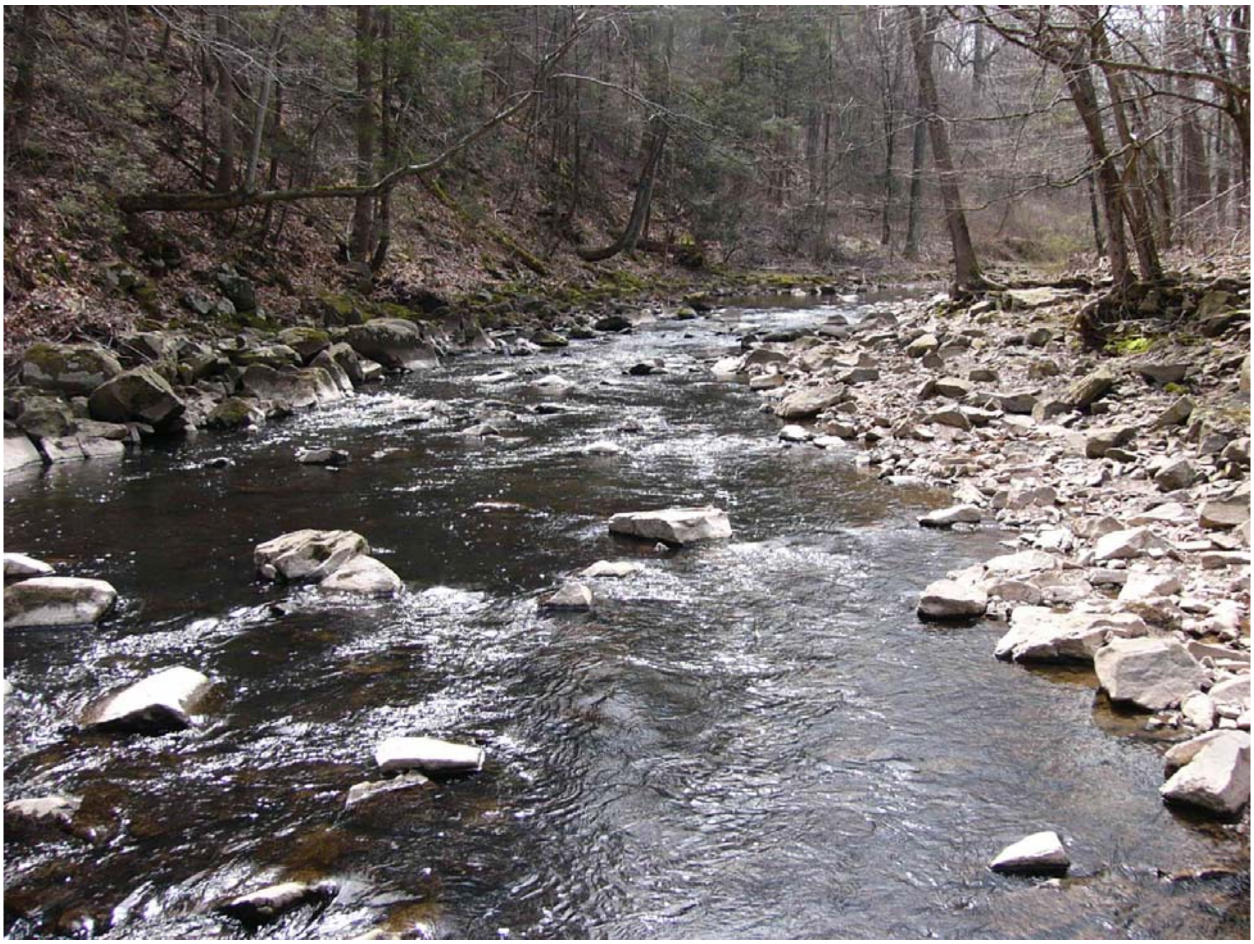
Scientific and Educational Aspects of Water Quality and Stream Health in Eastern Pennsylvania

A Final Report Based on Historic (1967-71) and Recent (2007-2008) Environmental Monitoring and Educational Activities



Submitted by:
Stroud Water Research Center
Contribution No. 2010002
970 Spencer Road
Avondale, PA 19311

March 2010

STROUD WATER RESEARCH CENTER

Report Prepared by:

Anthony K. Aufdenkampe, Ph.D.

Thomas L. Bott, Ph.D.

Charles L. Dow, Ph.D.

John K. Jackson, Ph.D.

Louis A. Kaplan, Ph.D.

Alfred E. Schuyler, Ph.D.

Bernard W. Sweeney, Ph.D. *

* Contact person: sweeney@stroudcenter.org; 610-268-2153 x222

Photo: Pidcock Creek

Acknowledgments

The authors of this report represent only a few of the many folks who contributed their hard work to the project. Without the dedication of the following employees and many summer interns, this project would never have gotten off the ground:

Melanie Arnold
Juliann Battle
Heather Brooks
Stephanie Dix
David Funk
George Dang
David Fralinger
Michael Gentile
William Milliken
David Montgomery
Sally Peirson
Ann Rhoads
Sherman Roberts
Lorae' Simpson
Kyle Stem
Roberta Weber

Special thanks is extended to Bonnie Zobel who, as an intern from Delaware Valley College, hand-entered all of the historic data into digital files allowing for the permanent preservation of this valuable set of data. Also thanks to Drs. John Mertz and Ron Johnson of Delaware Valley College for valuable discussions and insights into the historical data and logistical help with various aspects of designing and executing the project.

We thank the many private land owners within the Bucks County watersheds we visited who allowed us to access streams on their property. This project was funded by a grant under the National Aeronautic and Space Administration (NASA).

Table of Contents

Executive Summary

A generally explicit goal of stream water-quality monitoring programs is to assess the state of current water quality in a given study region. Part of such an assessment is the obvious question 'how have things changed?' Too often, this question can only be answered through inference. For example, a relationship between current water-quality and current population could be used to predict historic water quality given the availability of historic population data. The applicability of such a prediction relies on the premise that the relationship between a measure of stream water quality and population does not change over time. In lieu of actual historically measured water-quality data, such predictions of historic water-quality based on some related measure of historic watershed conditions is the only viable option for answering the question 'how have things changed?'

Due to forward-thinking individuals in the Division of Natural Resources of Bucks County, and Delaware Valley College in Doylestown, an extensive historic stream water-quality dataset exists for most of Bucks County, Pennsylvania. Launched in 1967, this innovative monitoring program had as a primary goal the establishment of a baseline of information on the health of the county's stream and river ecosystems and the quality of their water. The temporal scale, with data collection occurring from 1967 through 1971, coupled with the spatial scale of 47 intensively-sampled sites along with another 72 synoptically-sampled sites made this an ambitious monitoring project. However, the truly innovative aspect of this historic monitoring program was the breadth of chemical and biological measures that comprised the sampling and the quantitative nature of the data collection. The vision of the monitoring program participants to approach the question of stream water quality from both a chemical and biological perspective makes the resulting dataset quite valuable as a baseline.

The historic monitoring program came in response to calls for the construction of flood control dams, water supply reservoirs and other measures that were intended to improve water quality in the county's surface streams. Sampling stations included sites above and below towns and sewage treatment plants, at proposed dam construction sites and in rural settings for control purposes. At the end of the project (1971), the Clean Water Act was passed and the Environmental Protection Agency was established. In the intervening years pollution controls have been implemented, urban areas have expanded and some of the rural areas have been intensively developed. After the initial baseline data had been collected, the program was abandoned and these data were never fully analyzed or used for planning or evaluation purposes.

The primary objective of the historic monitoring program was simply to provide a stream water-quality baseline. Secondary objectives that arose as the project progressed were as follows:

1. Assess the present (i.e. at that time) state of water quality across the entire County
2. Predict water quality trends that might accompany increasing urban/suburban development. and
3. Develop a program of water quality management for the County.

The initial study design established 35 sites across the County that were divided up among 5 categories defining similar location characteristics or study goals. These study site groupings

included site locations relative to proposed dam sites or WWTP outfalls, sites within the Neshaminy watershed or on the Delaware River, and sites selected on small watersheds to characterize general, County-wide, water quality. Twelve additional sites were added in 1970 to provide supplemental data to that being collected at the original 35 study sites. Lastly, a host of new sites were added in 1970-71 which were synoptically sampled in an effort towards obtaining a spatially broader overview of county-wide stream water quality.

The Stroud Water Research Center had three primary objectives in revisiting the historic Bucks Co stream water-quality monitoring work:

1. Examine changes in water quality over the 40 years since the initial study.
2. Add to the baseline of water-quality information that was established by the initial study.
3. Use the historic and new baseline for piloting education programs related to water quality in Bucks County

Re-visiting all 47 of the original study sites (not including the 72 synoptically-sampled sites) where the complete suite of historic chemical and biological sampling took place would have been ideal. However, financial limitations of the project required a greatly reduced scope in terms of the number of sites to sample for the current effort. The eleven sites chosen from the original 47 were selected to be representative of the types included in the historic effort including: urbanizing; up-stream v. down-stream of impoundments; small v. large watersheds; nested watersheds within the Neshaminy, and a control (i.e. minimally impacted) site. Examining changes in water quality hinged on re-sampling as many of the historical parameters as possible, especially the biological ones (i.e. macroinvertebrates, periphyton, and phytoplankton). Adding to the baseline of information required selecting new, cutting-edge parameters such as the class of organic compounds commonly referred to as molecular tracers (i.e. PAHs, Caffeine, etc) and Carbon and Nitrogen isotopes.

Of the 116 historic monitoring sites whose watersheds are primarily within Bucks County (i.e. not including the Delaware River monitoring sites), only 8 experienced a reduction in population from 1970 to 2000 based on U.S. Census data. The majority of the 116 sites (84) experienced at least a 50% increase in population over that time period. The 11 sites that were re-visited in 2007/08 study period experienced an increase in the number of people of between 55 and 224%. Despite the already suburban nature of Bucks Co at the time of the historic study, these changes in population suggest that the County as a whole, and the 11 re-visited study sites specifically, experienced a good deal of urban/suburban growth over the 40 years since the initial water-quality monitoring study.

Highlighted findings from the current study:

- Phosphorus and sulfate, and to a lesser extent, alkalinity and pH showed the strongest regional changes among the chemical parameters measured both historically and in the present study. Reductions in phosphorus are likely due to the ban of phosphates in detergents in Pennsylvania in 1989 [Phosphate Detergent Act, Act of July 5, 1989 (P.L. 166, No. 31)]. The reduction in sulfate along with increases in pH an alkalinity may be tied to improvements made in air quality specifically to reduce acid deposition following an amendment to the Clean Air Act in 1990 that specifically dealth with acid deposition.

- Many molecular tracers such as polycyclic aromatic hydrocarbons (PAH), caffeine, fragrances, and fecal steroids were found in nearly every stream water sample collected in 2007/2008. In contrast, only one of three pesticides (atrazine) was found in nearly all samples. The other two pesticides, metalaxyl and chlorpyrifos, were found in less than a third of those samples. The three polychlorinated biphenyls (PCB) were found in only a few stream water samples.

- Selected molecular tracers as well as ratios of selected tracers were significantly and positively related to the change in population from 1970 to 2000 suggesting an association between watershed condition, and perhaps changes in watershed condition over time, to these very specific measures of contamination sources.

- Striking improvement in water quality based on fecal coliform density data was found between current and historic sampling efforts.

- Macroinvertebrate sampling suggests significant improvement in stream condition across most of the 11 sites sampled both historically and currently. This improvement comes despite increased watershed pressures as indicated by increased population densities for all 11 watersheds.

- Improvements in wastewater treatment from the historic study period to the current study period are suggested by decreases in live phytoplankton units (planktonic algae in the water column) between the two periods. However, an increase in live phytoplankton units was evident at a site below a stream impoundment (reservoir) built in the early 1970s. A decrease in live phytoplankton units suggests an improvement in water quality based on lower nutrient availability.

Complementing the research effort was education outreach conducted by Stroud Water Reseach Center educators that reach approximately 1000 teachers, student, and community organization volunteers in Bucks County. The goal of this effort was to educate Bucks County residents about the importance of their water resources and watersheds.

----------------------Intentionally Blank----------------------

Chapter 1. Technical Design

Overview

Study site selection and the landscape template (including land cover, geology, and hydrology) of those selected Bucks Co study sites will be described here. This information provides background material for interpreting results from the current sampling effort as well as for the comparison between current and historical data. An overview of the historical sampling effort and motivation behind repeating that effort will also be presented in this chapter. Throughout this section, as well as other sections in the report, ‘current’ implies the 2007-08 sampling effort while ‘historic’ implies the 1967-71 sampling effort.

In 1967, the Division of Natural Resources of Bucks County and Delaware Valley College in Doylestown launched an innovative monitoring program whose primary goal was to establish a baseline of information on the health of the county’s stream and river ecosystems and the quality of their water. The joint program came in response to calls for the construction of flood control dams, water supply reservoirs and other measures that were intended to improve water quality in the county’s surface streams. Streams and stream sampling stations were chosen, and sampling began in August 1967 and continued for three years. The sampling procedures and parameters were unique – almost visionary – for the time, and the protocol would even now be considered state of the art. Sampling stations included sites above and below towns and sewage treatment plants, at proposed dam construction sites and in rural settings for control purposes. At the end of the project (1971), the Clean Water Act was passed and the Environmental Protection Agency was established. In the intervening years pollution controls have been implemented, urban areas have expanded and some of the rural areas have been intensively developed. After the initial baseline data had been collected, the program was abandoned and these data were never fully analyzed or used for planning or evaluation purposes.

Study Design

Initial (Historic) Study

Perhaps the most valuable aspect of the initial study was its intent of establishing a stream water-quality baseline. A baseline that future managers and researchers could use to evaluate specific stream management programs or simply to track historical changes in stream ecosystem health. Without the foresight of the original project participants, this current study of looking at actual changes in measured water-quality measures, and consequently at stream ecosystem health in general, would not have even occurred. As this initial project progressed secondary objectives were established to:

1. Assess the present (i.e. historical) state of water quality across the entire County
2. Predict water quality trends that might accompany increasing urban/suburban development. and
3. Develop a program of water quality management for the County.

The initial study design established 35 sites across the County (Fig. 1.1). These sites were divided up among 5 categories that defined similar location characteristics:

I - Stations located below future dam sites
II - Stations located below WWTP outfalls
III - Stations that can provide general information about the Neshaminy watershed that aren't already part of I or II above.
IV - Stations located on the Delaware River
V - Stations on small watersheds to characterize general water-quality information.

Twelve additional sites were added in 1970 to provide supplemental data to that being collected at the original 35 study sites (Fig. 1.1). Three of these 12 new sites were located upstream of newly created reservoirs in order to have upstream data to contrast with already established downstream sites. The remaining 9 sites were added in an effort to better understand WWTP effluent on stream water-quality. A host of new sites were added in 1970-71 (Fig. 1.1) which were sampled only once or twice. This synoptic sampling effort was meant to get a spatially broader overview of county-wide stream water quality.

Sampling at the 35 original sites and at the 12 supplemental sites consisted of physical, chemical and a host of biological measures (Table 1.1) that made this holistic approach to stream ecosystem monitoring truly ahead of it's time. The synoptic sampling effort in 1970-71 included only chemical and physical measures. It is not clear from the historic data reports whether sampling was meant to target a specific flow regime (i.e., baseflow). Flow conditions at the time of both historic and current sampling will be discussed further in a subsequent section.

Current Study

Our study of revisiting the historic Bucks Co stream water-quality monitoring work had three primary objectives:

1. Examine changes in water quality for selected stations over the 40 years since the initial study.
2. Add to the baseline of water-quality information that was established by the initial study.
3. Use the historic and new baseline for piloting education programs related to water quality in Bucks County

Secondary objectives included 1. making a digital version of all historic data; 2. providing a re-assessment of stream water-quality in the study area; and 3. evaluating the impact of dams constructed following the initial study.

Re-visiting all 47 of the original study sites where the complete suite of historic chemical and biological sampling took place would have been ideal (i.e. 35 original plus 12 supplemental sites). However, financial limitations of the project required a greatly reduced scope in terms of the number of sites to sample for the current effort. The 11 sites included in the current effort (Fig. 1.1, Table 1.2) were selected to be representative of the types included in the historic effort (to the extent possible): urbanizing (could include any of the sites but especially: I3A, V2, V4, III6); up-stream (I3A, II11) v. down-stream (I3, I11) of impoundments; small (I1) v. large watersheds (III6); nested watersheds (the Neshaminy sites: I1, I3, II1, II7, and III6); a control (i.e. minimally impacted) site (V1).

Along with a greatly reduced number of sites was a modified list of study parameters for the current monitoring effort (Table 1.1). The list of chemical and biological parameters under the current sampling period category in Table 1.1 was meant to satisfy the primary study objectives with the followoing caveats: (i) examining changes in water quality hinged on re-sampling as many of the historical parameters as possible, especially the biological ones; and (ii) adding to the baseline of information required selecting new, cutting-edge parameters such as the class of organic compounds commonly referred to as molecular tracers (i.e. PAHs, Caffeine, etc) and C & N isotopes.

Watershed Characteristic Data

Landscape Data

Study site locations and watershed delineations. All historic study sites were located using latitude and longitude coordinates provided in the original data reports (Table 1 in the Appendix of Broadfoot et al. 1969; and Table 2 in the Appendix of Mankelwicz et al. 1972). Site description information contained in the two aforementioned tables was used to verify latitude and longitude coordinate locations. There were two stations (III7 and II16), established in 1970 as part of the supplemental synoptic monitoring work, whose coordinates did not match the site location description provided in the original data reports. In both cases, the site description was used as the final location. Neither of these sites was part of the current sampling effort.

An existing, state-wide, watershed boundary layer (available at www.pasda.psu.edu; ERRI – small watersheds) was modified via on-screen digitizing to properly define the mouth of a watershed relative to a study site location. On-screen digitizing was accomplished using USGS 1:24,000 topographic maps at scales between 1:3000 to 1:6000. The watershed delineation work along with all other GIS work was carried out using ArcMap™ (version 9.1, ESRI, Inc., Redlands, CA).

Land cover. PAMAP rasterized land-cover data (30m pixels) corresponding to 2005 was obtained from the Pennsylvania Spatial Data Access (PASDA) website (www.pasda.psu.edu). These land use/cover data were created from a mix of remotely sensed data and other ancillary data layers. The satellite data actually covered the period of 2003-2007 and were used primarily to identify forest, row crop, and pasture land uses/covers. Water and wetlands came directly from the National Wetlands Inventory (NWI) wetlands layer. Roads that were detectable using satellite imagery were combined with road width data from the PA Department of Transportation (PennDOT) to define all roads with a width greater than 20 ft. Other urban areas, including airports were visually interpreted from USDA National Agriculture Imagery Program (NAIP) imagery at a minimum mapping unit of 5 acres (~20,000 m^2) Land use/cover classification was based on the Anderson Land Use/Land Cover system (Anderson et al. 1976).

Urban/suburban land use/cover, beyond the specific categories of roads and airports described in the previous paragraph, was separated into 3 levels of impervious cover within residential land use and industrial/commercial land use. These 3 levels of impervious cover, 5-30%, 31-74%, and >74%, where further subdivided into 3 sublevels based on the type of forest cover occurring within the defined impervious cover mapping area: deciduous, coniferous, and mixed. A reduced set of urban/suburban land cover categories was created by collapsing across the 3 levels of impervious cover; i.e. all urban land uses/cover within the 5-30% (low), 31-74% (mid), and >74% (high) impervious cover levels.

Population and road density. Population density was compiled from both the 1970 and 2000 Census data using census tracts, the smallest population units available in both time periods, within each county in the study area. The Census tract boundary and population data were downloaded as GIS data layers by county (Bucks and Montgomery) from National Historical Geographic Information System (NHGIS) website (www.nhgis.org). The fraction of the census-tract area falling within a given watershed was multiplied by the total population count for that census tract, summed for all census tracts within a delineated area, and then divided by that area to estimate scale-specific population densities.

Road densities were quantified from digitized 2009 PennDOT state-owned and maintained public roads and a separate layer of 2009 locally owned and maintained roads. These road data layers are available through the PASDA website. Road data layers were intersected with the watershed boundaries for all study sites and the lengths of roads in each watershed were summed and divided by watershed area to derive road densities.

Point-source locations. Two separate PA Department of Environmental Protection (PADEP) GIS data layers, published in 2007, were used to compile numbers of permitted wastewater treatment plants (WWTP) within each study watershed. The Water Resources layer contains facility information related to PADEP's Water Use Planning Program and was used to compile numbers of standard WWTPs. The second layer, Water Pollution Control Facility, contains facility information corresponding to PADEP's Water Pollution Control Program. This second layer provided location information for industrial WWTPs. Both GIS data layers were downloaded from the PASDA website.

Bedrock Geology. Geology for the study area was summarized using a digital version of a state-wide bedrock geology map originally published by (Berg et al. 1980). The GIS data layer was downloaded from the PA Geological Survey website (http://www.dcnr.state.pa.us/topogeo/gismaps/geomaps.aspx). Geographic locations of the geologic formations found within the current study area are shown in Fig. 1.3. Additional information on those specific formations, taken from the attribute table of the original GIS data layer, is provided in Table 1.1.

Landscape data relationships.

Principal Components Analysis (PCA) was used to investigate whether any primary land-cover gradients existed among the 11 current study sites. The study sites were not selected to be representative of landscape conditions across Bucks County. However, it is still instructive to determine whether or not the study sites can be separated based on similar landscape conditions. Therefore, this analysis is meant only to assess whether any general landscape gradients exist across the study watersheds. The analysis is not meant to assign any defined land use/cover gradients to the entire county. All land use/cover variables were arcsine square root transformed. Population densities, road densities, and watershed area were all log transformed prior to being included in the PCA. The numbers of standard and industrial WWTPs were normalized for watershed size by dividing by watershed area and then were log-transformed with 0.001 added to avoid taking the log of zero.

Hydrology data

A total of 6 US Geological Survey (USGS) streamflow monitoring sites were selected to represent hydrologic conditions within the study area (Fig. 1.2, Table 1.5). Two of these USGS sites (Tohickon Cr nr Pipersville and Neshaminy Cr nr Langhorne) had the necessary period of record to compare current to historic conditions. The remaining 4 sites were used to add to the current hydrologic condition description. Daily mean discharge data for the 6 sites was downloaded from the USGS website (waterdata.usgs.gov).

Hydrologic summaries were made on a weekly and annual basis for the 1967-71 and 2007-08 water years (October to September). Defining the annual period to be from October of one year to September of the following year is done to minimize changes in water storage (i.e. primarily realized as changes in groundwater levels) between successive years. In this geographic region, changes in waters storage tend to be at a minimum in the fall because of seasonally low precipitation and a lack of any snowpack. The daily mean discharge data, in ft^3/s, were converted to cm^3/cm^2, or simply cm, for the given time interval, by dividing by watershed area and then converting seconds to days and finally summing over the desired time interval (week or water year).

The current sampling effort was meant to be carried out under baseflow conditions. While instantaneous flow was sporadically measured during the historic sampling effort, there is no indication of whether stream flows were stable or changing while the historic sampling took place. The daily mean discharge data at the 6 USGS sites previously mentioned were used to provide some indication of the hydrologic conditions at the time of both historic and current sampling. Changing flow conditions (e.g. storm flow) were determined by comparing discharge for a given date to the discharge of the previous day and the following day. Any daily discharge value that was greater than either the previous day or the following day was identified as a peak discharge. A discharge cutoff value was selected such that any peak discharge occurring within a single ‘storm’ hydrograph that was above the selected cutoff value was deemed a storm peak discharge with the coinciding ‘storm’ hydrograph then considered an actual storm. The cutoff value was arbitrarily set at 0.03 $m^3/km^2/d$ for all sites based on examining a handful of hydrographs for each USGS site. ‘Storm’ hydrographs were defined as starting 2 days prior to a peak discharge value and ending 3 days following that peak discharge. Study sites were assigned to a particular USGS site based on location and time period; these assignments are provided in Table 1.6.

Watershed Characteristic Relationships

Landscape Data

The study region, reflecting the larger geographic character of Bucks County and areas around the city of Philadelphia, is a densely populated, urban/suburban environment. The watershed characteristic data for the 11 current study sites (Table 1.3) reflect this urban/suburban character. Only 1 site (V1) has a 2000 population density < 100 people/km^2. In fact, of the 116 historic monitoring sites, only 20 (17%) have 2000 population densities < 100 people/km^2 and only 1 site has a value < 50 people/km^2 (data not shown). The site with the lowest 2000 population density also had the highest % forest cover of the 11 current study sites and was the only one of the current sites with > 50% forest cover. Broadening the scope to include all 116 historic sites results in only 23 sites (20%) having >50% forest cover, with only 6 having > 75% forest cover.

The majority of permitted WWTPs are located in the Neshaminy Creek watershed; only 2 such sites are found in the Tohickon Creek watershed. Only the 3 most eastern watersheds, V1, V2, and V4 do not have any WWTP facilities within their respective watershed boundaries (Table 1.3). While WWTP information is available in one of the original water quality monitoring reports (Table 2 in the Appendix of Broadfoot et al. 1969) no exact location information was given (i.e. latitude/longitude coordinates) to match up the current and historic WWTP information. The majority of the current WWTP are municipal facilities. Based on the facility names provided, the historic facilities were a mix of municipal and school-owned WWTPs.

The study region corresponding to the current sampling effort can effectively be split into north v. south sub-regions in terms of bedrock geology (Fig. 1.3, Table 1.4). The northern portion of the study region, which contains the Tohickon and Tinicum Cr. watersheds, is dominated by 2 formations: Diabase and Brunswick. Diabase is the only formation in the current study region belonging to the younger Jurassic period and is an igneous rock. Brunswick is comprised of mudstone, siltstone and shale. The Tinicum Cr watershed also contains a fair portion of the Lockatong Formation which can contain some limestone. The southern portion of the study region, which primarily encompasses the Neshaminy Cr. watershed is generally dominated by the Stockton Formation (sandstone/siltstone/mudstone) and the Lockatong Formation. The L Neshaminy Cr watershed (II7) and the lower part of the Neshaminy Cr watershed (III6) are where the Stockton Formation is primarily found. The W. Br. Neshaminy Cr. watershed (II1) on the western edge of the study region and Pidcock Cr watershed (V2) on the eastern edge are both dominated by the Brunswick Formation.

The PCA using the 11 current study sites did successfully separate sites into definable watershed characteristic categories (Fig. 1.4). Axis 1 of the PCA, which explained 51% of the variability in watershed characteristics between sites, plotted the sites along a gradient of forested/agriculture/suburban areas to urban areas. Axis 2 explained only 15% of the variability between sites and roughly defines an agriculture to wetland gradient among the study sites. The site that plotted the furthest to left of this axis, or in the forested/agriculture/suburban end of the gradient, was Tinicum Cr. (V1). This plot position supports the designation of Tinicum Cr as the least disturbed 'control' site within the group of 11 study sites, within a land use/cover framework. At the urban end of this gradient defined by axis 1 were the W. Br. Neshaminy and Little Neshaminy Creeks. Perhaps somewhat coincidentally, the site groupings within this PCA loosely corresponded to their original site designations.

Hydrology Data

Based on the two USGS sites that have data spanning both study periods, the historic period was drier than the current period (Table 1.5). Although not statistically significant, due most likely to the small sample size (i.e. n=5 for the historic period, n=2 for the current), the historic period had approximately 8% less annual discharge relative to the current period. Within the current sampling period, the watershed area-normalized mean annual discharge for five of the six USGS sites did not vary greatly with values between 50 cm to 67 cm. In stark contrast, the mean annual value for NB Neshaminy Cr below Lake Galena site of 93 cm was more than a third greater than the next highest mean-annual value of 67 cm. This large difference in mean-annual discharge is likely due to inter-basin transfers of water into the NB Neshaminy Cr. There is a WWTP facilities located within this watershed upstream of Lake Galena. It is quite possible that this municipal facility serves a geographic area much larger than the watershed it is located within and therefore has effluent volumes that greatly augment streamflow in the NB Neshaminy Cr.

The relative distribution of flow at each of the two USGS sites between the two time periods was compared by examining historical annual-mean weekly-summed flow values v. current weekly-summed flow values (Fig. 1.5). The same period of historic annual-mean weekly flows was plotted against the individual 2007 and 2008 weekly flows in Fig. 1.5. Relative to the mean historical values, the beginning of 2007 was wetter (i.e. more discharge) with a more dynamic hydrograph (i.e. flashier). However, by the end of the 2007 water year, in the summer months, streamflow volume was much less and the hydrograph dramatically less flashy relative to the mean values for the 1967-71 period. These drier conditions seemed to extend into the 2008 water year where weekly flows were generally lower than those in 2007 and more similar to the historical mean flows. The difference in mean annual flows (Table 1.5) would therefore seem to be driven by the wetter conditions at the start of the current study period.

Within the current sampling period, weekly streamflow was rather consistent in terms of both watershed area-normalized volume and flashiness for the three USGS sites located within the Neshaminy Cr watershed (Fig. 1., lower panel) and also the Tohickon Cr near Pipersville site (Fig. 1.6, upper panel). In contrast, the weekly flows for the NB Neshaminy Cr. below Lake Galena site were very different from the other sites in terms of volume and flashiness. This difference in weekly flows at the NB Neshaminy Cr site reinforces the idea of inter-basin transfers due to WWTP operation within this watershed. Discharge at this site was consistently elevated with a much less dynamic hydrograph suggesting a constant and large input of water to the stream.

A general picture of hydrologic conditions prior to and during the sampling effort is provided for both the historic (Fig. 1.5) and current (Figs. 1.5, 1.6) sampling periods. As previously stated, no mention was made in the historical water-quality monitoring reports in regard to sampling under specified hydrologic conditions. Historic sample timing relative to the mean-annual weekly flows bears this out given that sampling was done throughout the year under varying hydrologic conditions. Only the phytoplankton sampling seemed to be carried out at a specific time of year: summer months. The greatly reduced sampling effort conducted during the 2007/08 period allowed for a much more targeted approach to sampling under specified hydrologic conditions. The current phytoplankton sampling effort as well as the initial chemistry sampling effort were conducted during the rather dry and hydrologically stable summer months of 2007. The second chemistry sampling effort, however, took place in February under much more dynamic streamflow. In fact, the research technicians conducting the sampling observed that the elevated flows (based on elevated turbidity in the streams) at the time of the February 2008 sampling effort was likely due to snow melt.

The attempt at characterizing stream flow dynamics at the time of both historic and current sampling efforts supports the idea that at least a portion of the chemistry and macroinvertebrate samples in both time periods were collected under changing flow conditions (Table 1.6). For historic chemistry samples, 37 of the 165 collected samples (16%) may have been collected during variable or changing stream flow. During the current sampling effort, 7 of the 13 chemistry samples collected may have been collected under variable flow conditions. For macroinvertebrates, 25 of the 109 (19%) historic samples and 2 of the 14 (15%) current samples may have been collected under variable flow conditions. It should be noted that collecting macroinvertebrates under varying flow conditions, assuming those flows are not too extreme, would affect the actual sampling effort but should not really effect what is being sampled.

Literature Cited

Anderson, J. R., E. E. Hardy, J. T. Roach, and R. E. Witmer. 1976. A land use and land cover classification system for use with remote sensor data. Professional paper 964, U.S. Geological Survey, Washington, D.C.

Berg, T. M., W. E. Edmunds, A. R. Geyer, and others. 1980. Geologic map of Pennsylvania, 4th ser., Map 1, 2nd ed. 3 sheets, scale 1:250,000. Pennsylvania Geological Survey.

Broadfoot, D. W., J. C. Mertz and J. R. Powell, Jr. 1969. Water Quality Monitoring Project: Year End Report June 1969. A report to the Natural Resources Division, Bucks County Planning Commission, PA.

Mankelwicz, J. M., D.W. Broadfoot, B.E. Conroy, and J. C. Mertz.1972. Water Quality Monitoring Project: Supplemental Report III (Data Update 1972). A report to the Natural Resources Division, Bucks County Planning Commission, PA.

Table 1.1. Comparison of directly sampled components plus derived parameters between the historic (1967-71) and current (2007-08) study periods. Specific to the current sampling work and in the interest of space, acronyms or abbreviations were used. Refer to the appropriate chapter for more specific information on any of the currently-sampled parameters.

Parameter categories	Sampling Period	
	Historic	Current
Chemical		
Cations	Hardness (as a proxy for Ca^{2+} & Mg^{2+})	Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}
Anions	$SO4^{2+}$, Cl^{-}, NO_3^{-}, NO_2^{-}, PO_4^{3-}, Alkalinity	$SO4^{2+}$, Cl^{-}, NO_3^{-}, PO_4^{3-}, Alkalinity
Nutients		TKN, SKN, TP, TDP, PP, TDN, TN, DNP
Suspended solids	Turbidity, Total Dissolved Solids (TDS)	Total suspended solids (TSS)
Other (primarily in-situ)	pH, Conductivity, DO, Biochemical Oxygen Demand (BOD), Odor, Color, CO_2, Stream temperature	pH, Conductivity, DO, Stream temperature,
Organic Matter		Dissolved Organic Carbon (DOC), Biological DOC (BDOC), Particulate Organic Carbon (POC)
Organic Compounds	Alkyl Benzyl Sulfonates	Poly-Chlorinated Biphenyls (PCB; n=3), Polycyclic Aromatic Hydrocarbons (PAH; n=12), Fecal Steroids (n=10), Pesticides (n=3), Caffeine, Fragrance material (n=2)
C & N Isotopes		^{13}C, ^{15}N; %C & %N
Biological		
Bacterial	Coliform bacteria	*E. coli* & Total Coliform
Macro-invertebrates	Quantitative sampling, family-level ids	Quantitative sampling, genus/species-level ids,
Periphyton	qualitative survey to id taxa	qualitative survey to id taxa; chlorophyll, total organic matter
Phytoplankton	qualitative survey to id taxa	qualitative survey to id taxa; chlorophyll, total organic matter
Macrophytes	qualitative survey; genus/species-level ids	qualitative survey; species-level ids
Fish	quantitative sampling, species-level ids.	

Table 1.2. Stream sites (arranged approximately north to south) sampled in 1967-71 and 2007-08. The notes highlight whether or not a proposed dam was actually constructed.

Site [1]	Stream Name	Latitude	Longitude	Notes
V1	Tinicum Cr	40.4756	-75.1000	
II11	Upper Tohickon Cr	40.4547	-75.2797	
I11	Lower Tohickon Cr	40.4631	-75.1744	Dam completed in 1973
V4	Paunnacussing Cr	40.3925	-75.0575	
V2	Pidcock Cr	40.3294	-74.9378	
I1	County Line Cr	40.2956	-75.2797	Dam not constructed
II1	W. Br. Neshaminy Cr	40.2761	-75.2475	
I3A	Upper N. Br. Neshaminy Cr	40.3597	-75.1481	
I3	Lower N. Br. Neshaminy Cr	40.305	-75.2119	Dam completed in 1973
II7	Little Neshaminy Cr	40.2389	-75.0611	
III6	Neshaminy Cr [2]	40.1742	-74.9575	

[1] The roman numeral in the site code defines four of the five study-site categories as defined for the original monitoring program:

I = Below Dam
II = Below Major WWTP outfall
III = Routine Station – tributaries
V = Routine Station - small watersheds

[2] Also referred to as 'Lower Neshaminy Cr' throughout the report.

Table 1.3. Selected watershed characteristic data for the 11 Bucks County study sites. See text for details on how the data were gathered. Site names are provided in Table 1.2 with site locations shown in Fig. 1.2.

Site	Wtsd area (km2)	Pop Density (#/km2)		Impervious Surface (%)		2005 Land use/cover (%) [1]				2007 Road density (m/km2)	nos of WWTP (2007) [2]	
		1970	2000	1985	2000	Urb	Agr	For	Wet		Std	Ind
V1	50.3	35	57	0.12	0.23	8.2	16	69	1.4	2311	0	0
II11	89.2	156	253	3.3	5	19	19	49	3.8	3906	1	1
I11	195	95	155	1.6	2.5	13	15	59	2.5	3141	1	1
V4	17.46	62	201	0.044	0.27	21	38	34	0.5	3089	0	0
V2	32.8	51	107	0.028	0.17	13	37	41	2.1	2555	0	0
I1	7.74	118	219	0.37	0.72	15	29	46	1.8	2731	0	0
II1	46.0	464	721	12	22	54	14	19	0.89	7025	1	1
I3A	16.5	66	162	0.63	1.5	15	39	35	0.54	2907	1	0
I3	48.6	77	156	0.35	1.1	14	34	40	0.92	2629	1	0
II7	103	321	561	8	17	48	14	17	2.4	6852	5	0
III6	539	241	480	4.6	11	40	20	25	2	5816	15	0

[1] Land use/cover percentages do not sum to 100 because not all possible categories are shown.
[2] WWTP – waste water treatement plants as based on PA DEP permitting data; Std = standard plant, Ind = Industrial-related plant.

Table 1.4. Bedrock geologic formations found in the study watersheds. See Fig. 1.3 for the geographic distribution of these formations.

NAME	AGE	LITHOLOGY (Order in Dominance: Primary/Secondary/Other)
Primary Formations (major in area):		
Diabase	Jurassic	Diabase
Brunswick Formation	Triassic	Mudstone/Siltstone/Shale; argillite
Lockatong Formation	Triassic	Argillite/Black shale/Limestone; calcareous shale
Allentown Formation	Cambrian	Dolomite/Limestone/Calcareous siltstone; chert
Stockton Formation	Triassic	Arkosic sandstone/Siltstone/Sandstone; mudstone
Stockton conglomerate	Triassic	Quartz conglomerate/Conglomeratic sandstone
Felsic gneiss	Precambrian	Felsic gneiss
Other Formations (minor in area):		
Beekmantown Group	Ordovician	Limestone/Dolomite/Chert
Cocalico Formation	Ordovician	Shale/Siltstone/Argillaceous sandstone
Felsic to mafic gneiss	Precambrian	Felsic gneiss/Intermediate gneiss/Mafic gneiss
Hardyston Formation	Cambrian	Quartzite/Feldspathic sandstone/Quartz-pebble conglomerate
Leithsville Formation	Cambrian	Dolomite/Shaly dolomite/Chert; shale
Mafic gneiss	Precambrian	Mafic gneiss/Amphibolite/
Metadiabase	Precambrian	Metadiabase
Trenton Gravel	Quaternary	Gravelly sand/Sand/Clay-silt; alluvium; swamp deposits

Table 1.5. Summary of annual discharge (as cm3/cm2 or cm) for USGS sites located within Bucks County. The October-to-September water year was used as the annual period. The 1967-71 period represents the historic sampling period; 2007-08 represents the current sampling period.

USGS Site ID	USGS Site Name	Time period	Water Year Discharge Statistics (cm)	
			Mean	Stderr
1459500	Tohickon Cr nr Pipersville	1967-71	53	6.4
		2007-08	63	5.7
1465500	Neshaminy Cr nr Langhorne	1967-71	48	5.2
		2007-08	57	6.8
1464645	NB Neshaminy Cr bl Lake Galena nr New Britain	2007-08	93	7.1
1464720	NB Neshaminy Cr at Chalfont	2007-08	50	9.4
1464750	Neshaminy Cr nr Rushland	2007-08	59	6.4
1464907	Little Neshaminy Cr at Valley Road nr Neshaminy	2007-08	67	6.9

Table 1.6. Summary of inferred hydrologic conditions at the time of historic (1967-71) and current (2007-08) chemistry, macro-invertebrates, and phytoplankton sampling efforts. Hydrologic conditions are in terms of baseflow (Q_b) versus non-baseflow (non-Q_b). Daily mean discharge data from the listed USGS sites were used to infer stream flow conditions at one or more study sites.

Time Period	USGS site [1]	# sites [2]	# of Samples [3]	
			Q_b	non-Q_b
Chemistry				
1967-71	Neshaminy Cr nr Langhorne	7	107	22
1967-71	Tohickon Cr nr Pipersville	4	31	5
2007-08	NB Neshaminy Cr bl Lake Galena nr New Britain	1	1	1
2007-08	L Neshaminy Cr at Valley Rd nr Neshaminy	1	1	1
2007-08	NB Neshaminy Cr at Chalfont	2	1	1
2007-08	Neshaminy Cr nr Langhorne	1	1	1
2007-08	Tohickon Cr nr Pipersville	6	2	3
Macro-invertebrates				
1967-71	Neshaminy Cr nr Langhorne	7	84	19
1967-71	Tohickon Cr nr Pipersville	4	25	6
2007-08	NB Neshaminy Cr bl Lake Galena nr New Britain	1	2	.
2007-08	L Neshaminy Cr at Valley Rd nr Neshaminy	1	2	.
2007-08	NB Neshaminy Cr at Chalfont	2	2	1
2007-08	Neshaminy Cr nr Langhorne	1	2	.
2007-08	Tohickon Cr nr Pipersville	6	4	1
Phytoplankton				
1967-71	Neshaminy Cr nr Langhorne	7	14	.
1967-71	Tohickon Cr nr Pipersville	4	5	.
2007-08	NB Neshaminy Cr bl Lake Galena nr New Britain	1	.	1
2007-08	L Neshaminy Cr at Valley Rd nr Neshaminy	1	1	.
2007-08	NB Neshaminy Cr at Chalfont	2	1	.
2007-08	Neshaminy Cr nr Langhorne	1	1	.
2007-08	Tohickon Cr nr Pipersville	6	5	.

[1] The USGS site used to represent hydrology for the study site(s).
For the 1967-71 period:
Tohickon Cr nr Pipersville: II11, I11, V1, V4
Neshaminy Cr nr Langhorne: I1, V2, I3, I3A, II1, II7, II6
For the 2007-08 period:
Tohickon Cr nr Pipersville: II11, I11, V1, V2, V4, I3A
NB Neshaminy Cr bl Lake Galena: I3
L Neshaminy Cr at Valley Rd: II7
NB Neshaminy Cr at Chalfont: I1, II1
Neshaminy Cr nr Langhorne: III6

[2]. Number of study sites represented by a particular USGS site based on the above assignments.

[3]. Number of samples collected under baseflow (Q_b) v. non-baseflow (non-Q_b) conditions.

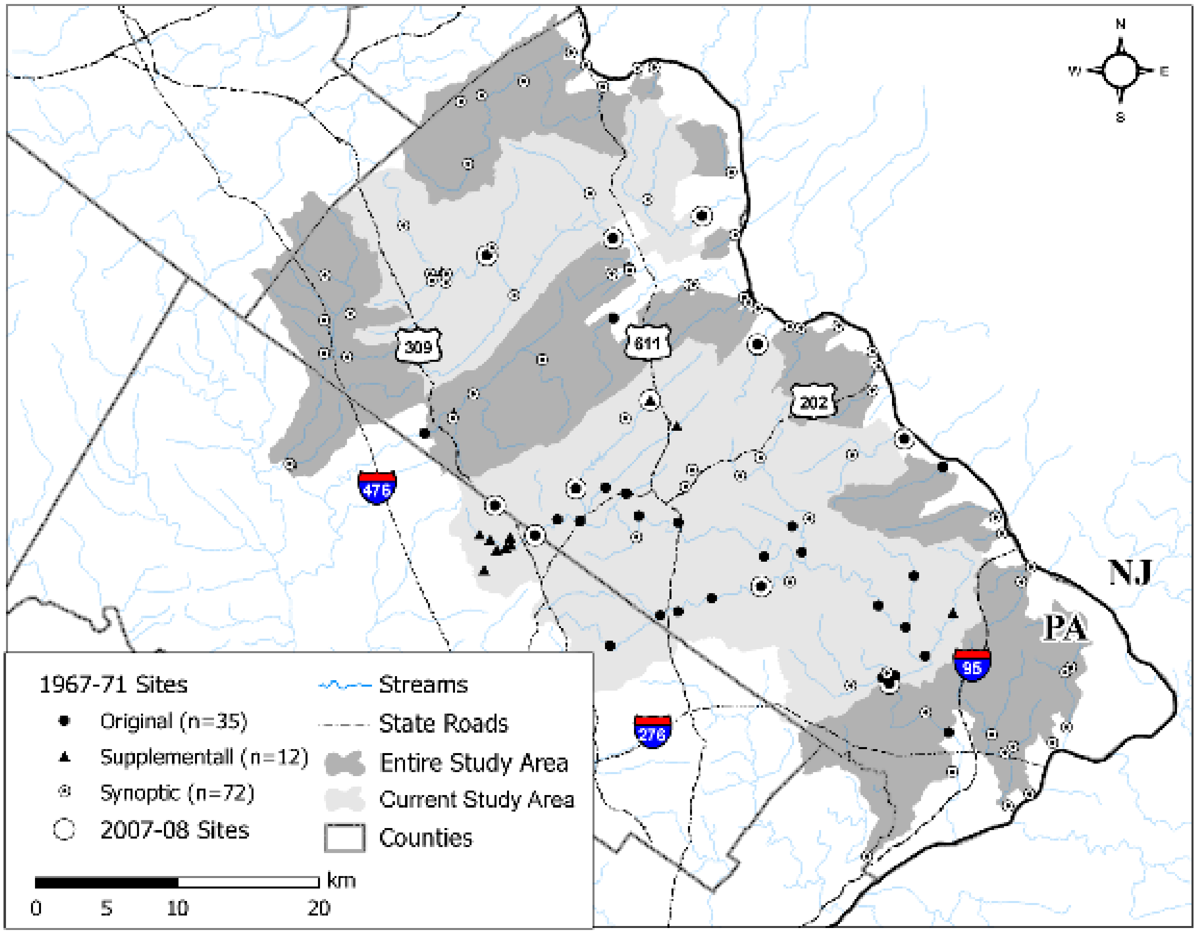


Figure 1.1. Locations of all original study sites (i.e. sampled in 1967-71) with those that were also sampled during the 2007-08 study period shown as large circles with black dots or triangles in the middle.

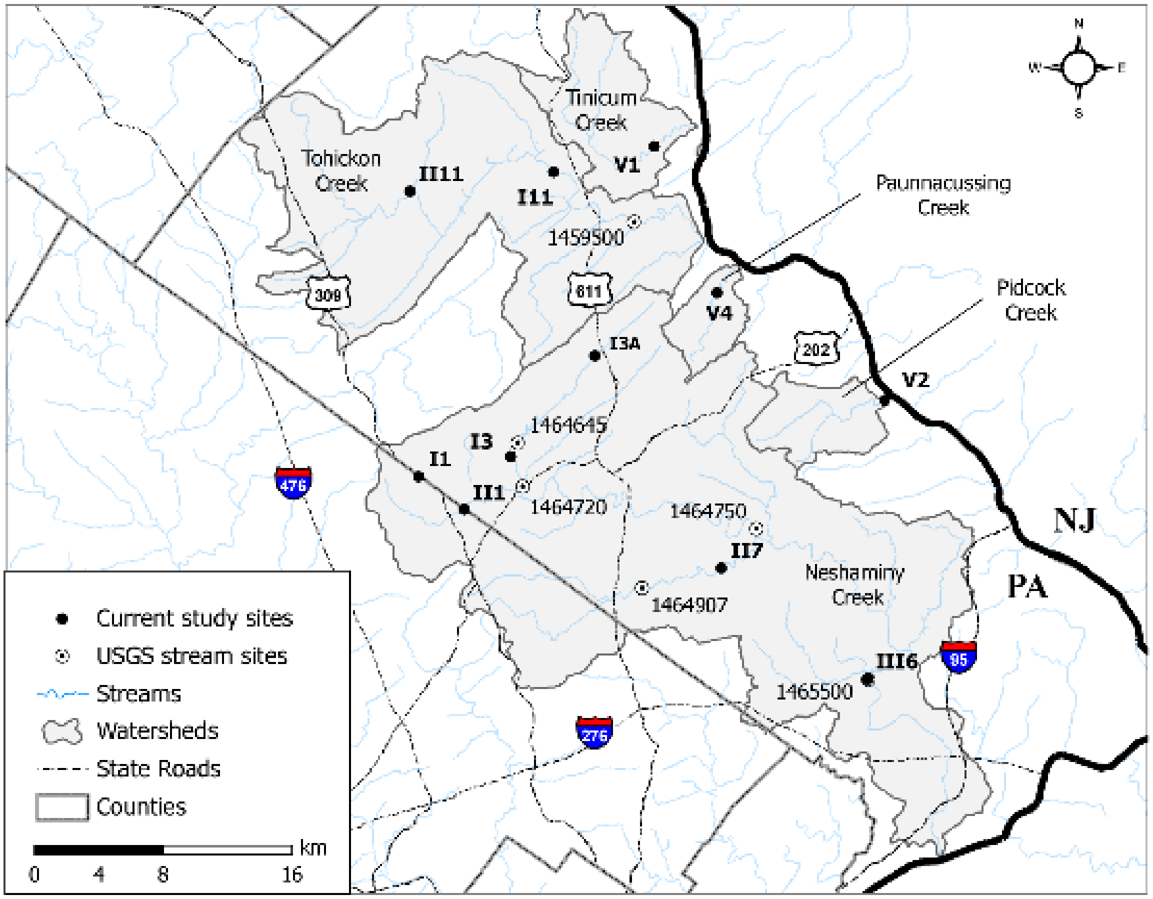


Figure 1.2. Locations of the current (2007-08) Bucks County study sites along with USGS gauging sites used in the hydrologic conditions summary.

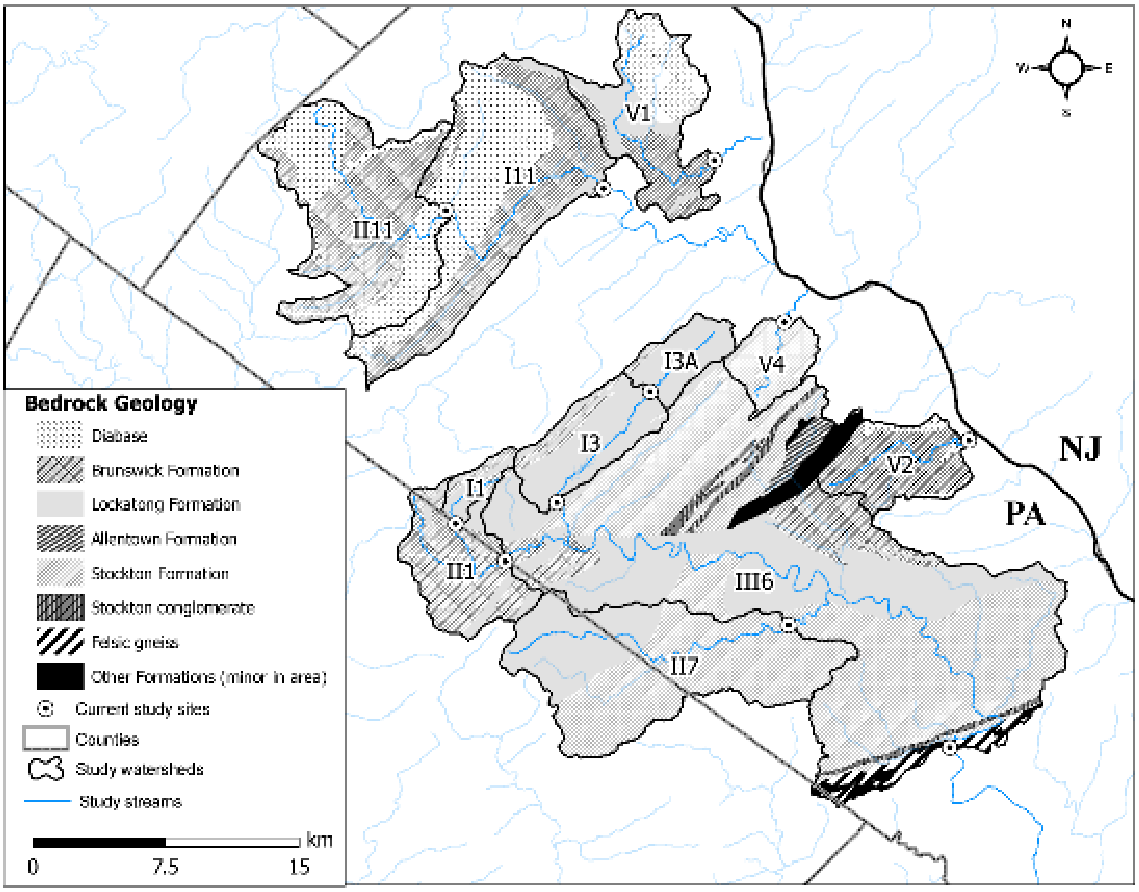


Figure 1.3. Bedrock Geology within the study (2007-08) watersheds. See Table 1.4 for more detail regarding the formations shown in this figure.

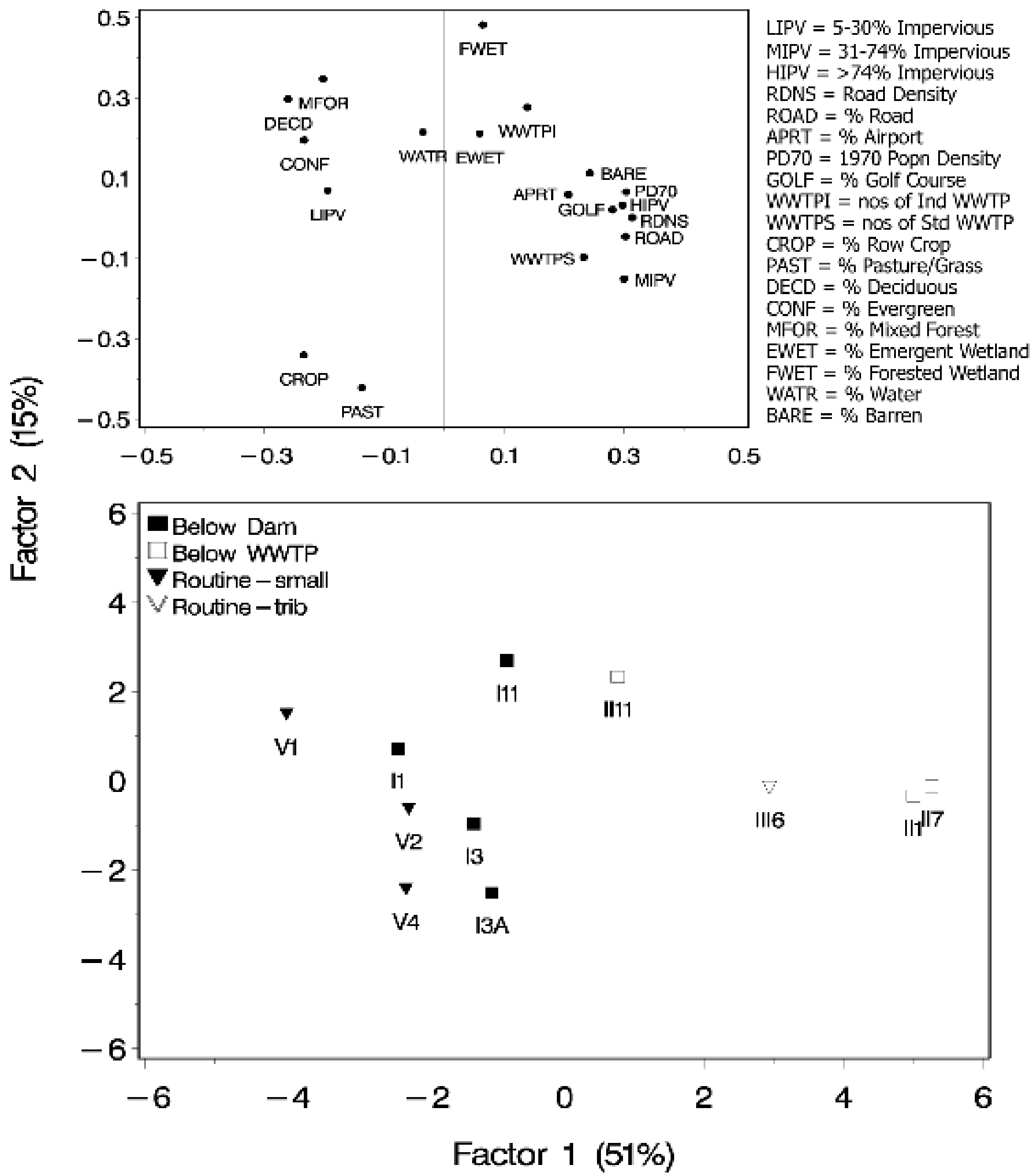


Figure 1.4. Principal Components Analysis (PCA) of 2005 land use, population, road density, and wastewater treatment plant data for the current study site watersheds. Factor loadings are provided in the top plot with scores shown in the bottom plot; percentage of variation explained by each PCA axis is provided in the axes labels. See Table 1.4 for site names corresponding to site ids provided in the bottom plot. See text for further explanation of watershed characteristic variables.

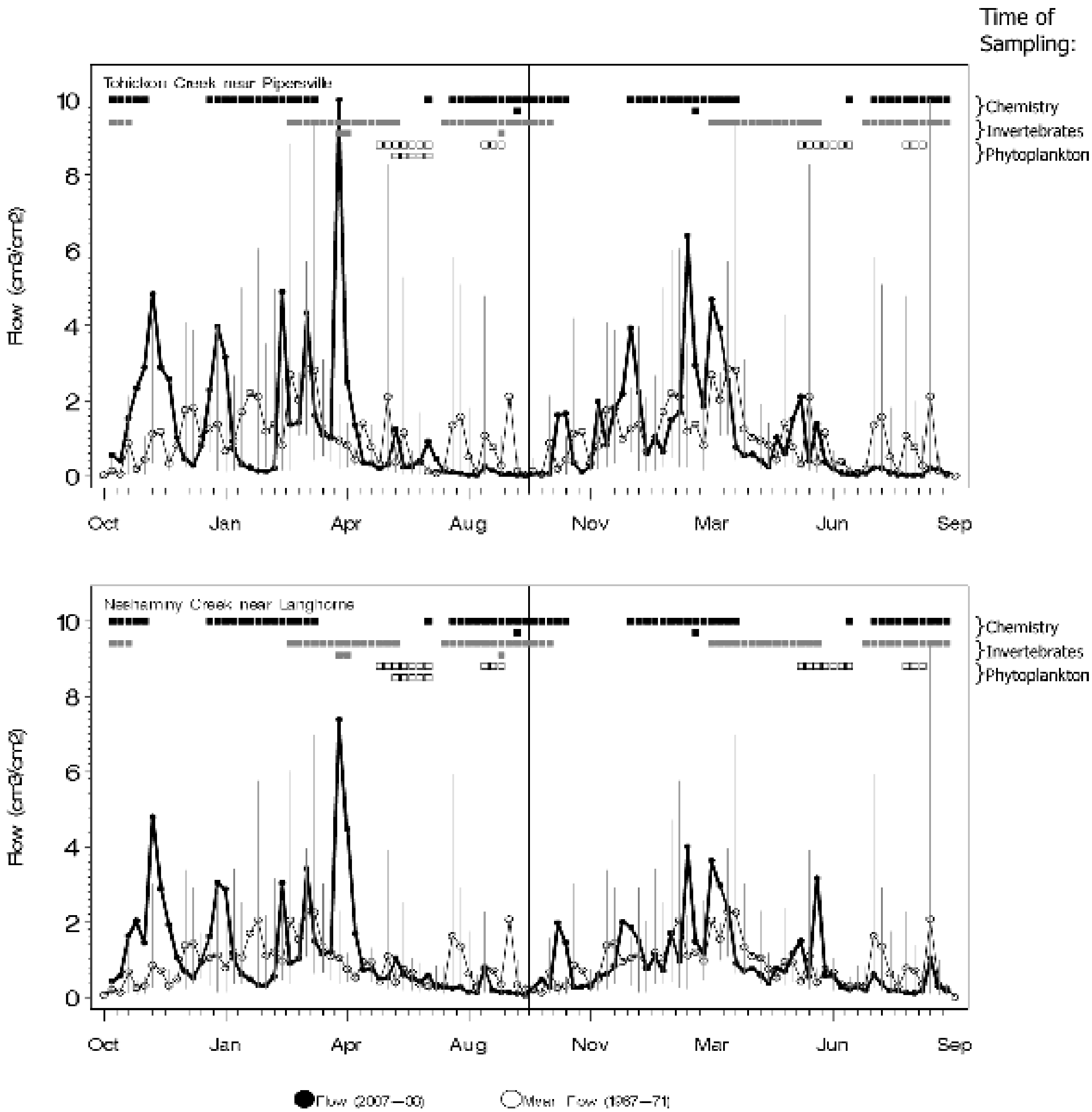
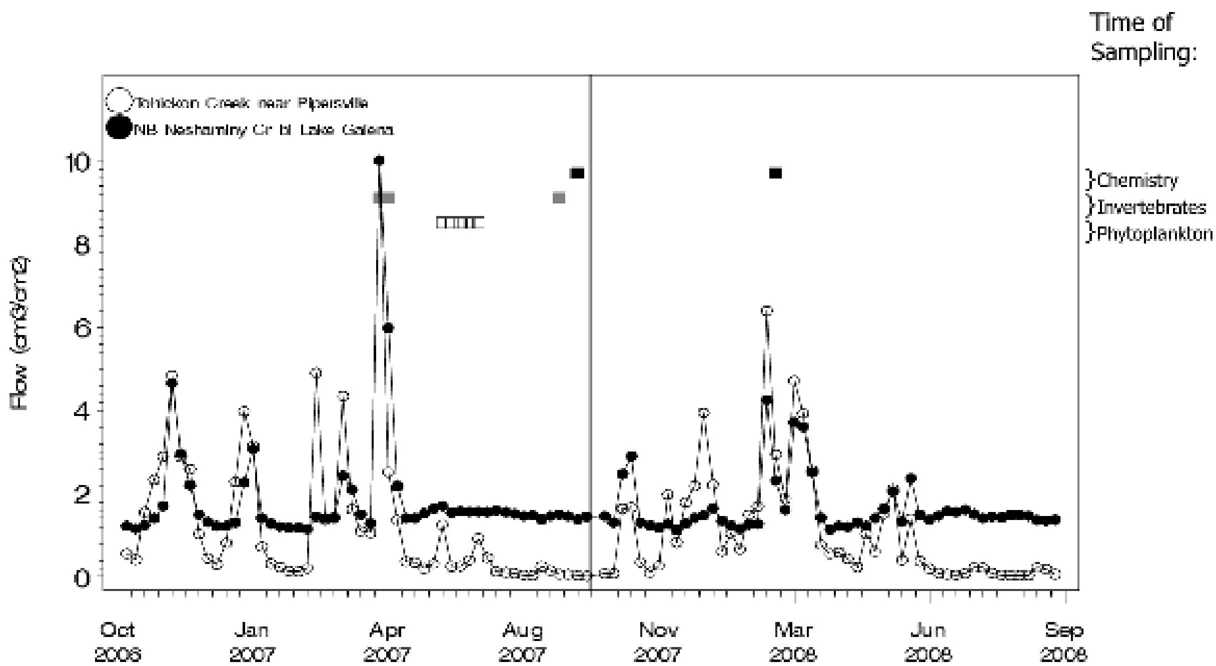


Figure 1.5. Comparison of hydrologic conditions between the historic (1967-71) and current (2007-08) sampling periods using the Oct-Sept water year over a 2-year time span. The two USGS sites were the only two having the necessary period of record for the historic v. current comparison. USGS daily mean discharge data were converted to units of cm^3/cm^2 (i.e. normalizing discharge by dividing flow rate by watershed area) and summed over a weekly time step. Current discharge data plotted above are for the period of October 2007 to September 2008. Historic weekly discharge data, as annual averages from the 5-year 1967-71 water-year period, are repeated for each of the 2 annual periods in the plot. The vertical lines for the mean historic values represent the range in weekly discharge values for each mean. Weekly sampling periods for chemistry, invertebrates and phytoplankton are provided at the top of each plot. The historic sampling effort data (first row of each group; data groups are contained with the separate brackets) are repeated for each of the 2 annual periods; the current sampling effort (second row of each group) spans the entire 2007-08 period.



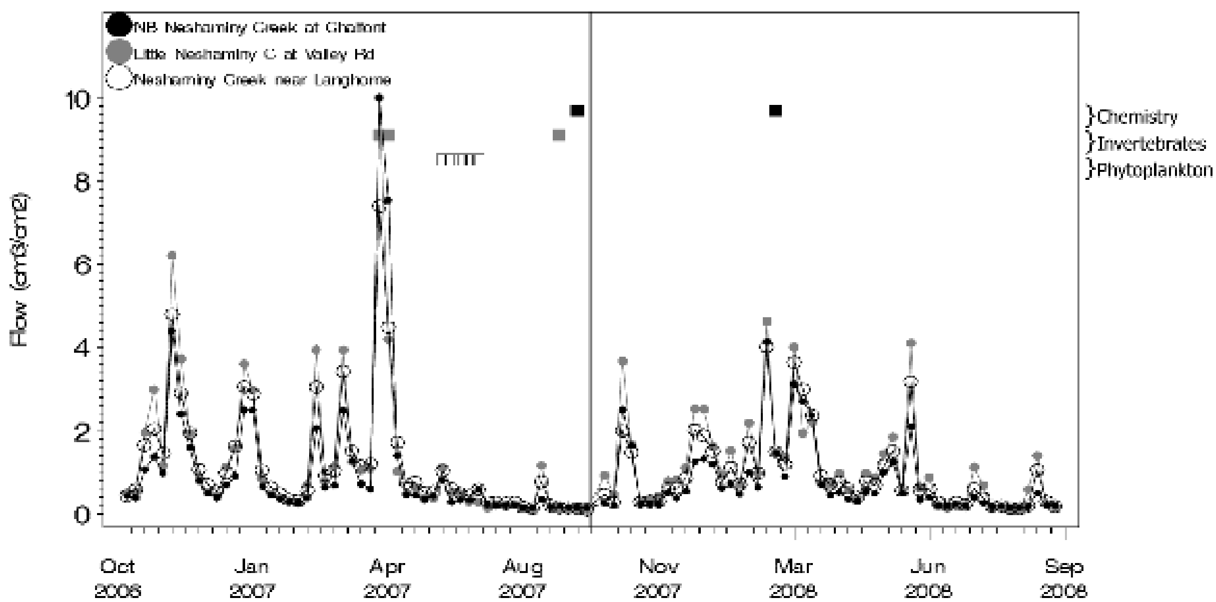


Figure 1.6. Comparison of hydrologic conditions among 5 USGS sites within the current (2007-08) sampling period using the Oct-Sept water year over a 2-year time span. USGS daily mean discharge data were converted to units of cm^3/cm^2 (i.e. normalizing discharge by dividing flow rate by watershed area) and summed over a weekly time step. The top plot contains USGS sites below reservoirs; the bottom plot contains the remaining 3 USGS sites all within the Neshaminy Creek watershed. Current weekly sampling periods for chemistry, invertebrates and phytoplankton are provided at the top of each plot.

Chapter 2. Stream Water Chemistry – Inorganic/Organic/Isotope

Overview

Stream water chemistry reflects processes on the Earth's surface based on the distribution of atoms, isotopes and molecules derived from the geological environment of a watershed and modified by biological systems within a landscape. Dissolved solutes, along with light, temperature and water velocity, form the foundation of the environment within which aquatic organisms live and can be altered through the contributions by man through point and non-point sources. Availability of bioactive elements – carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), and sulfur (S) and many trace elements, from whatever source – constrains the growth of organisms. Conversely, changes in concentrations of bioactive elements can reflect the net growth in biological communities though any natural and anthropogenic compounds can have toxic and other negative effects on aquatic biota. Toxicity may be a function of the overall chemical environment (i.e., pH controls heavy metal solubility, speciation and overall bioavailability), and the transport of toxic substances is affected by other, non-toxic species (i.e., heavy metals and organic pollutants are often chelated by natural organic matter or sequestered by sediments). Studies of the interaction between biology and geology via observations of chemical species are commonly referred to as biogeochemistry.

Understanding how, when and where bioactive elements and compounds move through an ecosystem is fundamental to understanding ecosystem function and in this section, we use water chemistry to describe the chemical setting of water sampled from 11 streams in Bucks County. Grab samples for chemical analyses represent a snap shot of water quality rather than a comprehensive view of stream health that is obtained from analyses of biological samples that integrate water quality over the life time of an organism. Nevertheless, these analyses are informative as they provide a background for the biological components of our study and a view of changes in stream health when compared to water chemistry performed at a different time.

The concentrations of several analytes measured in1968-1971 at the 11 streams were measured again in 2007-2008 including conductivity, alkalinity, pH, nitrate, nitrite, phosphate, chloride, calcium, and sulfate. Additional measurements in 2007-2008 included magnesium, sodium, potassium, ammonium, total kjeldahl nitrogen, suspended kjeldahl nitrogen, total dissolved nitrogen, particulate nitrogen, total phosphorus, particulate phosphorus, total dissolved phosphorus, total suspended solids, particulate organic carbon (POC) and nitrogen (PON) and the isotopic values of the POC and PON, dissolved organic carbon (DOC), and biodegradable dissolved organic carbon (BDOC). The comparison of water chemistry parameters from 1968-1971 and 2007-2008 were done to assess whether the intervening Clean Water Act had any measurable influence on water quality in the Bucks County streams.

Methods

The historic chemical analyses from 1968-1971 were performed either in the field with portable meters (pH, conductivity, DO, T) and a Hach model DR-EL Direct Reading Portable Engineer Laboratory (phosphate, nitrate, and nitrite) or in the laboratory as outlined by Standard

Methods for the Analysis of Water and Wastewater. The 2007-2008 data were generated in the field with portable hand-held meters (pH, conductivity, T, DO), or on samples collected in the field and brought back to the Stroud Water Research Center for processing and analyses.

The Stroud Water Research Center biogeochemistry team surveyed physical and chemical parameters within the Bucks County streams twice, once during cold weather (winter) and once during warm weather (late summer or early fall) under baseflow conditions. However, stream discharge in several of the sites was impacted in the winter by snowmelt. The field measures included temperature, dissolved oxygen, pH, and conductivity. Water samples were also collected for the following laboratory analyses: major anions and cations; nutrients; dissolved organic carbon (DOC) and biodegradable dissolved organic carbon (BDOC). Samples for chemical analyses were collected as grab samples in pre-cleaned labware, which involved standing in the stream facing into the current, submerging the sample bottle upstream, rinsing the bottle with stream water, and then collecting the water and closing the bottle. Where possible, samples were collected from the thalweg or zone of maximum velocity to obtain a well mixed sample. Where the water was too deep to safely stand in the thalweg, samples were taken closer to the stream bank. All samples were placed on ice in a cooler and transported back to the Stroud Water Research Center for further processing.

At the Stroud Water Research Center, samples were processed and analyzed using predefined and tested standard operating procedures. Samples for anion and cation determinations were filtered through 0.22 µm syringe type filters (Millipore MillexGP) and analyzed by ion chromatography with conductivity detection (Dionex ICS 3000). Samples for DOC and BDOC analyses were filtered through ~0.7 µm glass fiber filters (Whatman GF/F) and dispensed into 40 ml borosilicate vials. DOC samples were analyzed immediately with an Inonics Sievers 800 or 900 TOC analyzer equipped with an inorganic carbon removal module. The filtered BDOC samples were amended with a nutrient salts solution, half of the samples were analyzed immediately and the other half were capped and sealed with Teflon–lined silicone septa to prevent organic carbon exchange with the atmosphere, and incubated at ~25ºC in the dark for 1 month. At the end of 1 month, the samples were filtered through GF/F filters and analyzed for DOC. BDOC concentrations were calculated as the difference between the initial DOC concentrations and the final DOC concentrations in the BDOC vials. Unfiltered samples were sent to the Academy of Natural Sciences of Philadelphia for sample digestion and analyses of total Kjehldahl nitrogen, particulate phosphorus, and dissolved organic phosphorus using continuous flow analysis with colorimetric detection. The stable isotope composition of TSS was analyzed by automated elemental analysis (EA) coupled via a continuous flow interface to a Finnigan DeltaPlus XP Isotope Ratio Mass Spectrometer (IRMS). All isotope values are provided using the lower-case delta (δ) scale in units of per mil (‰) relative to Vienna PeeDee Belemnite (VPDB) for carbon and relative to air for nitrogen.

The sampling frequencies of the initial historic sampling effort (i.e. not including the synoptic survey effort conducted towards the end of the historic study period) were very different from the current sampling frequency of sampling once during the fall season and once during winter months. To reconcile the two sampling schemes, historic data values were selected if sampling occurred during separate 3-month periods centered on the two months corresponding to the current sampling effort (i.e. September and February). Mean values were then calculated for each 3-month period (n=1 to 19 depending upon site, 3-month period, and analyte). An exception to this treatment of historic data had to be made for the Upper N. Br. Neshaminy site. This site was one of the ‘supplemental’ sites added after the first year or two of the historic monitoring effort (see Chapter 1 for more detail). Samples were only collected during summer months at this site, requiring samples collected in July to be included in the mean ‘fall’ value. Fall samples only included samples collected during August, September, and October for the other historic sites. No winter samples were collected at the Upper N. Br. Neshaminy site site over the historic study period.

A slightly modified treatment of the data from that just described was made in comparing historic and current stream chemistry to changes in watershed condition as represented by the change in population from 1970 to 2000. As noted above, the February 2008 sampling effort was potentially impacted by snowmelt at several stream sites. In addition, no winter sampling took place historically at the Upper N. Br. Neshaminy Creek (I3A) site. This lead to using only ‘fall’ values in order to eliminate as much variability in the water quality data between the two sampling periods as possible. The September 2007 current water quality data were compared to the mean of values sampled between August and December for the 1967-71 period. Linear regression analysis was used to assess the statistical strength of the water quality versus change in population relationships.

Results and Discussion

Stream Conditions in 2007-2008

The concentrations of major anions and cations plus conductivity (Table 2.1), and the concentrations of dissolved nitrogen, phosphorus, and organic carbon (Table 2.2) generally separate the 11 streams into 2 categories, strongly enriched or impacted and moderately enriched or impacted. The impacted streams had conductivities that exceeded those at the other sites by 2- to 4-fold and included W. Br. Neshaminy, Upper Tohickon , Little Neshaminy , and Neshaminy. Alkalinities were also generally higher in samples taken from those 4 stream sites relative to the other sites (Table 2.3). Conductivity in undisturbed watersheds are a reflection of the underlying bedrock geology. In the study area, the geology is relatively complex with 4 major formations, Diabase, Mudstone, Argillite, and Sandstone (see Figure 1.3 and Table 1.4 in the Chapter 1), but the high conductivity sites are in watersheds with different geologies (e.g. Upper Tohickon v. Little Neshaminy) while some of the lower conductivity sites drain the same underlying geology as the high conductivity sites (e.g. Tinicum v. W. Br. Neshaminy; Table 2.1). Therefore, we interpret the elevated conductivities as indicative of alterations in land use or land cover, including agriculture, domestic water wastewater, municipal sewage disposal and possibly industrial/commercial wastewater. Additionally, an examination of the ionic composition of the stream water reveals that in the moderately enriched sites calcium and sulfate were the major cation and anion, respectively, while in the impacted sites, sodium and chloride dominated. The dramatic decline in conductivity during the winter sampling is likely due to dilution from snow melt that occurred in February 2008 (see Chapter 1 for more information). Concurrent with this drop in conductivity between the fall and winter sampling times was an increase in pH at 8 of the 11 sites (Table 2.3).

The impacted sites also had some of the highest nutrient and organic carbon concentrations. Nitrate concentrations during the fall in the impacted sites ranged from 2 to over 6 mg NO_3-N/L.

While well below the safe drinking water maximum concentration level of 10 mg NO_3-N/L established by the U.S. EPA (CFR Title 40), concentrations of nitrate in excess of 1 mg NO_3-N/L are sufficient to support nuisance algal blooms. Even two of the moderately enriched sites, Paunnacussing and Pidcock had nitrate concentrations that exceeded 2 mg NO_3-N/L, though the seasonal variation at Pidcock was dramatic, with the fall concentration 40-fold lower. Phosphorus concentrations were elevated in the impacted streams, approaching 1 mg/L total dissolved phosphorus during the fall at W. Br. Neshaminy and Upper Tohickon. DOC concentrations were also elevated at the same sites, especially within Upper Tohickon with a concentration of over 5 mg C/L. The elevated DOC from the Upper Tohickon was slightly moderated by Lake Nockamixon, but still elevated at the outfall that becomes the Lower Tohickon. Nitrate and phosphorus, in contrast, were reduced by a factors of approximately 30 and 10, respectively between the Upper and Lower Tohickon sites, while passage of the N. Br. Neshaminy through Lake Galena (from site I3A to site I3) reduced nitrate 20-fold and phosphorus 7-fold. In general, agricultural practices and anthropogenic land uses are associated with increased nutrient loadings to streams (Boyer et al. 2002), while wetlands, water flow path, and soil drainage and impervious coverage are strong influences on carbon concentrations (Kaplan et al. 2006), (Wilson and Xenopoulos 2008), (Mattsson et al. 2009). Although the present study could not distinguish among these factors, the high percentage of DOC that was biodegradable in the Upper Tohickon, Lower Tohickon, Little Neshaminy, Neshaminy, and the W. Br. Neshaminy, all in during the fall sampling (Table 2.4), suggest either surface runoff sources of DOC, algal exudates associated with lake phytoplankton growth, or sewage treatment plant effluents were involved.

The particulate loading of the streams as total suspended solids varied widely from < 1 mg /L at Tinicum to > 20 mg /L in the winter at Upper Tohickon with organic carbon contributing from 6.4% to 25.7% of the dry mass and organic nitrogen contributing from 0.8% to 3.7 % of the dry mass, with molar C/N ratios ranging from 6.1-14.9 (Table 2.5). Typically, under baseflow conditions, the ratio DOC:POC is < 3, with lower ratios representing streams with excessive sediment loading (Kaplan et al . 2006). Of the 11 streams sampled, 9 had DOC:POC ratios that were <3, but only 1, County Line, represented a sample that was not impacted by winter snow melt (based on field observation) and the attendant increased turbidity.

Stable carbon and nitrogen isotopes of total suspended solids reflect current human impacts to the streams (no stable isotope data were collected in 1968-1971). Stable carbon isotope values ($\delta^{13}C$) reflect differences in organic matter sources. Broadleaf plants and some grasses that use the C3 photosynthic pathway have $\delta^{13}C$ values that typically range from -27‰ to -32‰, whereas algae that growing in waters draining carbonate-rich lithologies (limestone, dolomite, etc.) or with heavily limed crops and lawns typically have $\delta^{13}C$ values around 20‰ (Fogel and Cifuentes. 1993). Warm climate grasses that use the C4 photosyntheic pathway, such as corn and sugar cane, and the animals that feed on them, have $\delta^{13}C$ values ranging from -11‰ to -14‰ (Fogel and Cifuentes. 1993). For the study streams, average $\delta^{13}C$ ranged from -32‰ to -27‰ was positively correlated to stream nutrients ($r = 0.59$, 0.63 and 0.71 for nitrate, TDP and alkalinity respectively), to E. coli ($r = 0.79$), and to year 2000 population density ($r = 0.55$). These data suggest that human activities are moderately but measurably contributing labile carbon inputs to streams, by increased algal growth and/or by direct sewage inputs, which have a higher contribution from C4 sources than natural vegetation. The relatively low carbon to nitrogen ratios (6.1-14.9) for such organic-rich suspended solids (6.4% to 25.7% organic carbon) support this conclusion, because detrital leaf material typically has much higher C/N ratios (20-40) and soil materials are typically not rich in organic carbon (1-5% organic carbon in the surface or A horizon and <1% organic carbon in deeper horizons). Stable nitrogen isotope values ($\delta^{15}N$) showed no distinct trends.

Changes in Stream Condition between 1968-1971 and 2007-2008

To initially compare the stream chemistry changes that have occurred in the last nearly 40 years, we plotted the historic data against the current data for several analytes. Clearly, the validity of these comparisons rests on the quality of the chemical analyses performed. Even though analytical methods have changed for some of the analytes, for this comparison we assume that all historic data are as accurate as the current data. Changes that are regional in nature and occurred across all sites include the reduction in phosphorus (total dissolved P for 2007 v. PO_4-P for the 1967-71 period) and sulfate concentrations (Fig. 2.1), and to a lesser extent, the increase in alkalinity and increase in pH (Fig. 2.2). The phosphorus reduction reflects the impacts of the ban on phosphate detergents in Pennsylvania and the sulfate reductions and alkalinity and pH increases are likely the combined result of reductions in sulfuric acid in precipitation as power plants cleaned-up sulfur emissions and increases in the agricultural application of lime to crops and lawns. However, the high pH values (8-9) measured during late winter (Feb. 19-21) of 2008 are associated with decreases in alkalinity, the opposite of what one might expect due to pH buffering (Fig. 2.2). This suggests a possible biological effect from changes in dissolved CO_2/carbonic acid, which changes pH but not alkalinity. For example, high microbial respiration at certain sites during the warmer season could decrease pH in spite of higher alkalinity. Season differences in alkalinity on the other hand are likely due to higher proportions of deep groundwater inputs (with higher alkalinity) to the stream during the dry early autumn season and higher proportions of shallow and surface water inputs (with lower alkalinity) during higher flow regimes, including snowmelt, in the late winter (Fig. 1.5-1.6).

Nitrate concentrations have largely remained the same with some notable exceptions. Nitrate concentrations have been reduced in Tinicum in both fall and winter samples, Little Neshaminy in the fall sample, and Pidcock in the fall sample, while increases in nitrates have occurred in the Upper Tohickon and the W. Br. Neshaminy (Fig. 2.1). Tinicum also showed significant reductions in chloride concentrations (Fig. 2.1) and conductivity (Fig. 2.2), as did the Lower Tohickon and the Upper N. Br. Neshaminy. In contrast, chloride and conductivity increases have occurred in Upper Tohickon, Neshaminy, and Little Neshaminy. Dissolved oxygen, expressed as a percentage of saturation, has declined in many of the streams, especially Pidcock, Upper and Lower N. Br. Neshaminy, Lower Tohickon Ck., and Neshaminy, while % saturation increased in W. Branch Neshaminy and in the fall sample at Upper Tohickon (Fig.2).

Of the parameters that could be compared between the current and historical efforts, sulfate and pH are the only two that showed no relationship with changes in population for either time period, statistical or otherwise (Figs 2.3 and 2.4, respectively). This result supports the idea of regional improvement in acid deposition impacts to stream water quality without regard to watershed condition. Alkalinity, however, does show an increasing relationship with population changes (i.e. parallel lines, Fig. 2.4) on top of potential regional improvements in water quality due to reduced acid deposition (i.e. consistent overall increase in alkalinity across the range of population changes, Fig. 2.4). This suggests a watershed-specific influence on alkalinity that existed across the time periods sampled super-imposed on improvements in water quality due to acid-deposition mitigation.

The previously noted improvements made in regard to phosphorus concentrations since the 1967-71 period are just as obvious when relating phosphorus concentrations to changes in population between 1970 and 2000 (Fig. 2.3). Equally evident though is that phosphorus, whether as total dissolved P for the 2007 data or as PO_4-P for the 1967-71 data, has an increasing and statistically significant relationship with increased human presence on a watershed scale. This increasing relationship between phosphorus concentration and the number of people within a watershed remains despite the dramatic decrease in the overall phosphorus concentrations.

Chloride, nitrate and conductivity relationships with population change offer a third view of differences in stream water quality over the past 40 years (Figs 2.3, 2.4). The chloride and nitrate relationships with population change (Fig. 2.3), while not statistically significant, do suggest a decrease in concentrations associated with watersheds that experienced less urban/suburban growth contrasted with increased concentrations within watershed that experience relatively greater urban/suburban growth. For chloride, this change in concentration relative to population change may reflect an increase in road salt use in urban/suburban areas. Less clear is a similar explanation for the nitrate concentration patterns. However, one possibility is an increase in lawn fertilization which might follow an increase in population reflecting increasing suburbanization.

The contrast in relative water-quality between the historic and current sampling periods shown for chloride and nitrate is further supported by the conductivity relationships (Fig. 2.4). Conductivity has often been used as a general indicator of anthropogenic influences on stream chemistry (Dow and Zampella 2000). However, the relationships shown here suggest that conductivity, as a surrogate for overall stream water quality relative to watershed condition, may not necessarily offer a consistent measure of this relationship over time.

Literature Cited

Boyer, E. W., C. L. Goodale, N. A. Jaworski, and R. W. Howarth. 2002. Anthropogenic nitrogen sources and relationships to riverine nitrogen export in the northeastern U.S.A. Biogeochemistry 57/58:137-169.

Dow, C. L. and R. A. Zampella. 2000. Specific Conductance and pH as Indicators of Watershed Disturbance in Streams of the New Jersey Pinelands, USA. Environmental Management 26:437-445.

Fogel, M. L. and L. A. Cifuentes. 1993. Isotope fractionation during primary production. Pages 73-98 *in* M. H. Engel and S. A. Macko, editors. Organic Geochemistry. Plenum, New York.

Kaplan, L. A., J. D. Newbold, D. J. Van Horn, C. L. Dow, A. K. Aufdenkampe, and J. K. Jackson. 2006. Organic matter transport in New York City drinking-water-supply watersheds. Journal of the North American Benthological Society 25:912-927.

Mattsson, T., P. Kortelainen, A. Laubel, D. Evans, M. Pujo-Pay, A. Raike, and P. Conan. 2009. Export of dissolved organic matter in relation to land use along a European climatic gradient. Science of the Total Environment 407:1967-1976.

Wilson, H. F. and M. A. Xenopoulos. 2008. Ecosystem and seasonal control of stream dissolved organic carbon along a gradient of land use. Ecosystems 11:555-568.

Table 2.1. Concentrations of major ions plus conductivity for the current (2007-2008) sampling effort in Buck Co streams. Cond = conductivity; Ca^{2+} = calcium; Mg^{2+} = magnesium; Na^{+} = sodium; K^{+} =potassium; Cl^{-} = chloride; SO_4^{2-} = sulfate. See Table 2.2 and Figure 2.2 in the Site Description chapter for site names and locations. September dates are considered fall samples; February dates are considered winter samples.

Site	Sample Date	Cond	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Cl^{-}	SO_4^{2-}
		uS/cm	mg/L					
V1	18SEP07	363	39.5	14.6	13.1	1.9	15.7	69.5
	19FEB08	136	9.0	3.8	9.0	0.9	10.1	12.3
II11	18SEP07	867	52.5	17.5	94.3	8.2	108.1	84.3
	19FEB08	224	14.8	5.2	24.6	1.9	38.3	16.0
I11	18SEP07	191	14.2	5.2	15.7	2.1	26.9	12.8
	19FEB08	217	14.6	5.3	23.6	2.1	35.9	16.4
V4	18SEP07	281	28.7	9.1	15.3	2.3	27.5	22.8
	19FEB08	203	16.4	5.5	16.7	2.1	25.8	18.1
V2	18SEP07	287	31	11.2	11.9	2.7	20.6	27.1
	21FEB08	220	18.7	7.9	17.3	2.1	22.0	20.0
I1	19SEP07	405	40.9	13.3	25.9	2.6	41.7	20.7
	20FEB08	233	17.1	5.8	24.2	1.6	36.4	19.7
II1	19SEP07	805	39.7	12.2	99.7	13.9	104.2	52.1
	20FEB08	602	36.5	10.6	79.5	4.0	121.1	32.3
I3A	19SEP07	219	20.4	7.0	13.3	2.0	20.7	19.6
	20FEB08	306	26.1	10.0	24.1	2.7	33.1	35.8
I3	19SEP07	208	19.4	6.7	12.8	2.4	20.0	16.9
	20FEB08	220	16.8	6.2	20.5	2.5	30.4	19.1
II7	19SEP07	855	62.4	17.2	130.7	13.7	35.5	16.4
	21FEB08	543	41.6	12.5	58.5	3.6	100.8	33.4
III6	18SEP07	605	42.5	13.5	73.6	6.9	80.1	42.4
	21FEB08	421	31.2	10.1	43.2	2.9	72.2	31.1

Table 2.2. Concentrations of dissolved nitrogen, phosphorus and organic carbon for the current (2007-2008) sampling effort in Buck Co streams. DOC = dissolved organic carbon; NO_3^--N = nitrate as nitrogen; NH_4^+-N = ammonium as nitrogen; SKN = soluble kjeldahl nitrogen; TDP = total dissolved phosphorus. See Table 2.2 and Figure 2.2 in the Site Description chapter for site names and locations. September dates are considered fall samples; February dates are considered winter samples.

Site	Sample Date	DOC	NO_3^--N	NH_4^+-N	SKN	TDP
		μg/L	mg/L			
V1	18SEP07	1522	0.02	0.011	0.09	0.005
	19FEB08	1051	0.44	0.042	0.19	0.014
II11	18SEP07	5464	6.46	0.004	0.89	0.115
	19FEB08	1765	0.63	0.011	0.35	0.024
I11	18SEP07	4618	0.27	0.105	0.32	0.019
	19FEB08	1290	0.47	0.004	0.30	0.007
V4	18SEP07	1152	2.23	0.01	0.13	0.035
	19FEB08	597	2.52	0.007	0.17	0.028
V2	18SEP07	2418	0.05	0.004	0.16	0.039
	21FEB08	1550	2.04	0.023	0.24	0.032
I1	19SEP07	1832	0.22	0.009	0.15	0.021
	20FEB08	998	1.22	0.01	0.13	0.012
II1	19SEP07	5290	5.39	0.016	0.92	0.923
	20FEB08	1784	2.74	0.036	0.65	0.039
I3A	19SEP07	2125	1.19	0.001	0.19	0.053
	20FEB08	1660	1.33	0.019	0.27	0.026
I3	19SEP07	3220	0.06	0.113	0.33	0.008
	20FEB08	2206	0.90	0.019	0.31	0.01
II7	19SEP07	5114	2.14	0.018	0.95	0.744
	21FEB08	1220	3.11	0.018	0.44	0.192
III6	18SEP07	3747	2.08	0.001	0.48	0.206
	21FEB08	1584	2.25	0.019	0.30	0.041

Table 2.3. In-situ plus alkalinity sample values for the current (2007-2008) sampling effort in Buck Co streams.

Site	Sample Date	pH	Alkalinity ueq/L	DO % Sat
V1	18SEP07	8.32	1615	110
	19FEB08	8.01	414	76
II11	18SEP07	7.91	1575	125
	19FEB08	8.67	1557	82
I11	18SEP07	7.56	732	101
	19FEB08	9.25	592	79
V4	18SEP07	7.78	1351	109
	19FEB08	7.91	507	80
V2	18SEP07	8.11	1783	98
	21FEB08	8.26	937	64
I1	19SEP07	7.94	2410	92
	20FEB08	8.35	992	81
II1	19SEP07	8.23	2230	133
	20FEB08	8.03	1724	95
I3A	19SEP07	7.86	1076	90
	20FEB08	7.79	1225	73
I3	19SEP07	7.96	1124	89
	20FEB08	8.65	774	82
II7	19SEP07	7.98	2721	87
	21FEB08	8.97	1638	90
III6	18SEP07	7.82	1976	97
	21FEB08	8.57	1221	79

Table 2.4. Dissolved organic carbon (DOC) and biodegradable DOC (BDOC) concentrations for the current (2007-2008) sampling effort in Buck Co streams. % BDOC = percentage of biodegradable carbon. See Table 2.2 and Figure 2.2 in the Site Description chapter for site names and locations. September dates are considered fall samples; February dates are considered winter samples.

Site	Sample Date	DOC	BDOC	% BDOC
		μg/L		
V1	18SEP07	1522	160	10.5
	19FEB08	1051	90	8.6
II11	18SEP07	5464	587	10.7
	19FEB08	1765	445	25.2
I11	18SEP07	4618	60	1.3
	19FEB08	1290	115	8.9
V4	18SEP07	1152	79	6.8
	19FEB08	597	106	17.7
V2	18SEP07	2418	180	7.4
	21FEB08	1550	303	19.5
I1	19SEP07	1832	113	6.2
	20FEB08	998	52	5.2
II1	19SEP07	5290	729	13.8
	20FEB08	1784	252	14.1
I3A	19SEP07	2125	214	10.1
	20FEB08	1660	242	14.6
I3	19SEP07	3220	45	1.4
	20FEB08	2206	474	21.5
II7	19SEP07	5114	860	16.8
	21FEB08	1220	178	14.6
III6	18SEP07	3747	375	10.0
	21FEB08	1584	340	21.5

Table 2.5. Concentrations of particulates plus stable Carbon and Nitrogen isotope values in transport for the current (2007-2008) sampling effort in Buck Co streams. TSS = total suspended solids; POC = particulate organic C; PON = particulate organic N; PP = particulate phophorus. See Table 2.2 and Figure 2.2 in the Site Description chapter for site names and locations. September dates are considered fall samples; February dates are considered winter samples.

Site	Sample Date	TSS	POC	PON	PP [1]	$\delta^{13}C$	$\delta^{15}N$	C/N
		mg/L				‰ (rel to VPDB)	‰ (rel to air)	molar
V1	18SEP07	0.9	0.22	0.03	0.00	-29.9	5.8	9.1
	19FEB08	4.7	0.52	0.06	0.006	-30.6	1.9	10.7
II11	18SEP07	1.8	0.26	0.03	0.008	-30.5	7.8	9.9
	19FEB08	23.1	1.48	0.20	0.023	-29.6	2.9	8.8
I11	18SEP07	2.4	0.3	0.03	0.025	-30.3	7.5	11.8
	19FEB08	7.3	1.08	0.18	0.019	-35.4	7.9	7
V4	18SEP07	2.9	0.24	0.02	0.005	-29.9	7.2	11.2
	19FEB08	4.4	0.58	0.07	0.009	-30.6	3.3	9.7
V2	18SEP07	2.5	0.34	0.04	0.002	-30.1	5.6	11.1
	21FEB08	3.3	0.36	0.05	0.009	-31.7	1.9	8.4
I1	19SEP07	18.5	1.98	0.15	0.0205	-28.4	7.5	14.9
	20FEB08	5.3	0.35	0.04	0.0035	-30.5	3.9	9.7
II1	19SEP07	1.4	0.35	0.05	0.00	-27.4	6.5	8.6
	20FEB08	3.6	0.64	0.10	0.021	-25.9	4.2	7.6
I3A	19SEP07	3.2	0.32	0.03	0.001	-29.3	5.4	11.2
	20FEB08	4.3	0.45	0.06	0.007	-30	3.5	8.5
I3	19SEP07	4.6	1.04	0.17	0.023	-30.7	7.2	7.1
	20FEB08	14	1.65	0.31	0.047	-32	7.4	6.1
II7	19SEP07	1.9	0.33	0.03	0.001	-30.8	9.6	11.5
	21FEB08	3.9	0.48	0.07	0.00	-29.5	6.1	7.9
III6	18SEP07	1.7	0.29	0.03	0.00	-29.3	8.8	11.9
	21FEB08	4.3	0.7	0.12	0.009	-30.8	7.4	6.7

[1] PP calculated by difference between total P and total dissolved P. Negative values were set to 0.

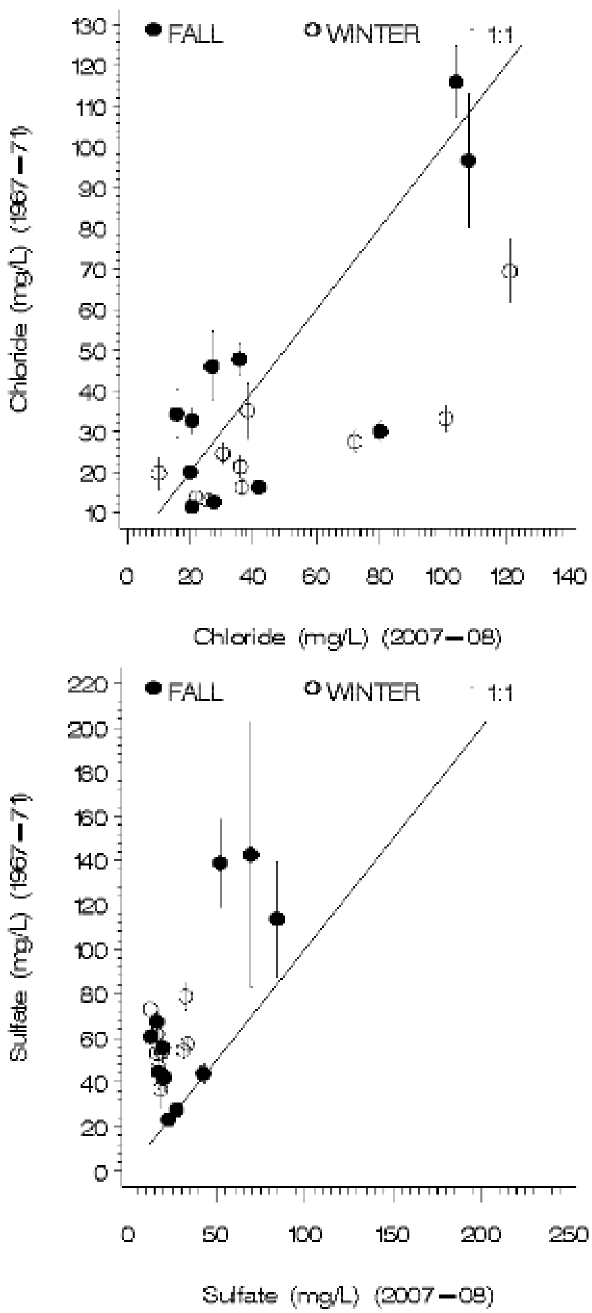


Figure 2.1. Comparison of mean historic (1967-71) values to current (2007-08) measured values for selected ions by season. Historic mean values are based on n=1 to 19 depending upon parameter or site. No winter samples for site I3A were sampled historically. The 1:1 line is shown for interpretation. Bars associated with the historic mean values represent standard errors.

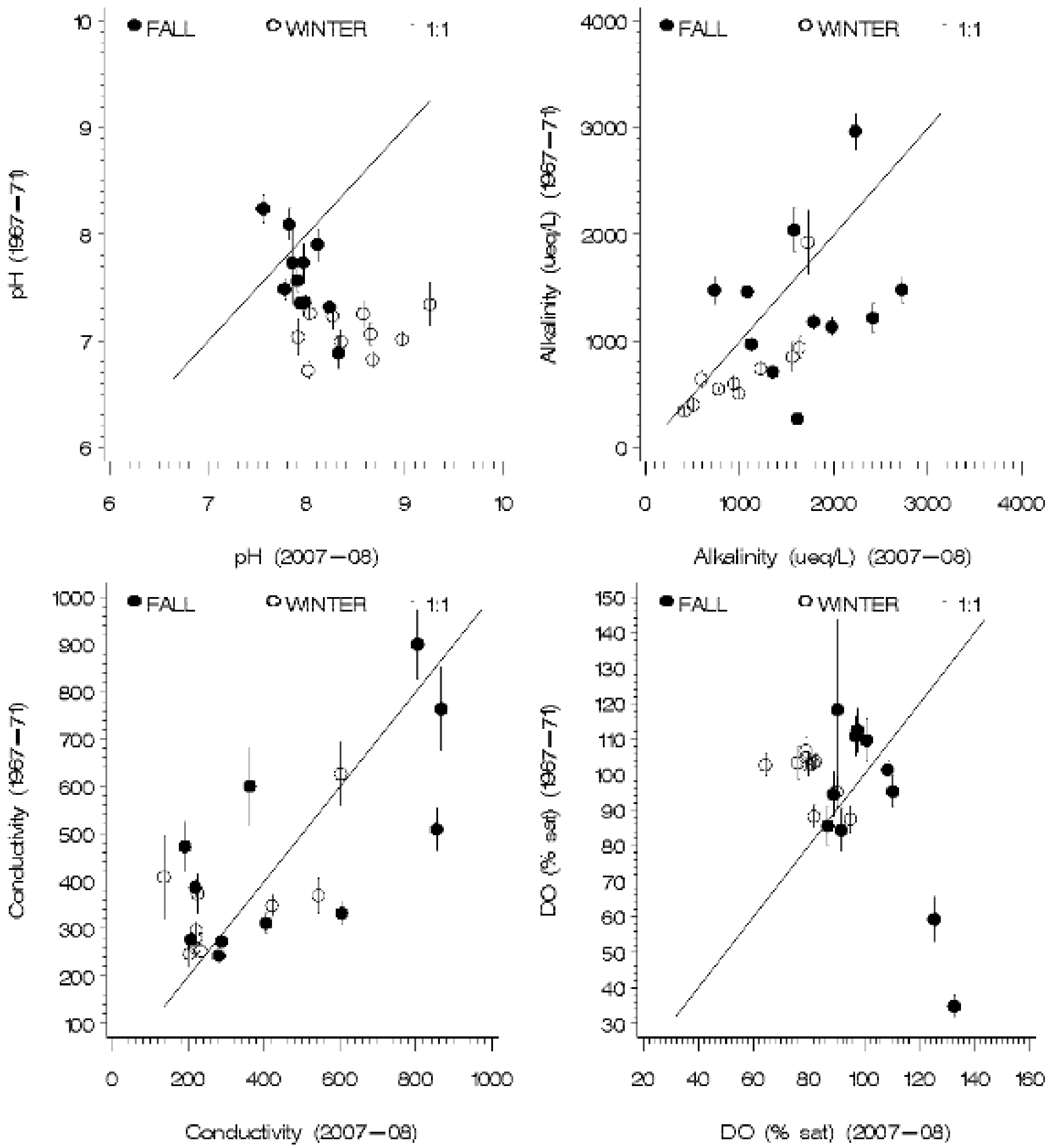


Figure 2.2. Comparison of mean historic (1967-71) values to current (2007-08) measured values for selected in-situ parameters and alkalinity by season. Historic mean values are based on n=1 to 19 depending upon parameter or site. No winter samples for site I3A were sampled historically. The 1:1 line is shown for interpretation. Bars associated with the historic mean values represent standard errors.

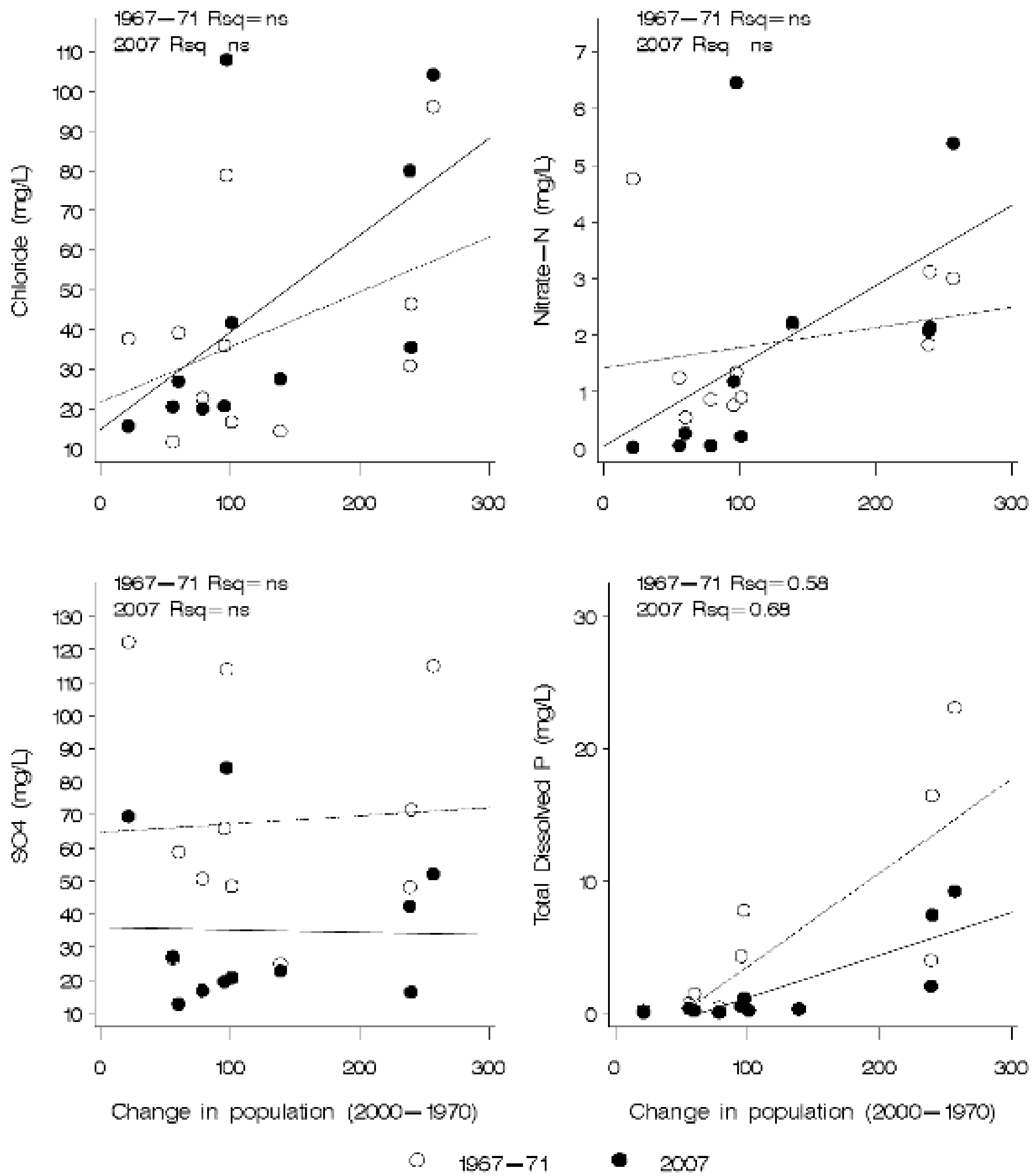


Figure 2.3. Selected ions and nutrients measured both historically (1967-71) and currently (2007) at the 11 Bucks Co stream sites plotted against the change in population from 1970 to 2000. The historic data are means of data values collected between September and December; current data are from a single sampling date in September 2007. Regression lines are shown for each set of data; if the regression was significant at an $\alpha \leq 0.05$ the associated R^2 values is shown (ns = non-significant). Specific to the data plotted in the lower right-hand panel: total dissolved P was only measured during the current sampling effort; PO4-P data were plotted for the historic sampling effort. In addition, the total dissolved P values were increased by a factor of 10 in order to plot on the same scale as the historic PO4-P values.

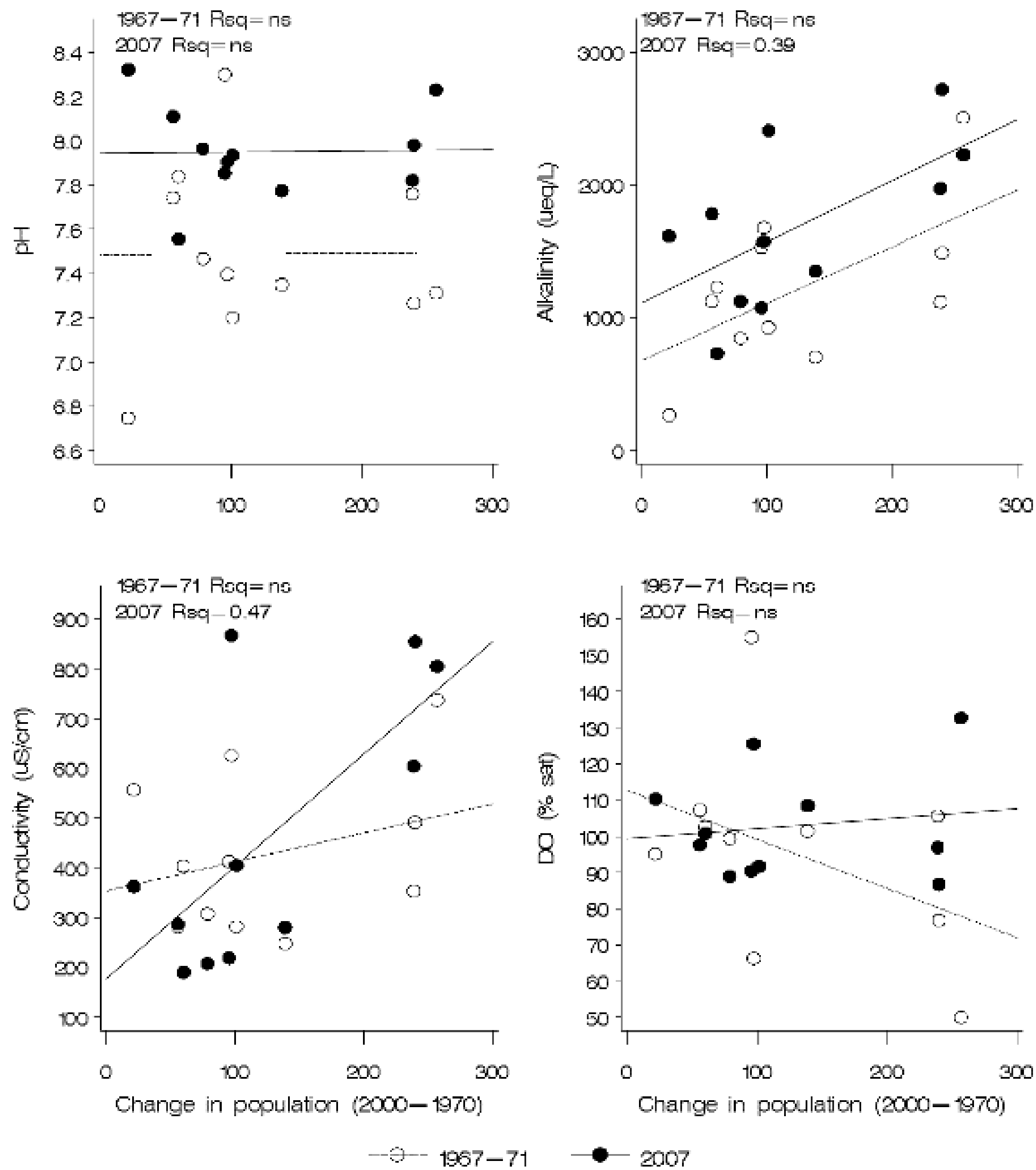


Figure 2.4. Selected in-situ parameters plus alkalinity measured both historically (1967-71) and currently (2007) at the 11 Bucks Co stream sites plotted against the change in population from 1970 to 2000. The historic data are means of data values collected between September and December; current data are from a single sampling date in September 2007. Regression lines are shown for each set of data; if the regression was significant at an (≤ 0.05 the associated R^2 values is shown (ns = non-significant).

----------------------Intentionally Blank----------------------

Chapter 3. Stream Water Chemistry – Molecular Tracers

Overview

A common challenge in mitigating stream water-quality degradation is identifying the specific source of that degradation. This is especially true of non-point sources of pollution. A relatively new technique has emerged that uses molecular tracer compounds to identify sources of contaminants by qualitatively linking chemical fingerprints unique to a specific contaminant source (Leeming et al. 1996), (Standley et al. 2000), (Kolpin et al. 2002), (Yunker et al. 2002), (Buerge et al. 2003), (Glassmeyer et al. 2005). These tracer compounds do not themselves need to be toxic or directly contribute to water quality degradation, but rather they only need to enable discrimination between different sources and therefore act as proxies for contaminants originating from those same sources.

Originally developed by organic geochemists to identify natural organic matter sources, the development of a compound as a biomarker, or tracer of sources, depends on meeting a certain set of criteria (Hedges and Prahl 1993): (1) the tracer must be detectable at a concentration well below that of interest; (2) ambient concentrations of the tracer molecule must be accurately quantified; (3) all sources of the tracer are known and relatively unique; and (4) environmental diagenesis or degradation of the tracer compound is either minimal, well understood, and/or proportional to other tracer compounds to which it might be compared (e.g., ratios do not change with degradation). We analyzed samples collected at 11 Bucks Co stream sites in the fall and winter of 2007/2008 for a suite of 31 organic compounds (Table 3.1). These compounds include twelve polycyclic aromatic hydrocarbons (PAH), two fragrance materials (FM), caffeine (CAF), three pesticides, 3 poly-chlorinated biphenyls (PCB) and ten fecal steroids (FS).

Polycyclic aromatic hydrocarbons are found in raw and refined petroleum and coal products and are also formed during the combustion of vegetation, wood, waste, coal and petroleum. Fragrance materials are anthropogenic compounds used in a variety of consumer products such as soaps, detergents and lotions that enter the environment primarily through greywater sewage (Simonich et al. 2000). Both AHTN and HHCB are non-biodegradable, making them particularly suited for tracers studies (Simonich et al. 2000). Caffeine is a natural compound that occurs in certain tropical plants, including tea and coffee, and is added to numerous food products and pharmaceuticals. In temperate climates, the primary source of caffeine to watersheds is via the urine of those who consume caffeine-containing products (Buerge et al. 2003). The pesticides analyzed in these samples include an herbicide (atrazine), an insecticide (chlorpyrifos) and a fungicide (metalaxyl). Atrazine and chlorpyrifos are both considered a 'PAN Bad Actor Chemical' indicating a chemical that has one or more of the following characteristics: highly acute toxicity, known/probable carcinogen, known groundwater pollutant or know reproductive/development toxicant (from the Pesticide Action Network [PAN] Pesticide Database - www.pesticideinfo.org – accessed 23 Feburary 2010). The manufacture and most use of PCBs have been banned in the US since 1978 (EPA 2002) but due to their chemical stability these compounds persist in the environment for decades if not centuries. For instance, in the tidal portion of the Delaware River (downstream of Trenton, NJ), sediment resuspension is thought to be one of the significant sources of PCBs (Du et al. 2008). The three congeners (unique compounds within the PCB category) analyzed in samples here were PCB118 (a pentachlorobiphenyl), PCB138 and PCB153 (both hexachlorobiphenyls). Fecal steroids are natural compounds that are produced in the intestines of birds and mammals. Tracer concentrations and ratios of between 2 or more tracers were then used to infer potential contamination sources to waters upstream of study sites. These tracer concentrations and ratios were also related to watershed landscape characteristics.

Methods

Stream Sampling

Molecular tracer concentrations were analyzed once in the fall of 2007 and again in the winter of 2008 at each of 11 Bucks Co stream sampling sites (see Table 1.2 and Figs. 1.2 in Chapter 1). Baseflow conditions were targeted for stream sampling, however, winter sampling at a few of the sites took place under varying flow conditions due to snowmelt. This sampling effort was coordinated with the inorganic/organic/isotope chemistry sampling effort (Chapter 2). We collected 8 L water samples for tracer analysis in pre-cleaned glass jars. Water samples were stored in a cool and dark place and extracted within 7 days. All glass sampling equipment and sample jugs were washed with detergent, rinsed with nanopure water and finally combusted in a kiln at 480°C for 4 h to remove all remaining organic compounds. Teflon sampling equipment (i.e. jug cap liners), which could not be kilned, were cleaned with detergent and nanopure water, dried and finally by rinsed with hexane/acetone (1:1) followed by dichloromethane.

Laboratory

Molecular tracers were extracted from all samples by liquid-solid extraction onto an Empore™ disk, using protocols similar to EPA approved alternate test method 608 ATM 3M0222 or to EPA Method 3535. As a whole, our methods for extraction and GC-MS analysis are very similar to EPA method 8270.

In brief, sample water was filtered through a glass fiber filter stacked on top of an Empore™ C-18 disk. Particulate tracer compounds were extracted from the filter by sonic extraction and dissolved tracers were eluted from the Empore disk with solvents. Surrogate recovery standards – perdeuterated phenanthrene (PHE-D10), perdeuterated chrysene (CHR-D12), perdeuterated perylene (PER-D12), perdeuterated caffeine (CAF-D9) and perdeuterated cholesterol (CHO-D6) – were added to the surface of both the filter and the disk, after they were separated but prior to extraction. Dissolved and particulate extracts were then back-extracted in a separatory funnel with an aqueous salt solution to remove impurities, mixed with anhydrous sodium sulfate to remove moisture, rotoevaporated, and transferred to auto-injector vials. Samples were gently dried under a stream of nitrogen, redissolved in 15 µL pyridine, and derivatized (in order to analyze fecal sterols, which contain alcohol groups) by purging sealed vials with N_2, adding 15 µL of BSTFA (N,*O*-bis(trimethylsilyl)trifluoroacetamide) with 1% TMCS (Trimethylchlorosilane), and heating to 70°C for 30 minutes in an aluminum heating block. Derivitized sample extracts were then spiked with 5 µL internal standard solution (25-ng/µL in each of p-terphenyl-d14 and 5α-cholestane in pyridine) and were analyzed for each of the molecular tracers compounds by capillary gas chromatography – mass spectrometry (GC/MS) in selective ion monitoring (SIM) mode, using a J&W DB1701 column (30 m, 0.25 mm i.d., 250 µm coating) on an Agilent 6890 series GC interfaced with a 5973n series MSD.

Quantification

Each batch of samples was analyzed by GC-MS along with 7-8 analytical standard mixes at 5-6 levels of 0.04, 0.2, 1.0, 4.0, 20 and 50 ng/µL nominal concentration (exact concentrations for each compound were slightly different, but known to 3 significant figures) and 2-3 check standards at 4.0 ng/ µL nominal concentration. To enable the greatest consistency, we quantified tracer concentrations from all 6 years using an automated data quantification system (Dow and Aufdenkampe 2006). In brief, after confirmation by the analyst, for each compound the peak areas of 1 quantitation and 1-2 confirmation ions were exported for all standards and samples from the Agilent GC-MS "ChemStation" chromatography software directly into our central server. We then manipulated these raw data with SAS-based scripts (SAS/Base v.9.1; SAS Institute, Inc., Cary NC) to produce final concentration data. Thus, decisions regarding how to fit the calibration curve, when to drop outlying standards, whether or not peak identity was adequately confirmed, etc. were all made uniformly for the entire 6-y dataset using the same objective criteria. Additional benefits of this quantitation system included documentation of all calibration decisions, which could be easily reviewed or revised at any time, less potential for error, and better quality control. If a compound concentration was above the highest calibration standard, the sample extract was diluted and reanalyzed. If a compound concentration was below the lowest calibration standard, the compound was flagged as "estimated" but nevertheless quantified using a linear fit from the origin to the lowest standard. If any compound in a check standard did not give a concentration within 20% of the known value, all samples analyzed after that check standard were reanalyzed for that compound.

All data presented here were corrected for extraction recoveries and other analytical biases measured for each sample using internal surrogate standards, which were added to each sample prior to filtration and extraction. Surrogate standard recoveries were assigned to tracer compounds, based on recovery data from lab-spiked matrix samples for all compounds, as follows (see Table 1 for analyte abbreviations): perdeuterated phenanthrene (FLU, PHE, ANT), perdeuterated chrysene (FLR, PYR, BAA, CHR, HHCB, AHTN, atrazine, PCB1118, PCB153, PCB138), perdeuterated perylene (BBF, BKF, BAP), perdeuterated caffeine (CAF) and perdeuterated cholesterol (fecal steroids). 2MP, 1MP, metalaxyl, and chlorpyrifos were corrected using the average recovery of perdeuterated phenanthrene and perdeuterated chrysene. These assignments were confirmed with lab-spiked test samples (i.e. known amounts of compounds added to clean water), by matching measured recoveries of each tracer with the surrogate having the most consistently similar recovery.

Laboratory reporting levels (LRL – Table 3.1) assigned to each analyte were based on NY watersheds project method detection work using the definitions and methods of USGS Open File Report 99-193 (USGS 1999). Likewise, the 75% and 95% confidence limits for no false positives were also based on NY watersheds project quality-control results (Table 3.1). The LRL is defined as the concentration above which there is 99% confidence that reporting a false negative will be avoided. In other words, if the ambient concentration is above the LRL, the laboratory is 99% confident to detect a concentration. Conversely, the no false positive levels indicate concentrations above which the laboratory has the stated confidence that a detected concentration indicates the actual presence of that compound.

Data were not censored below estimated MDL or LRL values *a priori* for most of our statistical analyses, with the exception of values for ratios of two or more compounds. A number of studies and reports have examined the numerous negative effects of censoring data [for example: (Helsel 1990)]. Ratios of two tracer compounds were censored, or eliminated from consideration, if one compound had a concentration below its censorship limit, which was either the LRL or the 75% percentile of measured blanks, whichever was greater. For the ratio of high to low molecular weight PAHs, the value was eliminated if the sum of measured concentrations in the either the numerator or denominator was less than the sum of the censorship limits for the same compounds.

Data Analysis

A fecal contamination source predictive model was developed as part of the NY watershed project (SWRC 2008) using fecal steroid data collected from various human and animal fecal samples. This predictive model was developed using selected ratios involving two steroid compounds and Principal Components Analysis to look at the variation in these ratios among the various fecal sources. Using those same steroid ratios for samples collected as part of the present monitoring study, the PCA model was used to predict potential sources of fecal contamination in the Bucks Co stream sites.

Selected tracer concentrations and ratios were regressed against changes in population from 1970 to 2000. Tracer concentrations were log10-transformed prior to the regression analysis, with 0.00003 added to all concentrations to avoid taking the log of zero. Tracer ratios were not transformed. The selection of specific compounds and ratios was based on initial correlation analyses involving all compounds and ratios against land use/cover data for the 11 stream sites (results not provided). In general, the compounds and ratios within each tracer group (i.e. PAH, Fragrances/caffeine, steroids, pesticides/PCBs) having the strongest correlations with population data were selected for the regression analysis.

Results and Discussion

Most of the PAHs, fragrances/caffeine, and steroids were detected in every sample collected from the 11 Bucks Co stream sites (Fig. 3.1). Only the steroids EPI and aONE had detection frequencies of < 82% (i.e. 18 of 22 samples). In stark contrast, of the pesticides and PCBs, only atrazine was detected in the majority of samples. The other two pesticides were detected in less than a third of the samples and two of the PCBs (PCB138 and PCB153) were detected in only one or none of the samples.

Bucks Co PAH concentration distributions were quite similar to that shown for a similar study in NYC source-water watersheds (SWRC 2008) with the median values generally occurring within the same order of magnitude and the Bucks Co inter-quartile (25^{th} to 75^{th} percentile) and 5^{th}-95^{th} percentile ranges also within the respective ranges of the NY watersheds project data. However, a different pattern was observed for the fragrances/caffeine and steroid concentration distributions between the two projects. Namely, the Bucks Co distributions shift towards higher concentrations; this is especially true in the case of the fragrance HHCB, caffeine and the steroids bCOP, aCOP, and eCHO. These differences in concentration distributions between the projects are likely due to differences in project design and number of sites/samples rather than actual regional differences. Site selection for the NY watersheds project was primarily based on capturing the range of land uses in that study region from completely forested to highly urbanized with sampling occurring at many more sites, over a greater period of time. Bucks Co site selection was more geared towards selecting sites that covered the predominant changes in watershed condition over time in the county; i.e. creation of reservoirs, greater number of WWTP. Despite any differences in the concentration distributions, the primary outcome of comparing the tracers between the two projects, and more specifically the two regions, is that there are no dramatic differences in the occurrence of these tracers in eastern PA streams v. streams and rivers in upstate NY.

No discernable patterns were apparent in selected PAH concentrations across sites or between seasons (Fig. 3.2). Tinicum Cr. (V1), the site with the highest percentage of forested area and the lowest road density of the 11 study sites, had the highest summed PAH concentration in the winter but the lowest in the fall. County Line Cr. (I1), the site with the smallest watershed area, had a much higher concentration of benzo(a)anthracene (BAA) and benzo(a)pyrene (BAP) for the fall sample relative to the other sites, but one of the lower winter concentrations. Tinicum Cr with the winter sample, and County Line Cr with the fall sample were the only two sites with BAA and BAP concentrations above the EPA human-health water-quality criteria. Only one other site, Upper Tohickon Cr (II11), had any concentration value above the EPA water-quality criteria (BAP winter value). The PAH ratios shown in Fig. 3.3 all suggest that combustion, not petroleum products, is the primary source of PAHs in these streams. A similar result was found for sites within the drinking water-supply watersheds for NYC (SWRC 2008).

Seasonal consistency in the caffeine and galaxolide (HHCB) concentrations, and to a lesser extent with atrazine, is apparent across the 11 study sites (Fig. 3.4). Such consistency suggests that the sources behind these compounds are constant over time with little variation in a given watershed, at least under baseflow conditions. With only 2 samples per site collected, and only one sample each for fall and winter, this observation of seasonal consistency in the concentrations of caffeine, HHCB, and atrazine should be viewed with appropriate caution. Neither caffeine nor HHCB showed appreciable downstream attenuation in the concentration signal for the 2-pairs of upstream-downstream sites having a reservoir in between [Upper (II11) and Lower (I11) Tohickon; Upper (I3A) and Lower (I3) N. Br. Neshaminy]. If there are no significant sewage inputs directly to these reservoirs, such as from septic system effluent, it would seem that little degradation of these two compounds occurs in reservoirs. Atrazine, one of the more commonly applied herbicides to crop and pasture lands (Thelin and Gianessi 2000), had the highest fall concentrations at the two sites located downstream of reservoirs, Lower Tohickon (I11) and Lower N. Br. Neshaminy (I3). The reason for this observation is not readily apparent.

Fecal steroids concentrations appear to be higher in the Neshaminy Cr sites (except for County Line Cr) relative to the other study sites, based on the sum of fecal steroids (top plot, Fig. 3.5) especially when considering the fall values. No other discernable seasonal patterns were apparent in the representative fecal steroid plots. The steroid-based ratios of bCOP/(bCOP+aCOP) and bCOP/(bCOP+CHO) do not suggest the dominance of one fecal source (i.e. human v. wildlife or human v. livestock) over another. Only the W. Br. Neshaminy (II1) and Little Neshaminy (II7) sites have ratios suggesting that humans are the primary source of fecal contamination relative to any other sources.

The application of the fecal contamination source predictive model to the Bucks Co data (Fig. 3.7) is based on the premise that the steroid ratio signals of the fecal source end-members collected in one region apply to another region. While we did not collect fecal source material to truly confirm the applicability of this model to Bucks Co, the pattern of predicted source values from the Bucks Co stream samples do provide evidence that the model can apply to this region. All of the predicted points in Fig. 3.7 are within the bounds created by the source values used to develop the model. In other words, none of the predicted values are outliers relative to the fecal source values.

The predicted fecal sources for the Bucks Co stream sites suggest that most of the sources are non-human; i.e. majority of the points in Fig.3.7B plot to the left of the first axis which has an increasing human signal to the right. Some seasonality is also suggested within the predicted fecal source values. At six of the eleven sites, signatures during the low-water fall season are further to the left and bottom relative to the higher water winter season (Fig. 3.7). This suggests that a higher proportion of the fecal sources are human during the fall, likely due to less dilution of sewage and also less overland flow carrying other fecal sources. At the same time, the human signature during the dry fall season appears more degraded (lower PC2 values), perhaps due to longer residence times in waste water treatment plants and septic systems. Two sites having the strongest human-source signals wre W. Br. Neshaminy Cr. (II1) and Little Neshaminy Cr. (II7). Both sites have at least 2 WWTPs within their respective watersheds and both are among the more urban sites of the 11 study sites based on 2005 land use/cover values shown in Table 1.3 (Chapter 1). Note that the first axis predicted scores (PC score 1 in Fig 3.7B) for both fall and winter samples were positively related to change in watershed population for these sites (left panel, Fig. 3.10).

The relationships shown in Figs. 3.8-3.10 of selected tracer concentrations and ratios relative to the change in watershed population from 1970 to 2000 demonstrate that some of these selected tracers can be related to watershed conditions. Caffeine and sum of Fragrances (Fig 3.8) along with coprostanol (bCOP) and the ratio of bCOP/(bCOP+aCOP) show relatively strong positive relationships with changes in population, regardless of season. However, a lack of a strong positive relationship with a single measure of human impacts at the watershed scale does not preclude a particular tracer or ratio from providing useful information regarding potential stream water contamination sources. For instance, atrazine concentrations were not significantly related to any of the watershed-level development variables, yet atrazine was significantly related to % water. Certainly this result should not be used to imply that the amount of water in a watershed will lead directly to increased atrazine concentrations. Yet, something might be occurring in around water bodies that might be behind this significant correlation. In similar fashion, the decreasing relationship between the ratio BAA/(BAA+CHR) v. change in population (upper right panel, Fig. 3.8), might provide some clues of the relative importance of automobile exhaust v. other combustion sources. (Dickhut et al. 2000) found that the ratio of BAA/CHR for automobile emissions was much less than found for other emission sources such as burning wood, smelters or coal/coke sources.

Literature Cited

Buerge, I. J., T. Poiger, M. D. Müller, and H.-R. Buser. 2003. Caffeine, an Anthropogenic Marker for Wastewater Contamination of Surface Waters. Environmental Science and Technology 37:691 -700.

Dickhut, R. M., E. A. Canuel, K. E. Gustafson, K. Liu, K. M. Arzayus, S. E. Walker, G. Edgecombe, M. O. Gaylor, and E. H. MacDonald. 2000. Automotive Sources of Carcinogenic Polycyclic Aromatic Hydrocarbons Associated with Particulate Matter in the Chesapeake Bay Region. Environmental Science and Technology 34:4635 -4640.

Dow, C. L. and A. K. Aufdenkampe. 2006. Using SAS to improve the quantification of environmental chemistry samples.*in* Proceedings of the Northeast SAS Users Group Conference, Philadelphia, PA, September 20-22, 2006. (Available at http://www.nesug.org/html/Proceedings/nesug06.pdf).

Du, S., T. J. Belton, and L. A. Rodenburg. 2008. Source apportionment of Polychlorinated Biphenyls in the tidal Delaware River. Environmental Science & Technology 42:4044-4051.

EPA. 2002. The Foundation for Global Action on Persistent Organic Pollutants: A United States Perspective. EPA/600/P-01/003F, Office of Research and Development, Environmental Protection Agency, Washington DC.

Glassmeyer, S. T., E. T. Furlong, D. W. Kolpin, J. D. Cahill, S. D. Zaugg , S. L. Werner, and M. T. Meyer. 2005. Transport of Chemical and Microbial Compounds from Known Wastewater Discharges: Potential for Use as Indicators of Human Fecal Contamination. Environmental Science and Technology 39:5157-5169.

Grimalt, J. O., P. Fernandez, J. M. Bayona, and J. Albaiges. 1990. Assessment of fecal sterols and ketones as indicators of urban sewage inputs to coastal waters. Environmental Science and Technology 24:357 - 363.

Hedges, J. I. and F. G. Prahl. 1993. Early diagenisis: Consequences for applications of molecular biomarkers. Pages 237-253 *in* M. H. Engel and S. A. Macko, editors. Organic Geochemistry. Plenum Press, New York.

Helsel, D. R. 1990. Less than obvious. Environmental Science and Technology 24:1767-1774.

Kolpin, D. W., E. T. Furlong, M. T. Meyer, E. M. Thurman, S. D. Zaugg, L. B. Barber, and H. T. Buxton. 2002. Pharmaceuticals, Hormones, and Other Organic Wastewater Contaminants in U.S. Streams, 1999-2000: A National Reconnaissance. Environmental Science and Technology 36:1202 -1211.

Leeming, R., A. Ball, N. Ashbolt, and P. Nichols. 1996. Using faecal sterols from humans and animals to distinguish faecal pollution in receiving waters. Water Research 30:2893-2900.

Mudge, S. M., M. J. A. F. Bebianno, J. A. East, and L. A. Barreira. 1999. Sterols in the Ria Formosa Lagoon, Portugal. Water Research 33:1038-1048.

O'Leary, T., R. Leeming, P. D. Nichols, and J. K. Volkman. 1999. Assessment of the sources, transport and fate of sewage-derived organic matter in Port Phillip Bay, Australia, using the signature lipid coprostanol. Marine and Freshwater Research 50:547-556.

Simonich, S. L., W. M. Begley, G. Debaere, and W. S. Eckhoff. 2000. Trace Analysis of Fragrance Materials in Wastewater and Treated Wastewater. Environmental Science and Technology 34:959 -965.

Standley, L. J., L. A. Kaplan, and D. Smith. 2000. Molecular tracers of organic matter sources to surface water resources. Environmental Science and Technology 34:3124-3130.

SWRC. 2008. Water quality monitoring in the source water areas for New York City: An integrative approach. A final report on monitoring activities, 2000-2005. Contribution No. 2008006., Stroud Water Research Center, Avondale, PA.

Thelin, G. P. and L. P. Gianessi. 2000. Method for estimating pesticide use for county areas of the conterminous United States. Open-File Report 00-250, United States Geological Survey, Sacramento, California.

USGS. 1999. New Reporting Procedures Based on Long-Term Method Detection Levels and Some Considerations for Interpretations of Water-Quality Data Provided by the U.S. Geological Survey National Water Quality Laboratory. Open-File Report 99–193, U.S. Geological Survey, Reston, Virginia.

Yunker, M. B., R. W. Macdonald, R. Vingarzan, R. H. Mitchell, D. Goyette, and S. Sylvestre. 2002. PAHs in the Fraser River basin: a critical appraisal of PAH ratios as indicators of PAH source and composition. Organic Geochemistry 33:489-515.

Zakaria, M. P., H. Takada, S. Tsutsumi, K. Ohno, J. Yamada, E. Kouno, and H. Kumata. 2002. Distribution of Polycyclic Aromatic Hydrocarbons (PAHs) in Rivers and Estuaries in Malaysia: A Widespread Input of Petrogenic PAHs. Environmental Science and Technology 36:1907 -1918.

Table 3.1. Compounds chosen as molecular tracers of contamination and their associated abbreviations used in text and figures. The Laboratory Reporting Levels (LRL) and no false positive values were reproduced from the NY watersheds project (SWRC 2008). The Laboratory Reporting Levels (LRL) are equivalent to 99% confidence levels for no false negatives, and the 75% and 95% confidence levels for no false positives were derived from distributions of measured blanks. Laboratory blank concentrations from present project are provided for comparison the LRL and no false positive values. Ambient water quality criteria are listed for reference. NY watersheds project samples were not analyzed for pesticides.

Analyte	Abbreviation	Laboratory Reporting Level (µg/L)	75% Confidence No False Positives (µg/L)	95% Confidence No False Positives (µg/L)	Bucks Co Project Lab Blanks (µg/L)		EPA: Human health for consumption of (µg/L)[a]	
					2007	2008	Water + Organism	Organism Only
PAH								
fluorene	FLU	0.00059	0.0007	0.0035	0.0002	0.	1100	5300
phenanthrene	PHE	0.00054	0.0024	0.0135	0.	0.		
anthracene	ANT	0.00066	0.0008	0.0038	0.0003	0.	8300	40000
2-methyl phenanthrene	2MP	0.0012	0.0011	0.0105	0.0006	0.		
1-methyl phenanthrene	1MP	0.00074	0.0007	0.0055	0.0004	0.		
fluoranthene	FLR	0.00036	0.0015	0.0044	0.	0.	130	140
pyrene	PYR	0.00033	0.00081	0.0078	0.0002	0.	830	4000
benz(a)anthracene	BAA	0.00035	0.00062	0.0025	0.0003	0.	0.0038	0.018
chrysene	CHR	0.00018	0.00053	0.0042	0.	0.	0.0038	0.018
benzo(b)fluoranthene	BBF	0.00031	0.00058	0.012	0.0005	0.0002	0.0038	0.018
benzo(k)fluoranthene	BKF	0.00065	0.00049	0.0108	0.0009	0.0005	0.0038	0.018
benzo(a)pyrene	BAP	0.00031	0.00048	0.0091	0.0005	0.	0.0038	0.018
Fragrances & Caffeine								
tonalide	HHCB	0.0068	0.0040	0.013	0.001	0.0033		
galaxolide	AHTN	0.0032	0.0058	0.016	0.0002	0.0151		
caffeine	CAF	0.0039	0.0023	0.011	0.0037	0.		
Steroids								
coprostanol (5β-cholestan-3β-ol)	bCOP	0.00059	0.0013	0.016	0.	0.		
epi-coprostanol (5β -cholestan-3α-ol)	EPI	0.0026	0.0016	0.017	0.	0.		
cholesterol (cholest-5-en-3β-ol)	CHO	0.013	0.024	0.038	0.0114	0.0121		
cholestanol (5α-cholestan-3β-ol)	aCOP	0.0015	0.0022	0.040	0.	0.		
cholestanone (5α-cholestan-3-one)	aONE	0.0021	0.0014	0.015	0.	0.		
coprostanone (5β-cholestan-3-one)	bONE	0.0052	0.0025	0.028	0.	0.		
24-ethyl-coprostanol (24-ethyl-5β-cholestan-3β-ol)	eCOP	N/A	0.	0.	0.042	0.		
24-ethyl-*epi* coprostanol (24-ethyl-5β-cholestan-3α-ol)	eEPI	N/A	0.	0.00054	0.0357	0.		
24-ethyl-cholesterol (24-ethyl-cholest-5-en-3β-ol)	eCHO	0.0923	0.1899	0.447	0.134	0.		
ethyl-cholestanol (24-ethyl-5α-cholestan-3β-ol)	SNOL	0.0050	0.0080	0.023	0.0174	0.0105		
Pesticides								
6-Chloro-N-ethyl-N4-Isopropyl-1,3,5-triazine-diamine	atrazine	N/A			0.0002	0.		
Methyl N-(2-methoxyacetyl)-N-(2,6-xylyl)-DL-alaninate	metalaxyl	N/A			0.0006	0.		
O,O-Diethyl-O-3,5,6-trichloro-2-2pyridyl phosphorothioate	chlorpyrifos	N/A			0.	0.		
PCBs								
2,3',4,4',5-Pentachlorobiphenyl	PCB118	N/A			0.0002	0.	0.000064	0.000064
2,2',4,4',5,5'-Hexachlorobiphenyl (153)	PCB153	N/A			0.0001	0.	0.000064	0.000064
2,2',3,4,4',5'-Hexachlorobiphenyl (138)	PCB138	N/A			0.0001	0.	0.000064	0.000064

a - USEPA. 2002. National recommended water quality criteria: 2002. EPA-822-R-02-047, United States Environmental Protection Agency, Washington, DC.

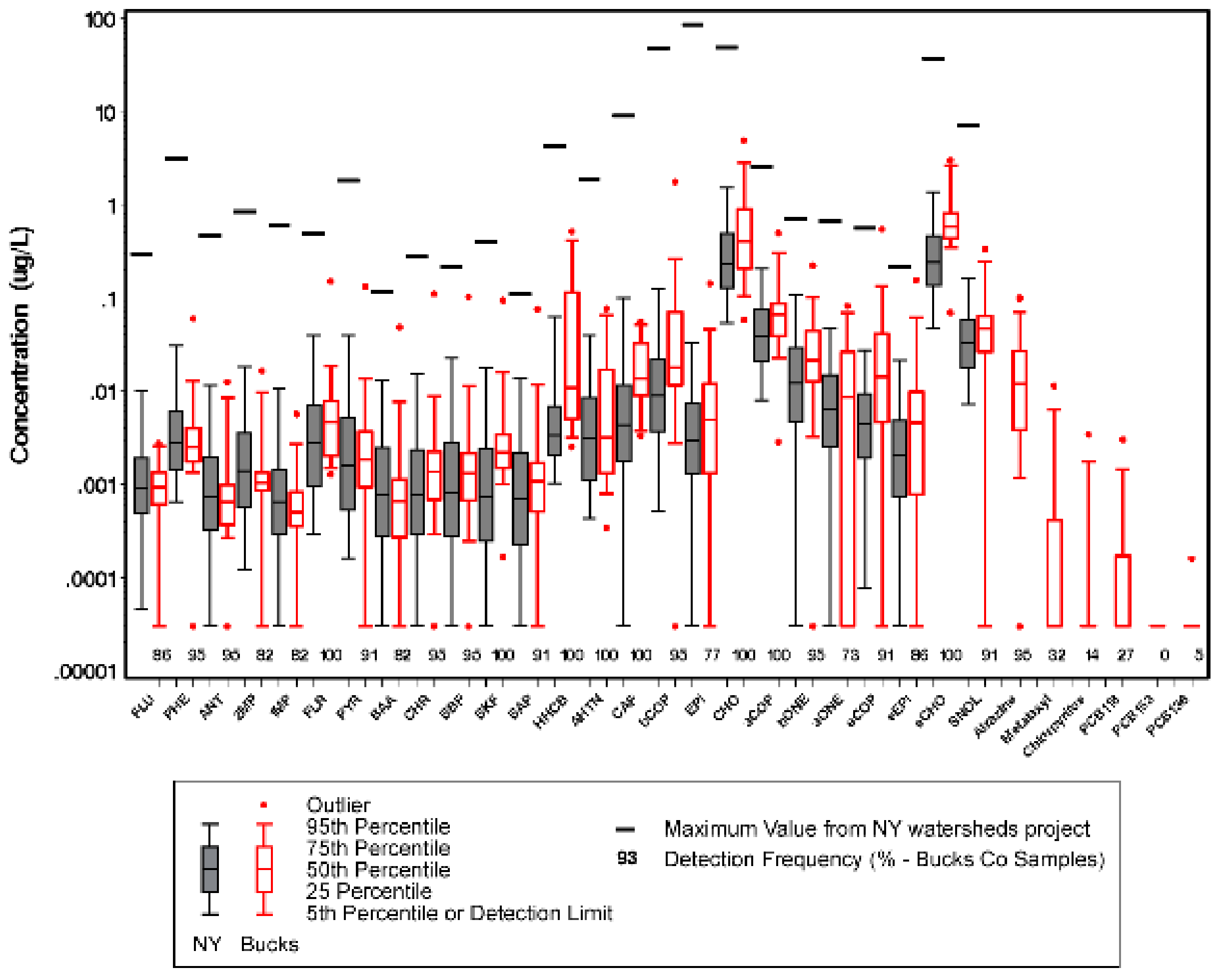


Figure 3.1. Distribution of streamflow concentrations for each of 31 tracer compounds measured in 11 Bucks County stream sites visited in 2007-2008 (n = 22 for each compound), relative to baseflow value distributions measured at 110 stream sites from 2000-2006 in the NY drinking-water watersheds (SWRC 2008). NY samples were not analyzed for the 3 pesticides and 3 PCBs shown in the plot. Detection frequency values for the Bucks County monitoring effort, as a percentage of total samples, are given in bold. 0.00003 was added to all values in order to plot all data on a log scale.

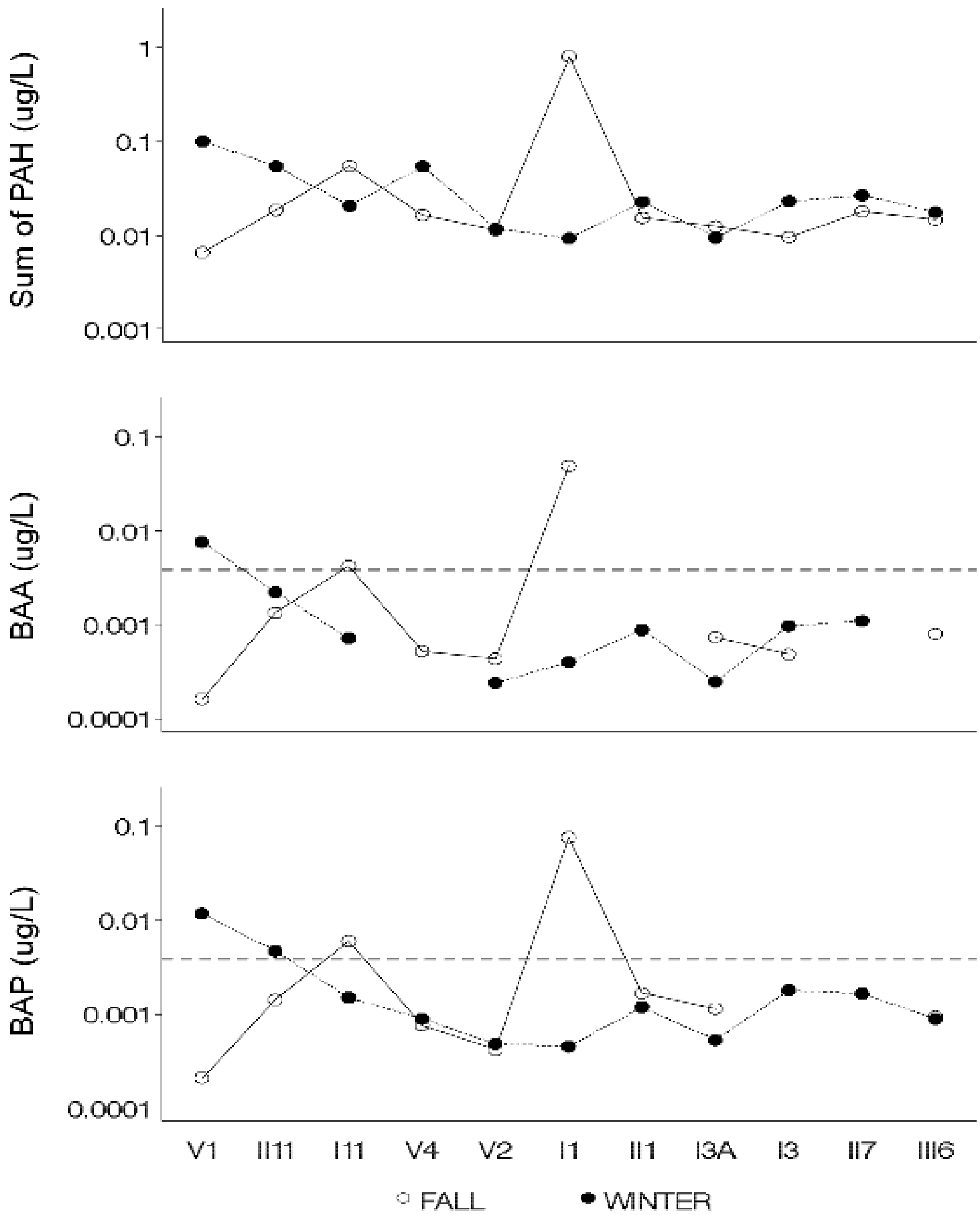


Figure 3.2. Concentrations of all measured PAH compounds (1MP, 2MP, ANT, BAA, BAP, BBF, BKF, CHR, FLR, FLU, PHE, PYR – top plot), benzo(a)anthracene (BAA – middle plot) and benzo(a)pyrene (BAP – bottom plot) in fall and winter samples collected at the 11 Bucks Co stream sites. Stream names corresponding to the site ids provided can be found in Table 1.2 in Chapter 1. Dashed lines in the BAA and BAP plots represent the EPA human health-related water quality criteria (See Table 3.1). Missing values for a site indicate a non-detect.

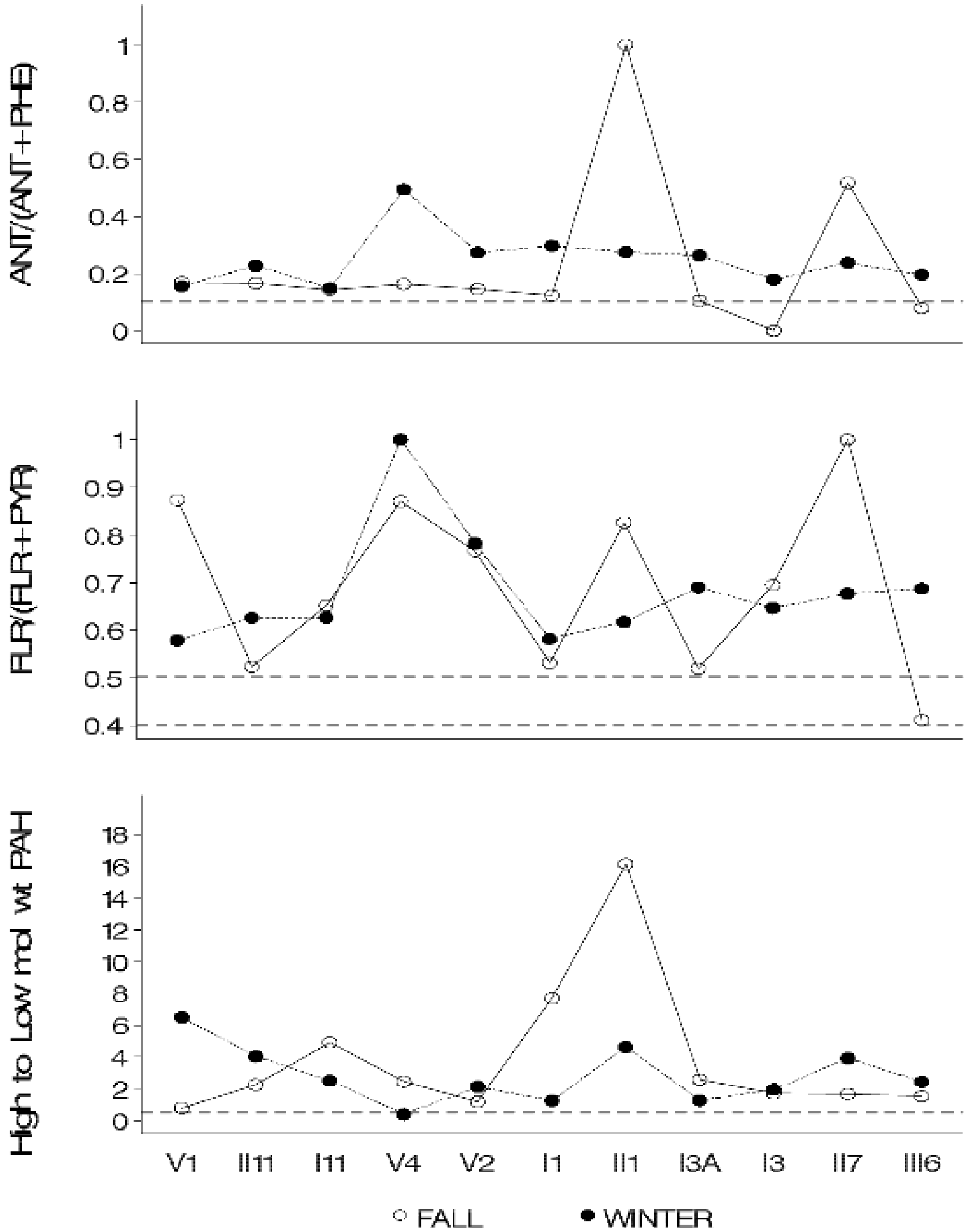


Figure 3.3. Selected PAH source-indicator ratios for fall and winter samples collected at the 11 Bucks Co stream sites. The dashed line in each plot represents a suggested delimitation between combustion and petroleum sources. In the top plot of ANT/(ANT+PHE) [anthracene/(anthracene+phenanthrene)], ratios > 0.1 suggest combustion sources while ratios < 0.1 suggest petroleum sources (Yunker et al. 2002). For the middle plot of FLR/(FLR+PYR) [fluoranthene/(fluoranthene+pyrene)] combustion sources are suggested by ratios >0.5 while petroleum sources are suggested for ratios < 0.4 (Yunker et al. 2002). In the bottom plot of high molecular weight PAHs [sum(FLR, PYR, BAA, CHR, BBF, BKF, BAP)] to low molecular weight PAHs [sum(FLU, PHE, ANT, 2MP, 1MP), ratios > 0.5 suggest combustion or asphalt sources while ratios < 0.5 suggest petroleum sources (Zakaria et al. 2002). Stream names corresponding to the site ids provided can be found in Table 1.2 in Chapter 1.

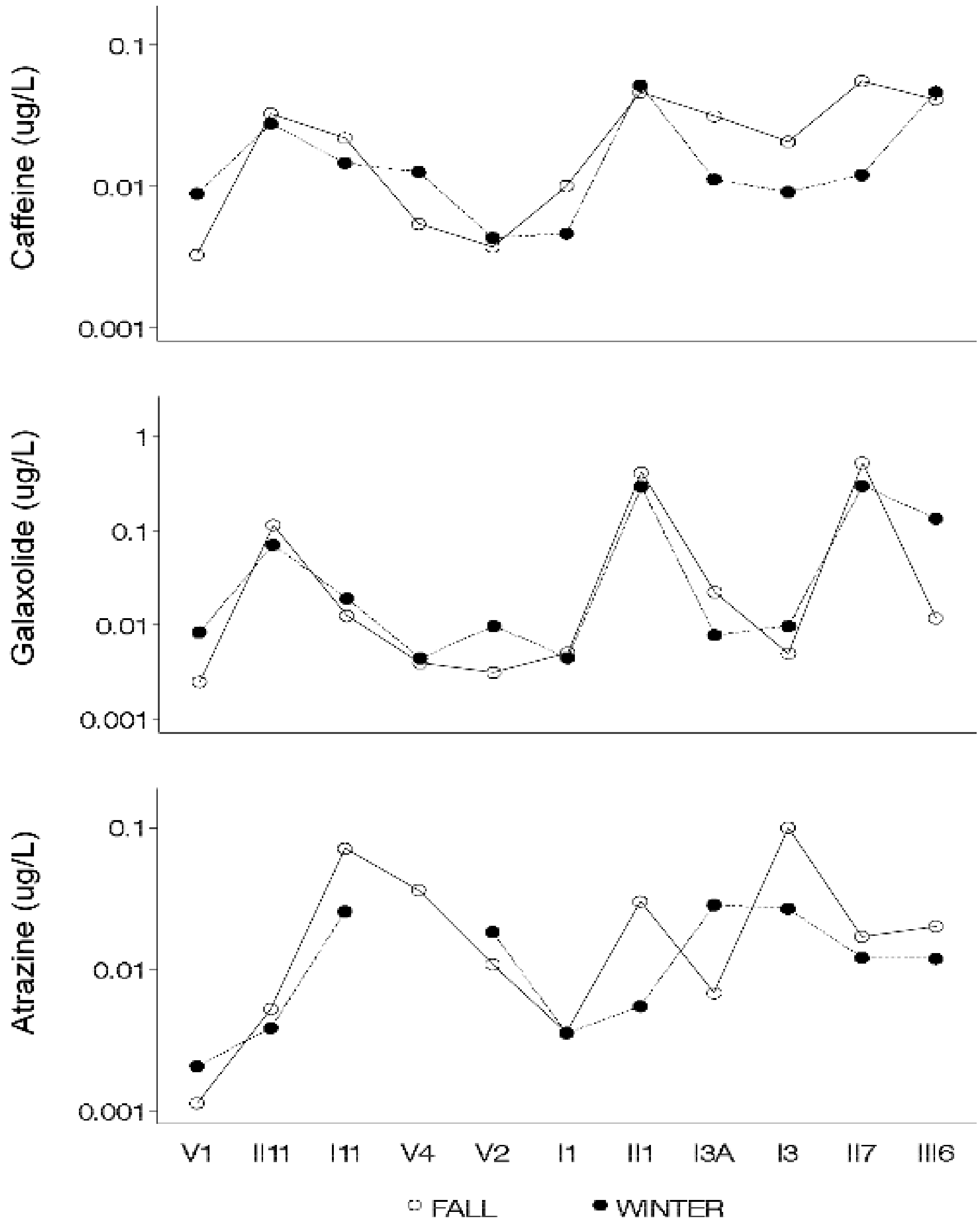


Figure 3.4. Concentrations of caffeine (top plot), the fragrance galaxolide (HHCB – middle plot) and the pesticide atrazine (bottom plot) in fall and winter samples collected at the 11 Bucks Co stream sites. Stream names corresponding to the site ids provided can be found in Table 1.2 in Chapter 1. Missing values for a site indicate a non-detect.

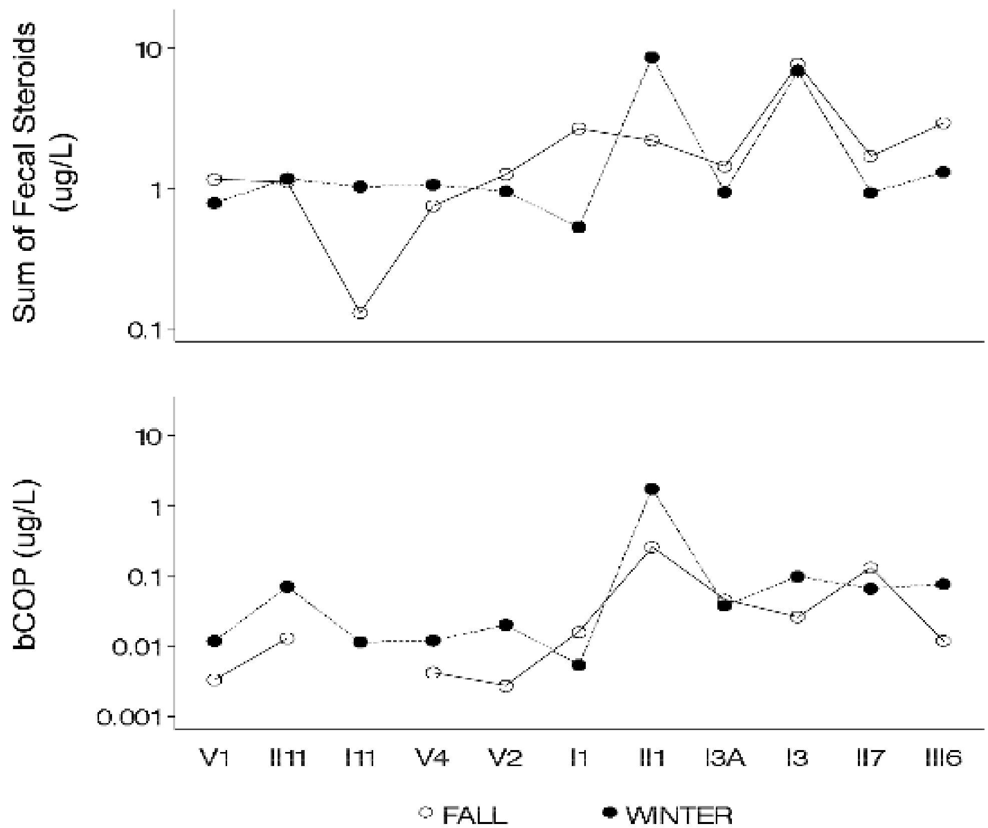


Figure 3.5. Concentrations of all measured steroid compounds (aCOP, aONE, bCOP, bONE, CHO, EPI and SNOL – top plot) and coprostanol (bCOP – bottom plot) in fall and winter samples collected at the 11 Bucks Co stream sites. Stream names corresponding to the site ids provided can be found in Table 1.2 in Chapter 1. Missing values for a site indicate a non-detect.

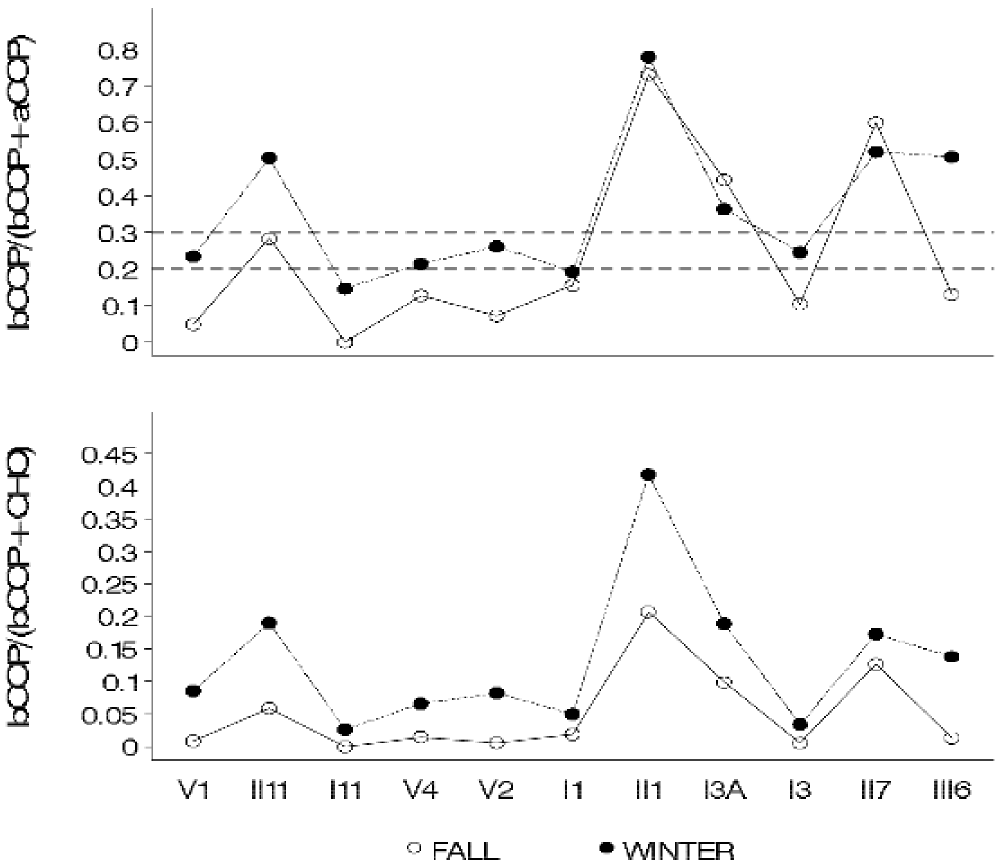


Figure 3.6. Selected fecal steroid source-indicator ratios for fall and winter samples collected at the 11 Bucks Co stream sites. In the top plot of bCOP/(bCOP+aCOP) [coprostanol/(coprostanol+cholestanol)] the dashed line provides a delimitation between human fecal sources (ratio > 0.3) and wildlife sources (ratio < 0.2) in watersheds with minimal livestock (Grimalt et al. 1990), (O'Leary et al. 1999). For the bottom plot of bCOP/(bCOP+CHO) [coprostanol/(coprostanol +cholesterol)] high ratio values suggest that human fecal sources dominate over livestock and wildlife sources (Mudge et al. 1999). Stream names corresponding to the site ids provided can be found in Table 1.2 in Chapter 1.

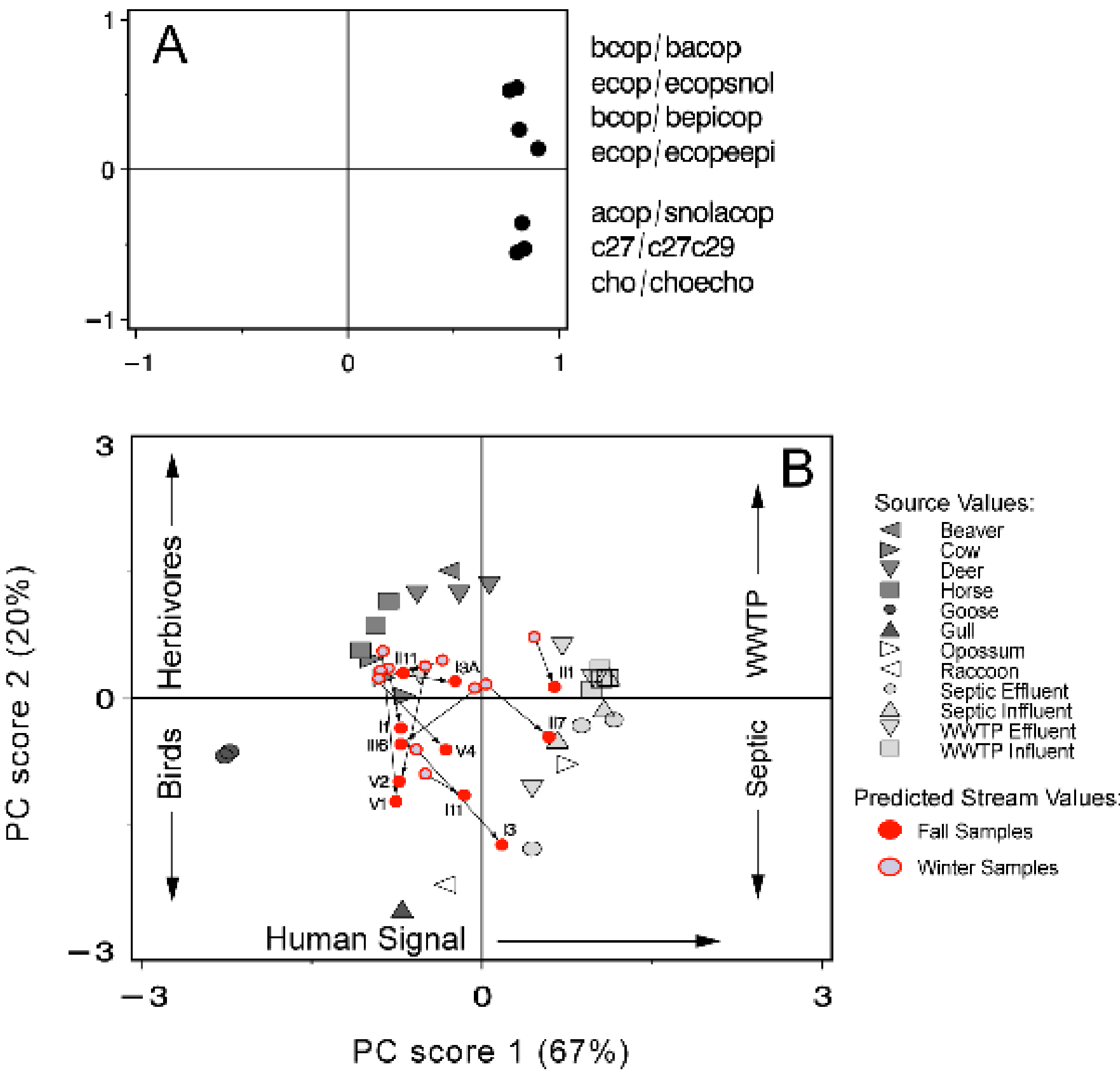


Figure 3.7. Predicted values of fecal sources for the fall and winter samples collected at the 11 Bucks Co stream sites. The fecal source model was developed using Principal Component Analysis (PCA) and fecal steroid ratios of fecal source samples collected during the NY watersheds project (SWRC 2008). See text for more detail.

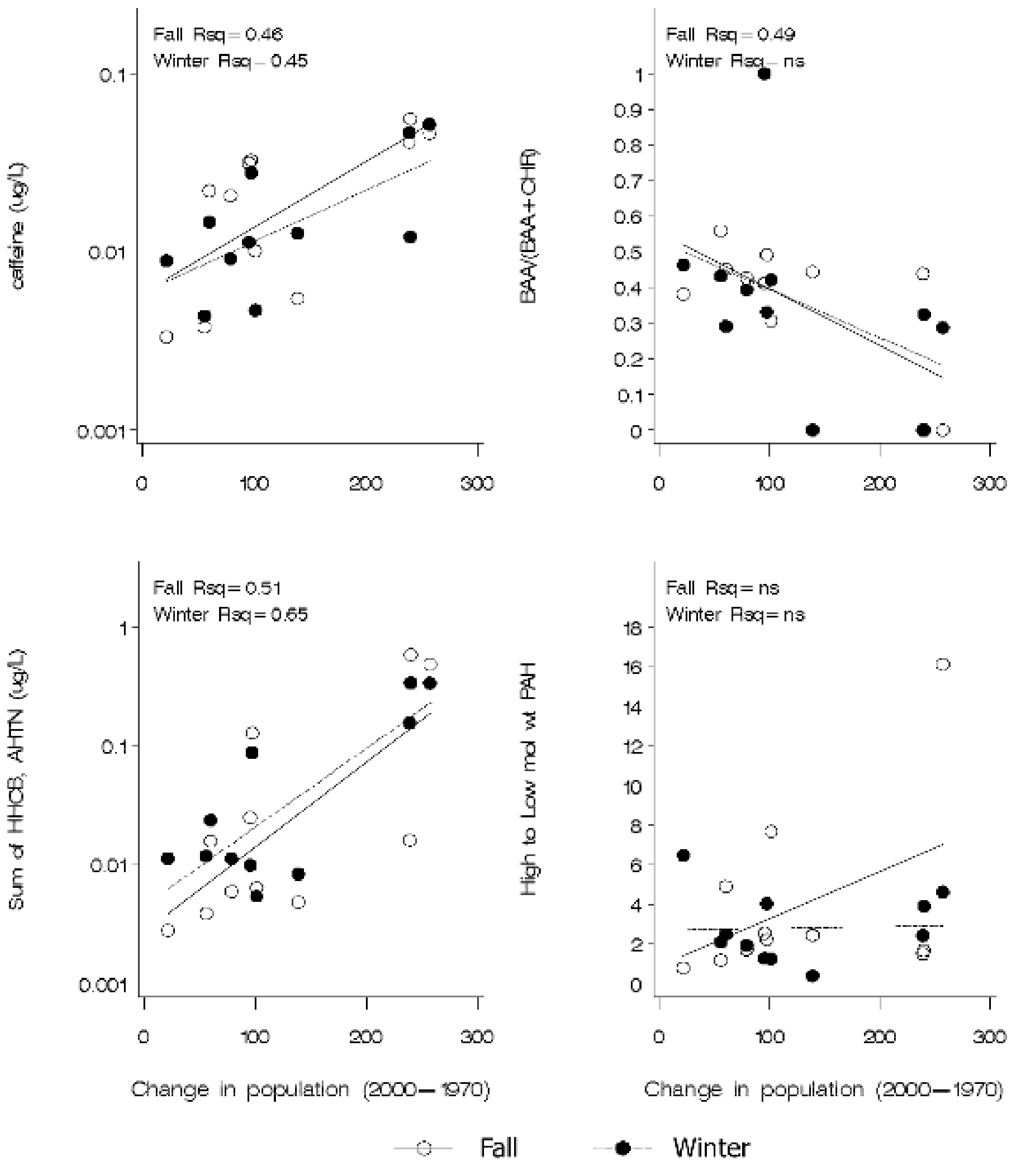


Figure 3.8. Separate relationships for fall and winter values of selected tracer concentrations (caffeine, sum of fragrances [HHCB + AHTN]) and PAH source-indicator ratios [(BAA/(BAA+CHR), high-to-low molecular weight PAHs] versus the change in watershed population from 1970 to 2000. Lines represent regression relationships which were based on regressing $\log_{10}$-transformed concentration values (0.00003 added to avoid taking the log of zero) or untransformed ratio values against the change in population values. Rsq values are provided if the regression equation was significant at α=0.05.

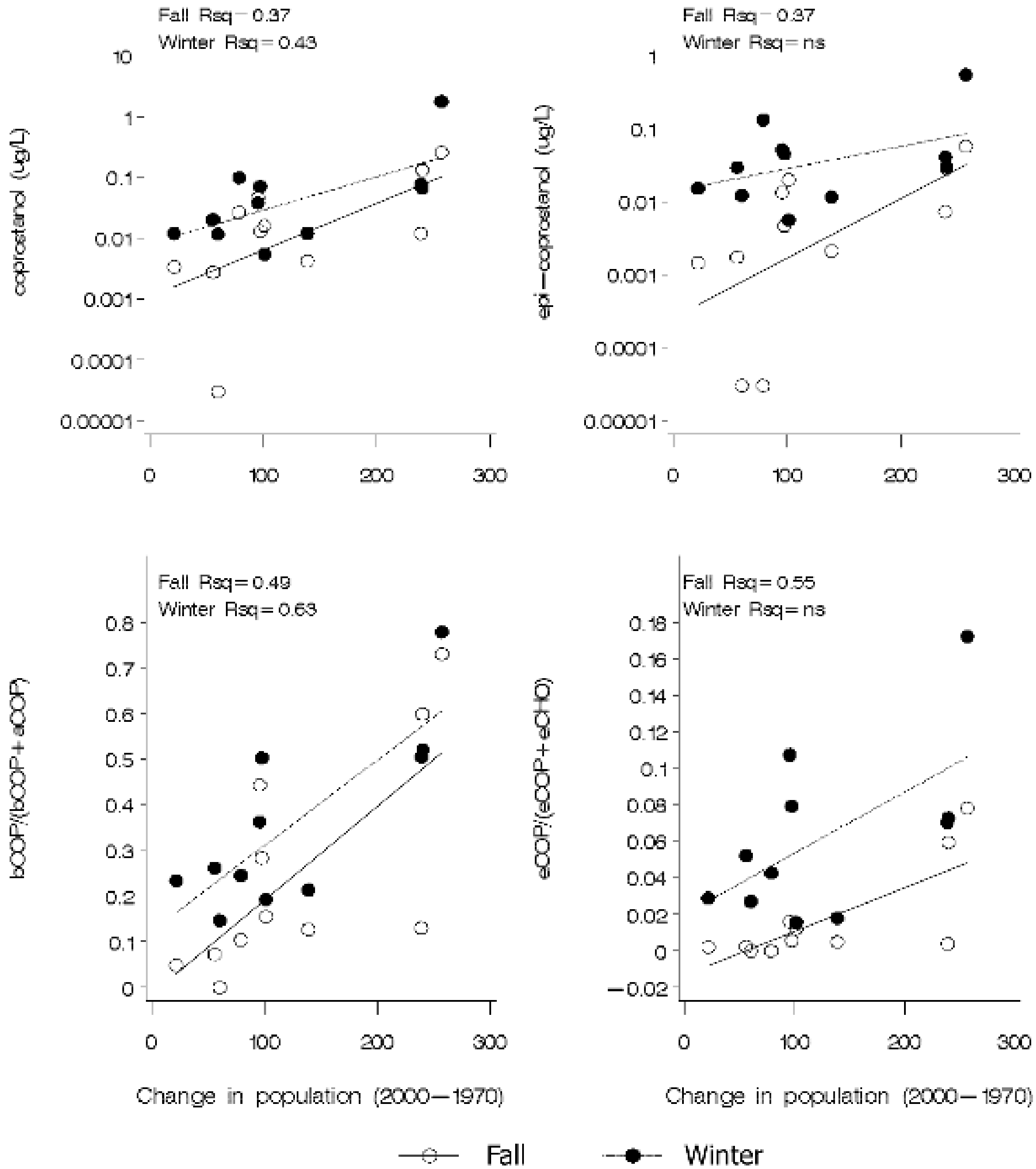


Figure 3.9. Separate relationships for fall and winter values of selected fecal steroid concentrations (coprostanol - bCOP, epi-coprostanol - eCOP) and fecal steroid source-indicator ratios [(bCOP/(bCOP+aCOP), eCOP/(eCOP+eCHO)] versus the change in watershed population from 1970 to 2000. Lines represent regression relationships which were based on regressing $\log_{10}$-transformed concentration values (0.00003 added to avoid taking the log of zero) or untransformed ratio values against the change in population values. Rsq values are provided if the regression equation was significant at α=0.05.

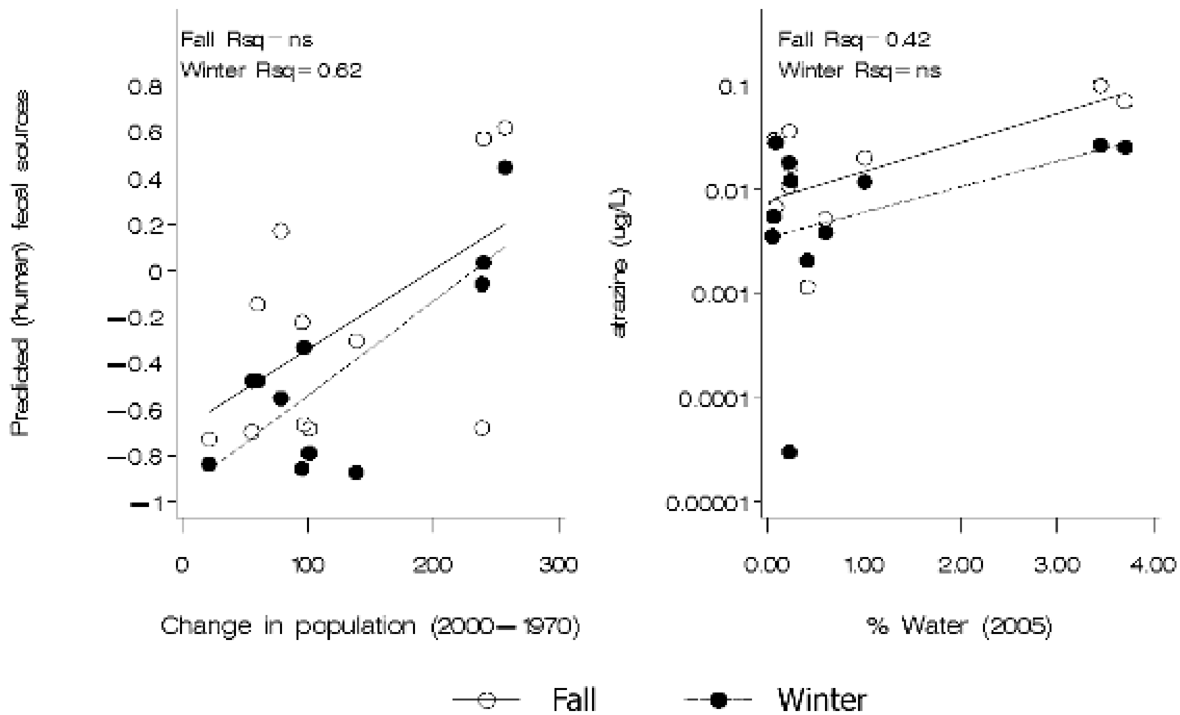


Figure 3.10. Separate relationships for fall and winter values of predicted fecal sources (axis 1 from the PCA model shown in Fig. 3.8) versus the change in watershed population from 1970 to 2000 and atrazine concentrations versus % water (from 2005 land cover data). Lines represent regression relationships which were based on regressing $\log_{10}$-transformed concentration values (0.00003 added to avoid taking the log of zero) against either the change in population values or % water. Rsq values are provided if the regression equation was significant at α=0.05.

----------------------Intentionally Blank----------------------

Chapter 4. *Escherichia coli* and Total Coliform densities

Overview

Coliform densities were included in the earlier survey of Bucks County streams as part of the chemistry program. These organisms serve as indicators of fecal pollution. This assessment was included in the present study by measuring the densities of *Escherichia coli* and total coliforms. The total coliform count indicates potential fecal contamination from humans and other animal sources, but the interpretation of the data is complicated by the fact that coliform bacteria may also be of non-fecal origin, e.g., soil or plant sources. Nevertheless, the total coliform count is still the standard test for drinking water because it indicates possible contamination of fecal origin (U. S. EPA 5.11 Fecal Bacteria). The U.S. EPA considers that *E. coli* is the most reliable indicator of health risk for recreational waters because of its specificity as an indicator of fecal contamination (Elmund et al. 1999, EPA 2003, Doyle and Erickson 2006) and recommends that it be used as the standard for evaluating the sanitary condition of freshwaters. By 2003, 18 states had adopted *E. coli* for that purpose, but Pennsylvania continues to use the fecal coliform assay in which elevated temperature of incubation is used to distinguish coliforms of fecal origin from those of other sources. The EPA method used here (Method 1604) allows the simultaneous quantification of *E. coli* and total coliforms on the same filter. We used equations from the literature to convert *E. coli* densities to fecal coliform densities because Pennsylvania uses the fecal coliform criterion and this allowed comparison of our results with earlier data. Four equations were tested, all derived from large data sets that included both numbers (Cude 2005, Francy et al., 1993, Rasmussen and Ziegler 2003) and the most reliable were used in estimating fecal coliform densities.

Methods

Streams were sampled between June 7 and July 2, 2007 and again on August 13-14 (Table 4.1). Water samples (100 ml) were collected from the bottom, middle and top of each reach using sterile containers (Fisherbrand, Fisher Scientific, Hampton, NH). Samples were placed on ice in a cooler immediately after collection and were processed within 4 – 12 h. Using aseptic technique, one 1 ml aliquot, one 10 ml aliquot and one 100 ml aliquot was filtered through a membrane filter (Whatman gridded cellulose nitrate membrane, 0.45 µm pore size, 47 mm diameter, packaged sterile) at 0.5 atmospheres. To ensure an even distribution of colonies on the filters, the 1 ml and 10 ml aliquots were diluted in 99 or 90 ml sterile groundwater, respectively, before filtration. A field blank was performed with each set of samples collected in June-July 2007 by filling a sample bottle with autoclaved groundwater in the field and processing it as a sample. A duplicate 10 ml volume was filtered for each downstream sample collected in June-July 2007 to assess reproducibility at the filtering step. The filtration apparatus was washed, rinsed and autoclaved between days of use and it was sterilized between sites processed on the same day in the field by spraying it with ethanol and flaming.

Following the filtration step, each filter was placed onto a pad saturated with 2 ml m-ColiBlue24 broth (Millipore, Billerica, MA) in a PetriSlide container (Millipore, Billerica, MA). The container was capped, inverted and placed in a portable Fecal Coliform incubator set at

35°C. Temperature was verified using a NIST traceable, digital min-max thermometer. After 24 h of incubation the numbers of *E. coli* and total coliform colonies were determined on each filter. Total coliforms on the filters appeared as red colonies and *E. coli* as blue colonies as the result of enzymes in the organisms acting on specific constituents in the medium. Other taxa appeared white or colorless.

Whenever possible, the counts reported here were obtained from filters with a dilution yielding between 20 – 80 *E. coli* or total coliform colonies and filters with ≤200 total colonies. However, because it was not possible to re-sample stations if counts were not in range, we accepted the data from non-ideal counts if necessary. Counting rules found in Method 9222 (APHA 1998) and the U. S. EPA Microbiological Manual (Bordner *et al*. 1978) were applied as follows. Counts from the duplicate 10 ml aliquots taken from the same downstream sample were averaged before use in further computations. When more than one count at a given dilution was in the acceptable (i.e, 20 – 80 colony) range, the counts were averaged to generate a number of *E. coli* or total coliforms/100 ml for the stream. If only one filter was in range, that count was used to generate the number for the stream. If all counts were below the acceptable range, the counts at the dilution closest to the range giving distinct colonies and most reasonable total densities were averaged and reported as "estimate". The filters never had confluent growth on them and colorless colonies were low in number, but sometimes the total coliform count in the 10 and 100 ml samples was greater than 200 colonies. Decisions pertinent to accepted data are reported in Table 4.2.

Four equations for estimating fecal coliform densities from *E. coli* densities were compared. Equation (1), presented in Cude (2005), with an $R^2 = 0.75$ ($p < 0.001$) was based on the analysis of ~ 875 stream and river samples collected at the time Oregon (OR) changed from the use of fecal coliforms to *E. coli* as the indicator of fecal pollution.

$$\text{Fecal coliform} = 1.82 \times (E.\ coli)^{0.946} \tag{1}$$

Equation (2) resulted from another statewide study involving 272 samples from Kansas (KS) streams and rivers (Rasmussen and Ziegler 2003).

$$\log_{10}\ \text{Fecal Coliforms} = \frac{\log_{10}\ E.\ coli + 0.00428}{0.966} \tag{2}$$

Fandrei (1985) measured both indicators in the Mississippi and St. Croix Rivers in Minnesota (MN) and found strong correspondence in densities (Equation 3, $R^2 = 0.97$).

$$\ln\ E.\ coli = 0.95 \times \ln\ \text{Fecal coliform} + 0.26 \tag{3}$$

Equation (4) was generated in a study of a recreational floatway in Alabama (AL) in which researchers found a good prediction ($R^2 = 0.81$) of *E. coli* from fecal coliform densities using the following equation (Milligan 1987).

$$l_{10}\ E.\ coli = 0.88 \times l_{10}\ \text{fecal coliform} + 0.73 \tag{4}$$

Here we used each of these equations to compute fecal coliform densities from the *E. coli* densities measured in June and August. Comparison of results indicated that the estimates from the OR and AL equations were significantly different, but that neither of these estimates differed significantly from the KS or MN estimates (ANOVA, $p = 0.03$, $df = 87$; Tukey test, $p = 0.05$). The difference between the high and low values generated by the OR, KS and MN equations was 51 colonies/100 ml whereas this difference was 143 colonies/100 ml when the KS, MN, and AL values were compared. Thus the estimate of fecal coliforms was based on the average value generated by the OR, KS, and MN equations.

Total coliform and *E. coli* density data were examined for correlations with geographical, chemical, physical and other biological data. Data were log transformed or arc-sin square root transformed (for ratios) before analysis.

Results and Discussion

Blanks never were positive for *E. coli* or total coliforms, which indicated that the sterilization procedure adequately protected against cross-contamination of samples. The relative percent difference (RPD) between duplicate filters from the same sample for the downstream sample averaged 12.5% for total coliforms, indicating good procedural reproducibility. Most of those RPDs ranged from 1 to 17% for samples with cell densities between 177 and 377; one RPD was 28.6% for a sample with a cell density of 38.5. The RPDs for *E. coli* were more variable because cell densities were lower, ranging from 1 – 49 cells/filter. *E. coli* colony densities exceeded 20 on 4 filter sets and the average RPD for them was 6.5%.

E. coli densities ranged from a high of 677/100 ml (W. Branch Neshaminy, August) to an estimated low of 17/100 ml (Lower Tohickon, June; Fig 4.1). The highest mean *E. coli* density occurred in the W. Br. Neshaminy and the lowest in Lower Tohickon. For recreational use of water the *E. coli* density should not exceed 235 colonies/100 ml in a single sample, or a geometric mean (based on >5 samples per 30 days) of 126 colonies/100 ml. The geometric means of the 2 samples collected from each stream are shown in Fig 4.1 in relationship to the geometric mean standard although the data are not strictly comparable because the sample size was less than 5. The values for W. Br. Neshaminy, County Line and Tinicum exceeded that criterion and Little Neshaminy was borderline with a geometric mean of 127/100 ml. Both samples for W. Br. Neshaminy and County Line exceeded the acceptable limit for *E. coli* in a single sample. One sample each from Little Neshaminy and Upper N. Br. Neshaminy exceeded the single-sample limit for *E. coli* density but neither sample from Tinicum did. Note that the arithmetic average for three streams, W. Br. Neshaminy, County Line, and Little Neshaminy, exceeded the limit for a single sample. Neither sample from any of the remaining streams exceeded the single sample limit for *E. coli* density, indicating acceptable water quality for recreational use.

Total coliform densities ranged from 12,400/100 ml (Little Neshaminy, June) to 510/100 ml (Upper N. Br. Neshaminy, August; Fig 4.2). As for *E. coli*, highest densities occurred in Little Neshaminy, County Line and W. Br. Neshaminy and lowest densities in Lower Tohickon. Pidcock had moderately high densities of total coliforms but low *E. coli* densities indicating that non-fecal coliforms were common there.

Earlier reports (1969 – 1972) did not specify whether total or fecal coliform densities were being reported. Our work only produced values for total coliform densities. The estimates of fecal coliform densities generated from *E. coli* densities using the equations from the OR, MN, and KS studies are shown in Table 4.3. Total coliform and estimated fecal coliform densities in 2007 were compared with data collected on dates between May 1 and September 30 found in reports dated 1969 – 1972 (Fig 4.3). If the earlier reported data were total coliforms, a comparison with our results suggests that total coliform densities increased or remained nearly the same in all but one stream. This is highly unlikely, given the improvements to wastewater treatment implemented during the intervening years. More, likely the 1967 - 1972 data were for fecal coliform densities, in which case the fecal coliform estimates from the present study show striking improvement over historical values in all streams.

The current standard for fecal coliforms for waters used for contact sports between May 1 – September 30 is set by Pennsylvania at 200 fecal coliforms/100 ml (geometric mean of 5 or more samples collected on different days during a 30-day period). Assuming that the historical coliform data were fecal coliforms, none of the streams would have met this standard for recreational use in 1967 – 1971 (based on sample sizes ranging from 5 to 29 collected during the summer over the 5-year period). In contrast, estimated fecal coliform densitites for 2007 are below this value for all streams but County Line, W. Br. Neshaminy and Tinicum, with the caveat that we did not have 5 samples in a 30-day period. The 1969 report states that all streams but Pidcock and Puanacussing failed to meet recreational criteria in the 1967 – 1968 period and that no coliforms were detected in Tinicum due to a toxic discharge from a chemical plant.

Total coliform densities correlated with only a few of over 160 variables (or ratios of variables) examined. *E. coli* showed a greater number of statistically significant correlations and a few with p values that were nearly significant (Table 4.4). The negative correlation of *E. coli* densities with % water in the watershed is strongly influenced by the two sites downstream of impoundments (Lower Tohickon and Lower N. Br. Neshaminy). It is reasonable that retention of water in a reservoir would allow for the removal of target bacteria through settling and ingestion by plankton, thereby lowering concentrations at downstream stations. However, some of the other correlations of *E. coli* with environmental variables are quite possibly indirect. For example, while the correlation with alkalinity could reflect local geology or perhaps wastewater treatment plant effluent the correlation might also be the result of intercorrelations of alkalinity with other chemical variables (e.g., particulate phosphorus) or with the geographic variable of % water in the watershed.

E. coli densities were essentially significantly positively correlated ($r = 0.59$, $p = 0.051$) with the molecular tracer bCOP (coprostanol), a fecal steroid strongly associated with human feces. The correlation of *E. coli* with the ratio bCOP/(bCOP+aCOP), i.e., coprostanol/(coprostanol+cholestanol) was significant ($r = 0.61$, $p = 0.045$). A ratio >0.2 is likely to be associated with human sources rather than other animals, at least in watersheds with limited livestock (Grimalt et al 1990, O'Learly et al. 1999), as our study watersheds were. Parenthetically, total coliform densities were nearly significantly related to the ratio bCOP/(bCOP+EPI), i.e., coprostanol/(coprostanol+epicoprostanol), a ratio with a similar implication ($r = 0.58$, $p = 0.064$). The highest bCOP concentrations were measured at W. Br. Neshaminy, and Little Neshaminy, which were locations downstream of wastewater treatment plants and bCOP was significantly and positively correlated with the nos. of WWTP/km^2

(r=0.70, $p = 0.017$). The strongest signal of fecal steroids (and their ratios) from human sources, wastewater treatment plants and septic systems, occurred at these sites (see Chapter 3, Molecular Tracer Analyses). Upper Tohickon is also downstream of a wastewater treatment plant, but the tracer signal there was less distinctive of human sources, perhaps because the plant was more efficient. *E. coli* was also correlated positively with concentrations of 24-ethyl-cholestanol (SNOL) and 24-ethylcoprostanol (eCOP), both fecal steroids but having weaker association with human feces. The highest concentrations of SNOL and eCOP were found at W. Br. Neshaminy and the second highest concentration of eCOP occurred at Little Neshaminy, which, as noted, are affected by permitted septic systems and wastewater effluents. However, the second and third highest concentrations of SNOL and the third highest concentration of eCOP occurred at Upper N. Br. Neshaminy and Lower Neshaminy. Lower Neshaminy is the furthest downstream study site and thus reflects the input of multiple upstream tributaries and fecal steroids from many sources. Upper N. Br. Neshaminy is a headwater site in a much smaller watershed with only one wastewater treatment plant discharge and a few permitted septic systems, although we do not know the number of non-permitted septic systems. Lower Tohickon and Lower N. Br. Neshaminy (both downstream of reservoirs) bore steroid tracer signals indicative of bird sources (geese, gulls). We conclude that the *E. coli* detected in the study streams can be linked to human sources in many of them, but that wildlife, birds, and domesticated animals must also be considered as sources.

Literature Cited

American Public Health Association (APHA), American Water Works Association, Water Environment Federation. 1998. Standard Methods for the Examination of Water and Wastewater, 20th ed. APHA, Washington.

Bordner, R., J. Winter and P. Scarpino (ed). 1978. Microbiological methods for monitoring the environment: Water and wastes. EPA-600/78-017. U. S. Environmental Protection Agency, Cincinnati OH.

Cude, C. G. 2005. Accommodating change of bacterial indicators in long term water quality datasets. Journal of the American Water Resources Association 41: 47-54.

Fandrei, G. L. 1985. 1984 Mississippi River bacteria study: Minneapolis, MN. Minnesota Pollution Control Agency, Division of Water Quality, Monitoring and Analysis Section. 29 pp.

Francy, D. S., D. N. Myers and K. D. Metzker. 1993. Escherichia coli and fecal-coliform bacteria as indicators of recreational water quality. Water Resources Investigations Report 93-4083, U. S. Geological Survey.

Grimalt, J.O., P. Fernandez, J. M. Bayone, and J. Albaiges. 1990. Assessment of fecal sterols and ketones as indicators of urban sewage inputs to coastal waters. Environmental Science and Technology 24: 357-363.

Milligan, J. D. 1987. Assessment of E. coli, enterococci, and fecal-coliform bacteria in a recreational floatway. Lake and Reservoir Management 3: 163-171.

O'Leary, T., R. Leeming, P. d. Nichols, and J. K. Volkman. 1999. Assessment of the sources, transport and fate of sewage-derived organic matter in Port Phillip Bay, Australia, using the signature lipid coprostanol. Marine and Freshwater Research 50: 547-556.

Rasmussen, P. P. and A. C. Ziegler. 2003. Comparison and continuous estimates of fecal coliform and Escherichia coli bacteria in selected Kansas streams, May 1999 through April 2002. Water Resources Investigations Report 03-4056, U. S. Geological Survey.

Table 4.1. Dates of sampling for *E. coli* and total coliform determinations.

Site No.	Site Name	2007 Sampling dates	
VI	Tinicum	13-Jun	13-Aug
II11	Upper Tohickon	26-Jun	13-Aug
I11	Lower Tohickon	26-Jun	13-Aug
V4	Paunacussing	12-Jun	13-Aug
V2	Pidcock	19-Jun	13-Aug
I1	County Line	2-Jul	14-Aug
II1	W. Br. Neshaminy	2-Jul	14-Aug
I3a	Upper N. Br. Neshaminy	27-Jun	14-Aug
I3	Lower N. Br. Neshaminy	7-Jun	14-Aug
II7	Little Neshaminy	12-Jun	14-Aug
III6	Lower Neshaminy	19-Jun	13-Aug

*Streams are arranged in an approximate north to south order in Tables 1 - 3.

Table 4.2. Rationale used for accepting data for *E. coli* and total coliform densities.

Site	Site Name	Count	Month: June	August
V1	Tinicum	*E. coli*	1 10-ml count in range; used. Tc TNTC.	3 10-ml below range; averaged. "Estimate"
		Total coliform	1 1-ml count in range; used.	3 1-ml counts in range; averaged.
II11	Upper Tohickon	*E. coli*	3 100-ml counts in range. Tc TNTC.	3 100-ml in range; averaged. Tc TNTC.
		Total coliform	3 1-ml below range; average. "Estimate"	3 1-ml counts in range; averaged.
I11	Lower Tohickon	*E. coli*	None in range; averaged 2 10-ml counts. "Estimate".	1 100-ml count in range; used. Tc TNTC.
		Total coliform	2 1-ml counts in range; averaged.	2 1-ml counts in range; averaged.
V4	Paunacussing	*E. coli*	10-ml all below range; averaged. "Estimate". Tc >200.	2 100-ml counts in range; averaged. Tc TNTC.
		Total coliform	3 1-ml counts in range; averaged.	2 1-ml counts in range; averaged.
V2	Pidcock	*E. coli*	3 100-ml in range; averaged. Tc TNTC	1 100 ml in range; used. Tc TNTC.
		Total coliform	3 1-ml counts in range; averaged.	2 1-ml counts in range; averaged.
I1	County Line	*E. coli*	3 10-ml counts in range; averaged. Tc >200.	2 10-ml counts in range; averaged. Tc >200.
		Total coliform	3 1-ml count in range; averaged.	2 1-ml counts in range; averaged.
II1	W. Branch Neshaminy	*E. coli*	10-ml counts in range; averaged. Tc >200.	3 10-ml counts in range; averaged. Tc >200.
		Total coliform	3 1-ml counts in range; averaged.	3 1-ml counts in range; averaged.
13A	Upper N. Branch	*E. coli*	10-ml counts in range; averaged. Tc >200	3 100-ml in range; averaged. Tc TNTC.
		Total coliform	3 1-ml count in range; averaged.	1 10-ml count in range; used.
I3	Lower N. Branch	*E. coli*	None in range; averaged 10-ml counts, "Estimate". Tc 126-253.	None in range; averaged 10-ml counts. "Estimate". Tc >200.
		Total coliform	1 1-ml count in range; used.	3 1-ml counts in range; averaged.
II7	Little Neshaminy	*E. coli*	10-ml counts in range; averaged. Tc TNTC	3 100-ml in range; averaged. Tc TNTC.
		Total coliform	All high; averaged 1-ml counts (smallest sample volume). "Estimate".	1 1-ml count in range; used.
III6	Lower Neshaminy	*E. coli*	1 10-ml count in range; used.	3 100-ml in range; averaged. Tc TNTC.
		Total coliform	3 1-ml counts in range; averaged.	1 10-ml count in range; used.

Table 4.3. Fecal coliform densities estimated from *E. coli* densities based on equations from studies conducted in OR, KS and MN, and the arithmetic and geometric mean values for each stream based on the three equations.

Month	Site No.	Site Name	No. *E.coli* / 100ml	Estimated Fecal Coliforms/ 100 ml (OR equation)	Estimated Fecal Coliforms /100 ml (KS equation)	Estimated Fecal Coliforms/ 100 ml (MN equation)	Mean fecal Coliforms/ 100 ml from 3 equations, by month	Arithmetic Mean over months: Est. fecal coliforms/ 100 ml	Geometric mean over months: Est. fecal coliforms/ 100 ml
June	V1	Tinicum	210	286	256	212	251	215	212
	II11	Upper Tohickon	37	55	42	572	223	134	100
	I11	Lower Tohickon	17	27	19	244	96	69	64
	V4	Paunacussing	95	135	113	92	113	77	68
	V2	Pidcock	41	61	47	38	49	39	38
	I1	County Line	395	521	493	412	475	405	399
	II1	W. Br. Neshaminy	260	350	319	265	312	565	505
	I3A	Upper N. Br. Neshaminy	240	325	294	54	224	136	104
	I3	Lower N. Br. Neshaminy	57	83	66	15	55	42	40
	II7	Little Neshaminy	540	700	681	34	472	255	136
	III6	Neshaminy	200	273	243	201	239	135	86
August	V1	Tinicum	150	208	181	149	179		
	II11	Upper Tohickon	41	61	47	27	45		
	I11	Lower Tohickon	31	47	35	44	42		
	V4	Paunacussing	34	51	39	31	40		
	V2	Pidcock	25	38	28	23	30		
	I1	County Line	280	376	345	286	336		
	II1	W. Br. Neshaminy	677	867	860	726	817		
	I3A	Upper N. Br. Neshaminy	47	69	54	21	48		
	I3	Lower N. Br. Neshaminy	23	35	26	28	30		
	II7	Little Neshaminy	30	45	34	38	39		
	III6	Neshaminy	26	40	29	23	31		

Table 4.4. Correlations of *E. coli* and total coliform densities with chemical, other biological, molecular tracer and geographic variables.

	Significant correlation with density of			
	Total coliforms		*E. coli*	
Class of Variable and variable	*r*	*p* value	*r*	*p* value
CHEMICAL				
Total alkalinity			0.67	0.024
Calcium			0.65	0.029
Magnesium			0.61	0.046
Particulate P			-0.67	0.023
BIOLOGICAL				
Total coliforms			0.71	0.014
MOLECULAR TRACERS				
Anthracene/phenanthrene	0.62	0.043		
Benzo(a)anthracene/Chrysene			-0.60	0.049
24-ethyl-cholestanol (SNOL)			0.67	0.024
EPI (Epicoprostanol)			0.74	0.009
bCOP/(bCOP+aCOP) [Coprostanol/(Coprostanol+Cholestanol)]			0.61	0.045
aCOP/(aCOP+bCOP+EPI) [Cholestanol/(Cholestanol+Coprostanol+Epicoprostanol)]			-0.60	0.051
Coprostanol (bCOP)			0.59	0.054
sum(betas)/sum(c27,c29)			0.58	0.059
bCOP/(bCOP+EPI) [Coprostanol/(Coprostanol+Epicoprostanol)]	0.58	0.064		
GEOGRAPHY				
% Water in watershed 2005			-0.67	0.024
% Emergent wetlands in watershed 2005	-0.61	0.044	-0.56	0.073
> 74% impervious surface in residential area 2005			0.60	0.05
High density urban land use 2000			0.64	0.033
Deciduous forest cover 2005			-0.56	0.076

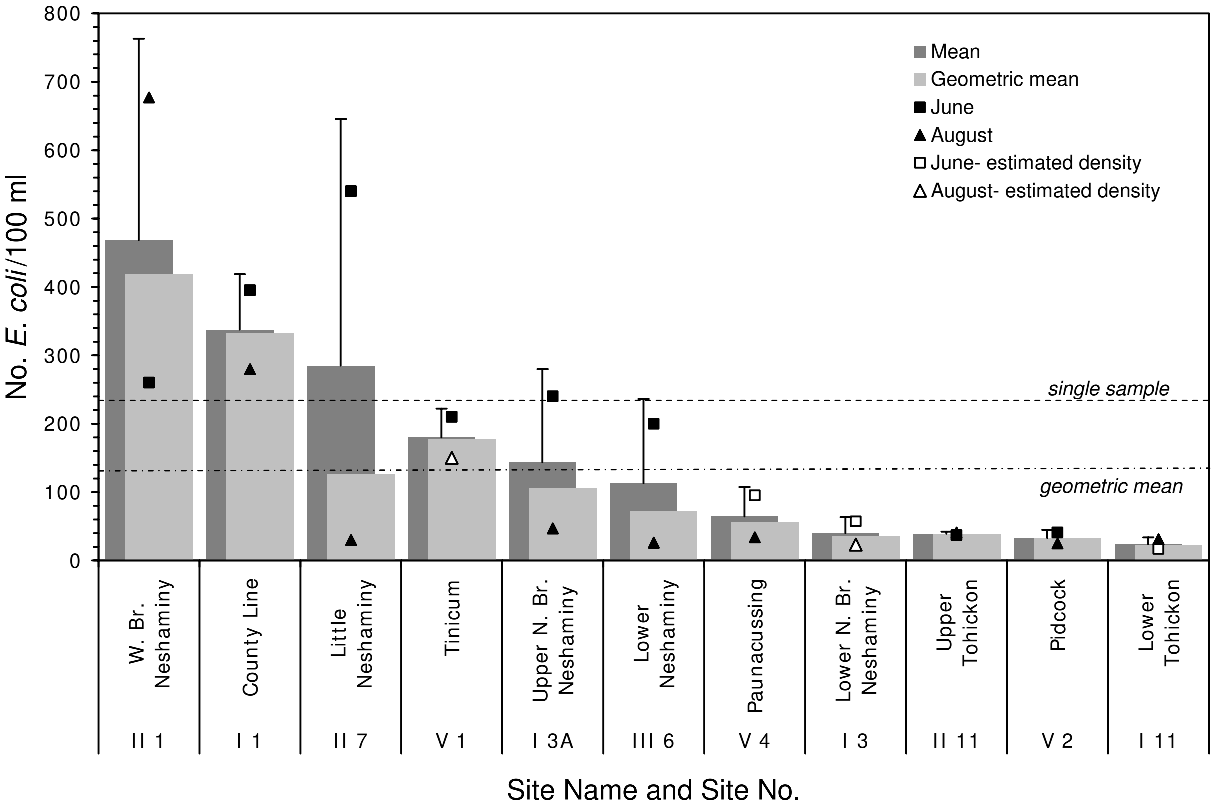


Figure 4.1. *E. coli* densities on each sampling date and the geometric and arithmetic mean values for each stream. Dotted lines display standard values not to be exceeded for a single sample and the mean based on 5 or more samples per month.

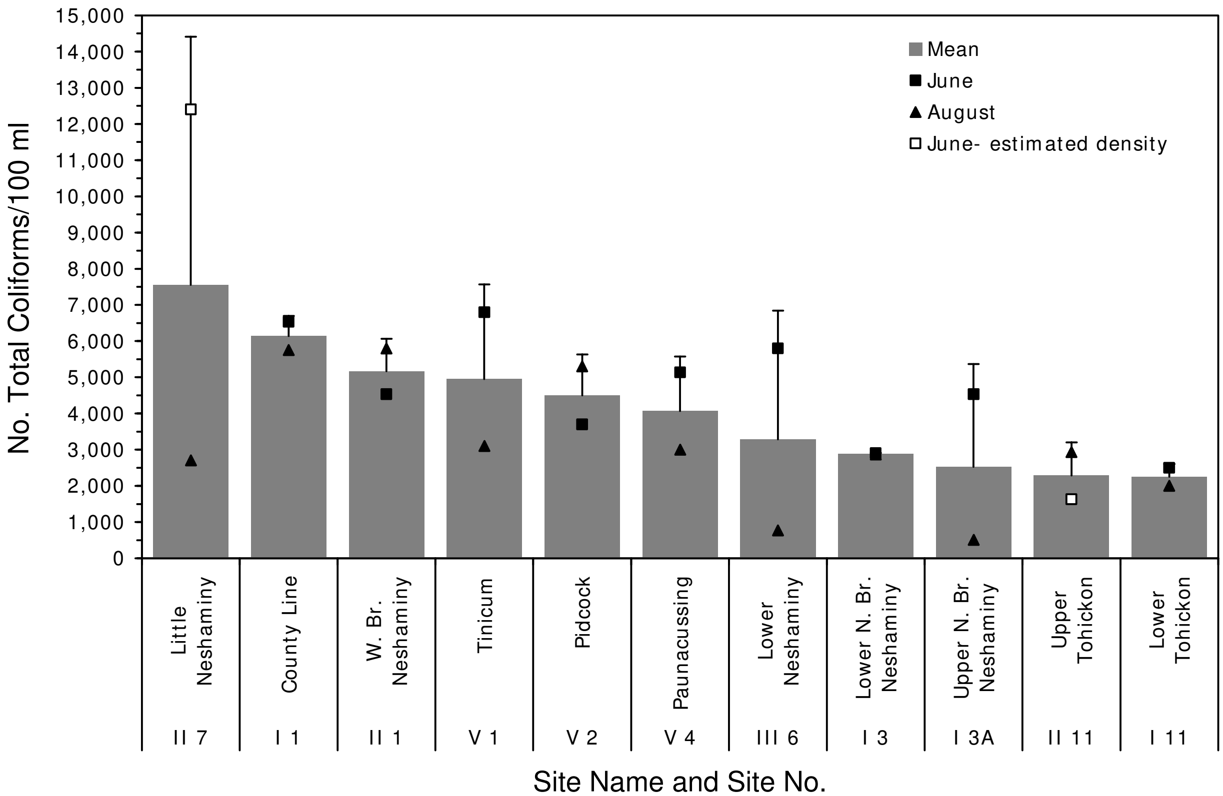


Figure 4.2. Total coliform densities on each sampling date and the arithmetic mean value over sampling dates for each stream.

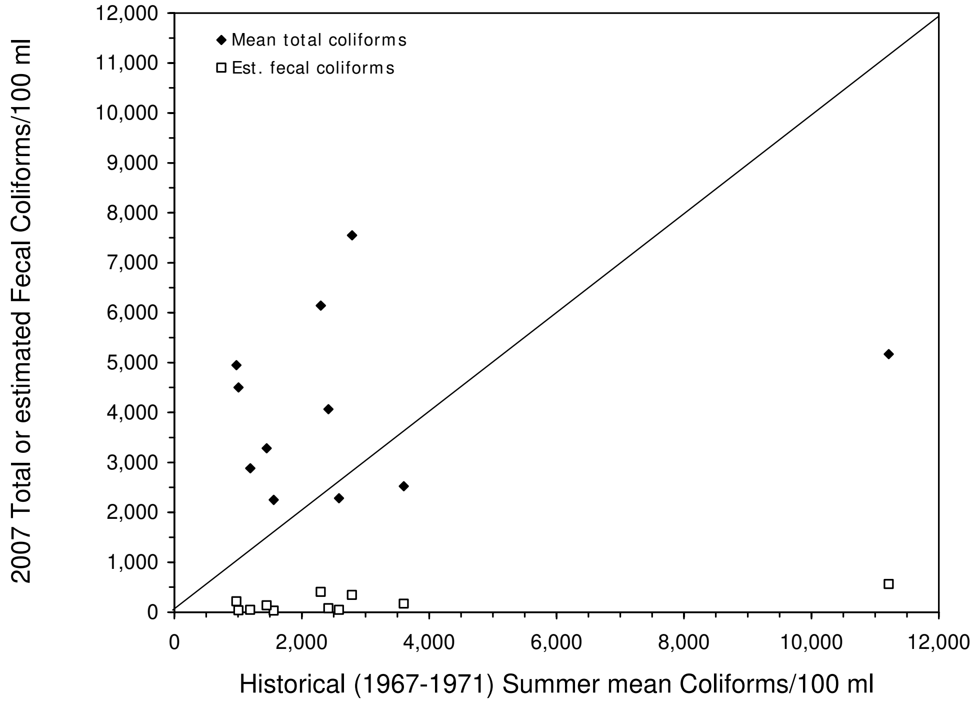


Figure 4.3. Comparison of 2007 measured total coliform and estimated fecal coliform densities with coliform densities reported for the 1967 – 1971 period ("historical"). The 1:1 line is drawn.

ERRATA: Bucks County Report

Escherichia coli and Total Coliform Densities

Substitute the following paragraph for the last paragraph on Pg. 2.

Here we used each of these equations to compute fecal coliform densities from the *E. coli* densities measured in June and August. A test of ln transformed data showed that estimates using the AL equation differed from those obtained with the other three equations (ANOVA, $p = 0.0008$, $df = 87$; Tukey test, $p = 0.05$). Thus the estimate of fecal coliforms was based on the average value generated by the OR, KS, and MN equations.

Substitute the following for Table 3 and Figure 3.

Table 3. Fecal coliform densities estimated from *E. coli* densities based on equations from studies conducted in OR, KS, and MN, and the arithmetic and geometric mean values for each stream based on the three equations.

Month	Site No.	Site Name	No. E. coli/ 100ml	Estimated Fecal Coliforms /100 ml (OR equation)	Estimated Fecal Coliforms /100 ml (KS equation)	Estimated Fecal Coliforms /100 ml (MN equation)	Mean fecal coliforms/ 100 ml from 3 equations, by month	Arithmetic Mean over months: Estimated fecal coliforms/ 100 ml	Geometric mean over months: Estimated fecal coliforms/ 100 ml
June	V 1	Tinicum	210	286	256	215	252	216	213
	II 11	Upper Tohicken	37	55	42	35	44	47	46
	I 11	Lower Tohicken	17	27	19	15	20	29	27
	V 4	Paunacussing	95	135	113	93	114	77	68
	V 2	Pidcock	41	61	47	38	49	39	38
	I 1	County Line	395	521	493	417	477	407	401
	II 1	W. Br. Neshaminy	260	350	319	269	313	567	507
	I 3A	Upper N. Br. Neshaminy	240	325	294	247	289	172	127
	I 3	Lower N. Br. Neshaminy	57	83	66	54	68	48	43
	II 7	Little Neshaminy	540	700	681	580	653	345	153
	III 6	Neshaminy	200	273	243	204	240	136	86
August	V 1	Tinicum	150	208	181	151	180		
	II 11	Upper Tohicken	41	61	47	38	49		
	I 11	Lower Tohicken	31	47	35	29	37		
	V 4	Paunacussing	34	51	39	32	41		
	V 2	Pidcock	25	38	28	23	30		
	I 1	County Line	280	376	345	290	337		
	II 1	W. Br. Neshaminy	677	867	860	736	821		
	I 3A	Upper N. Br. Neshaminy	47	69	54	44	56		
	I 3	Lower N. Br. Neshaminy	23	35	26	21	27		
	II 7	Little Neshaminy	30	45	34	28	36		
	III 6	Neshaminy	26	40	29	24	31		

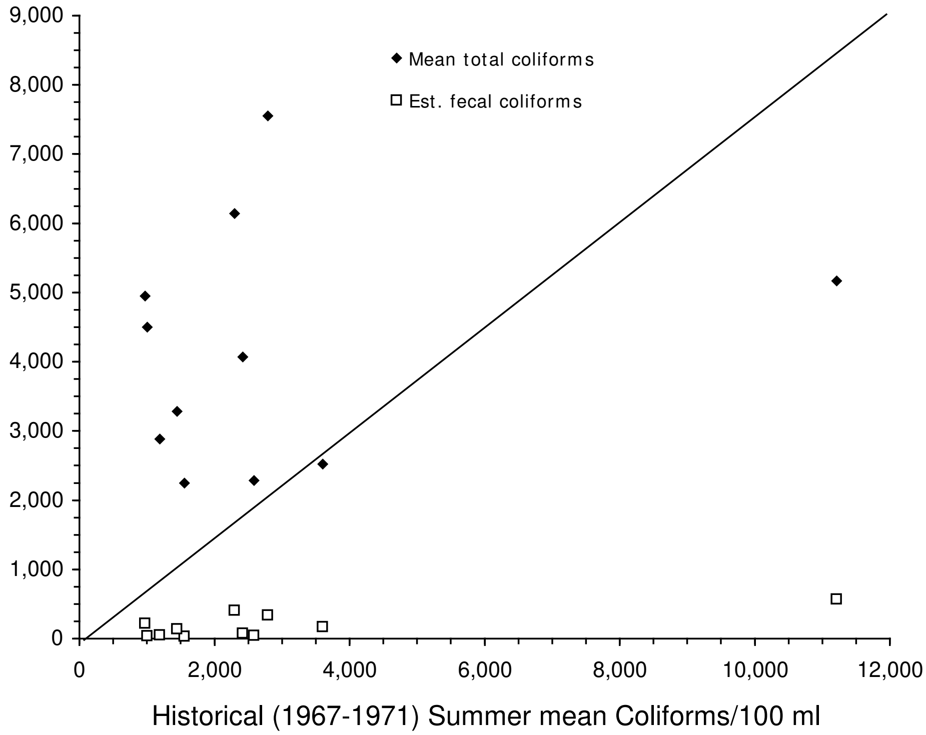


Figure 3. Comparison of 2007 arithmetic mean densities of (1) total coliforms and (2) fecal coliforms estimated from *E. coli* with coliform densities reported for the 1967-1971 period ("historical"). The 1:1 line is drawn.

Chapter 5. Macroinvertebrates

Overview

This chapter describes the portion of this study that used naturally occurring aquatic insects (and some common non-insects such as Oligochaeta, Nematoda, flatworms, small mollusks) to assess the present condition of 11 streams in Bucks County. Aquatic insects are a cost-effective, commonly used, and widely accepted tool in water quality monitoring programs for a number of reasons. (1) Most river and stream ecosystems have relatively diverse aquatic insect assemblages (100-200 species), with species from several different orders [e.g., Ephemeroptera (mayflies), Trichoptera (caddisflies), Plecoptera (stoneflies), Coleoptera (beetles), Diptera (true flies)]. Each species is to some degree evolutionarily unique; as a result, each potentially possesses different tolerances to changes in environmental conditions. Thus, together, the aquatic insects are a sensitive measure of environmental change and stress. (2) Their limited mobility and relatively long life spans (a few months to at least a year) make the presence or conspicuous absence of aquatic insect species 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 samples. (3) Aquatic insects are an important link in the food web, functioning as primary consumers (herbivores and detritivores) of plant and microbial matter that are then available to secondary consumers such as fish. (4) Their abundance lends itself to statistical analysis, which can play an integral role in water quality assessment programs. The data collected in 2007 were used to assess if there are statistically significant and ecologically meaningful differences among the 11 streams sampled in 2007, and to assess if statistically significant and ecologically meaningful changes in environmental quality have occurred at these sites between 1967-71 (when the original study was conducted; Broadfoot et al. 1969, 1971, 1972, Mankelwicz et al. 1972) and 2007.

Methods

Sampling

The historic macroinvertebrate data are from 1061 Surber samples (1-ft^2; mesh size was not recorded) collected in riffle habitat across 43 sites between 1 Sep 1967 and 25 Aug 1971 (Fig. 1.1, Chapter 1). We chose to describe current (i.e., 2007) conditions in spring (19-23 Apr 2007) and summer (5-6 Sept 2007) at 11 sites (Fig. 1.2, Chapter 1) because we did not have the resources needed to sample all 43 sites or multiple dates. These 11 sites represented the various factors (e.g., presence of waste water treatment plants discharging into the stream, locations of proposed dams, current land use) that contributed to the original site selection process (Table 1.2, Chapter 1). They also represented a range of current land and water uses that are common in Bucks County (Table 1.3, Chapter 1). We attempted to mimic field sampling techniques used to generate the historic data, but increased the effort per date to increase the date-specific accuracy of the new descriptions. Macroinvertebrates were collected with a Surber sampler (1-ft^2 with a 0.5-mm mesh, which we assumed was characteristic of the original sampler) in riffle habitat. Three composite samples were collected at each site – a composite sample consisted of four Surber samples, except at Sites V1 and I1 in September when low flow only permitted two samples per composite. Composite sampling addresses spatial variation within a site by increasing the area associated with each sample. This increased the accuracy of the conditions described on a single date relative to the original program. Composite samples were split in the field, and a random subsample representing the area of one Surber sample or 1 ft^2 was preserved with 5% formalin. In the laboratory, most 2007 samples were subsampled to a minimum of 200 individuals and sorted with the aid of a dissecting microscope. However, four samples had only 183-197 macroinvertebrates in the entire sample and were not subsampled. Insects were identified to genus/species where possible, including chironomid midges, and non-insects (e.g., oligochaetes, crustaceans) were left at higher taxonomic levels.

Data Analysis

In the 1967-71 study, the 43 sites were not sampled regularly or equally (e.g., bi-monthly, monthly or annually) – some sites were sampled 48 times while others were only sampled twice (median = 26 samples per site). Sites with 10-20 samples had data from 2-3 years; sites with $\geq$30 samples had data from 4-5 years. In the laboratory, these samples were processed entirely, and individuals were identified to family. Unfortunately, only one Surber sample per site was collected when a site was visited. Thus, spatial variation within a site (i.e., differences within and among riffles) was not addressed and could affect the description of conditions at a site on any given date. To make the historic data more comparable to the 2007 data, we summarized the 1967-71 data into two seasons (i.e., spring or summer). We included only samples that were collected $\leq$45 days before and after Apr 21 (for spring) and Sept 5 (for summer). For each year, samples (n=1 to 4) were averaged to describe either spring or summer conditions based on estimates of macroinvertebrate density or metrics describing community structure (see below). Most samples with <200 individuals were not used to calculate metrics unless they could be combined with another sample and together they had $\geq$200 individuals; however, there were a few samples (among the 43 sites) that had only 175-199 individuals and could not be combined with other samples (none of these were from the 11 sites sampled in both studies). Rather than lose these data, we calculated metrics from the smaller sample. Annual values (n=1 to 5) were averaged together to get a 1967-71 mean that was compared to the mean from 2007.

There were some taxonomic issues that needed attention before analyses. The 1967-71 macroinvertebrates were only identified to family whereas most of the 2007 macroinvertebrates were identified to genus/species. We combined the 2007 genus/species data to the family level where possible. This makes the analyses more conservative because it reduces the probability that taxonomic changes may affect the results (families have changed little over the last 40 years whereas some genus and species designations have changed dramatically). Because the 2007 oligochaete worms had been identified but only to subclass (Oligochaeta), we converted the 1967-71 data to the higher taxonomic level.

No single descriptor of aquatic macroinvertebrate assemblages is generally accepted as better than all others (i.e., most accurate, most sensitive, most reliable, etc). Thus, the macroinvertebrate data were summarized as estimates of density for individual taxa or groups and as community structure metrics that are commonly used in water quality monitoring programs.

Density of selected taxa or groups of taxa were examined, including pollution-sensitive taxa [e.g., many Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies)] and pollution-tolerant taxa [e.g., many Diptera (true flies), 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 species would be predicted. In some cases, species densities were pooled together (i.e., to estimate densities orders) because densities were low and/or pooled groups provided a statistical resolution that was not available otherwise. Densities of Ephemeroptera, Plecoptera, and Trichoptera are commonly pooled together and analyzed as a group (Total EPT) 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 ln transformed, a standard procedure to correct for the clumped spatial dispersion of invertebrate populations in rivers (Elliott 1977).

Macroinvertebrate Aggregated Index for Streams (MAIS) integrates various family level data from riffle habitat into a single number that can be used to compare streams. Ten individual metrics are used to calculate the multimetric MAIS Score:

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

The MAIS Score was developed by Smith and Voshell (1997) based on benthic macroinvertebrate data from streams in Maryland, Pennsylvania, Virginia, and West Virginia. MAIS Scores are predicted to decrease in response to a decrease in water/habitat quality. The difference between Good and Poor sites is dramatic. For example, EPT Richness (the number of mayfly, stonefly, and caddisfly families) might be 11-12 at the highest scoring Good sites, but only 1-3 at the Poor sites. The MAIS Scores classify sites 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"

Using density and community metrics, negative responses of macroinvertebrates to environmental stress will result in a decrease in the density of pollution-sensitive taxa accompanied by an increase in the density of pollution-tolerant taxa. Several species responding negatively to degradation will result in changes in macroinvertebrate community structure (e.g., EPT and Intolerant Richness would be lower while HBI and % 5 Dominant Taxa would be greater) that would result in a decrease in MAIS Score.

Prior to estimating measures of community structure (but not comparisons of density), all samples were standardized to a fixed number of individuals (i.e., 200) because measures of community structure based on richness generally increase as the number of individuals examined increases. To compensate for this potential bias, we used a computer program that employed a re-sampling without replacement routine to standardize samples to a preset number of individuals (i.e., bootstrapping) using SAS statistical package (Version 9.2, SAS Institute Inc., Cary, North Carolina). Where possible, samples that were processed in their entirety and still had <200 individuals were pooled together with other samples from that site/season/year in order to reach a minimum of 200 individuals (i.e., a standard fixed count size; Carter and Resh 2001). Although pooling samples reduced the number of samples, it allowed for comparisons that were not influenced by unequal numbers of macroinvertebrates found among samples or sites.

Results and Discussion

Stream Conditions Based on Macroinvertebrates Collected in 2007

A total of 194 taxa was collected across all 11 sites and two seasons in 2007 (Appendix 4.1). Only 12 taxa (6%) occurred at all the sites and 69 taxa (36%) occurred at only one site. Diptera represented 48% of the total number (93 of 194), and the majority (77) of these dipterans were chironomid midges. EPT taxa were also abundant (70 taxa) and made up 36% of the total number.

Abundance. In spring 2007, total macroinvertebrate density averaged 9202 individuals/m^2, and ranged from 706 individuals/m^2 at Pidcock to 23,325 individuals/m^2 at Upper Tohickon (Table 5.1a). Total macroinvertebrate density in summer 2007 averaged 20,682 individuals/m^2, and ranged from 2229 individuals/m^2 at County Line to 45,075 individuals/m^2 at Tinicum (Table 5.1b). Spring densities may have been low relative to summer because our sampling followed a relatively large storm. Likewise, low flow conditions in Aug and Sep may have elevated densities by increasing survivorship of summer populations. Dipterans and oligochaetes, two pollution-tolerant groups, made up a greater proportion (45 vs 27%) of total macroinvertebrate density in spring whereas EPT, a pollution-sensitive group, made up a greater proportion (41 vs 17% of total macroinvertebrate density in summer. Diptera and oligochaetes made up on average 63% and 25% of the total numbers and EPT made up 23% and 41% of the total numbers in spring and summer, respectively.

Differences in macroinvertebrate densities suggest that water quality differed among some sites. For example, pollution-sensitive mayflies and stoneflies were relatively common at Upper N. Br. Neshaminy, Tinicum, Pidcock, and Paunnacussing, but not at Lower N. Br. Neshaminy and W. Br. Neshaminy (Table 5.1a). This suggests better water quality at Upper N. Br. Neshaminy, Tinicum, Pidcock, and Paunnacussing than at Lower N. Br. Neshaminy and W. Br. Neshaminy. We used multimetric scores to combine various aspects in macroinvertebrate community structure at each site, and to quantify differences among sites based on macroinvertebrates.

Metrics. Because the 1967-71 macroinvertebrate data were left at the family level, we combined 2007 taxa densities to the family level and summarized macroinvertebrate community structure using the family-based MAIS Score. The seasonal and spatial differences in densities for certain taxonomic groups (e.g., EPT, Diptera, Oligochaeta) resulted in marked differences in MAIS scores. Among the 11 sites and two seasons, there was a range of conditions, with five sites (Paunacussing, Tinicum, Pidcock, Upper N. Br. Neshaminy, Upper Tohickon) that on average supported a macroinvertebrate assemblage characteristic of Good water quality, four sites (County Line, Lower N. Br. Neshaminy, Little Neshaminy, Lower Tohickon) that supported a macroinvertebrate assemblage characteristic of Fair water quality, and two sites (W. Br. Neshaminy, Lower N. Br. Neshaminy) that supported a macroinvertebrate assemblage characteristic of Poor water quality (Fig. 5.1). Adjacent sites in Figure 5.1 were generally not statistically different, but extremes along the range of scores were. For example, MAIS scores at the two Poor sites (W. Br. Neshaminy, Lower N. Br. Neshaminy) were significantly lower than at eight highest scoring Good and Fair sites. MAIS scores at the two lowest scoring Fair sites (Little Neshaminy, Upper Tohickon) were significantly lower than at the five Good sites. Thus, differences in MAIS Scores are evidence that macroinvertebrate communities have degraded significantly at some sites relative to the highest scoring sites we sampled.

There was also seasonal variation in MAIS Scores across sites. In spring 2007, MAIS scores ranged from 2.7 to 15.0 (average = 10.2), with three sites were classified as Good, six sites as Fair, and two sites as Poor (Table 5.2, Fig. 5.2). MAIS Scores in summer 2007 ranged from 4.7 to 15.8 (average = 12.3), with six sites classified as Good, four sites as Fair, and one site as Poor (Fig. 5.2). Seasonal variation was least among the three highest scoring sites, but variation at 5 of 8 remaining sites was great enough to result in a seasonal change in classification category. Across the 11 sites, MAIS Scores were significantly higher in summer (10.2 vs 12.3; $p<0.001$). The general pattern of higher scores during summer appears to reflect the greater relative abundance of EPT taxa (especially Trichoptera) in the summer (Table 5.1b) compared with spring (Table 5.1a), and might appear to suggest significantly better water quality in summer than in spring. We suggest caution in using this interpretation as it is not clear if this type of seasonal variation in macroinvertebrate communities was factored into the development of the MAIS Score. In addition, the correlations between MAIS Scores and factors known to affect water quality negatively or indicate the presence of pollution (i.e., land use, water chemistry, tracer compounds) were much stronger for spring than summer (Table 5.3). Thus, the 2007 data suggest that differences among sites and relationships between macroinvertebrates and environmental stressors may be more apparent using spring macroinvertebrate communities relative to summer macroinvertebrate communities.

We compared the differences in MAIS Scores with a variety of land use characteristics (Table 1.3, Chapter 1), and water chemistry parameters that were also measured in 2007 (see Chapter 3). Significant correlations between numerous land use, chemistry, and tracers variables and the MAIS Scores from spring, but far fewer with MAIS Scores from summer (Table 5.3). Highest spring MAIS Scores were associated with watersheds in the most natural condition (i.e., highest forest cover, and fewest people, anthropogenic land uses, and water chemistry and tracers characteristic of these land uses as well as waste and storm water reaching the stream (e.g., Fig. 5.3). Stream condition decreased as anthropogenic land uses and concentrations of wastes and biproducts of anthropogenic activity increased. It is not clear why land uses and water quality parameters known to be associated with stream degradation were clearly related with MAIS

Scores from spring but not summer, but it is again evidence that macroinvertebrates communities in spring may better differentiate environmental conditions than macroinvertebrates communities in summer.

Changes in Stream Condition between 1967 – 1971 and 2007

To quantify changes in the macroinvertebrate communities over the 37-40 year period between 1967 – 1971 and 2007, we converted all of the spring and summer data to MAIS Scores. This generated measures of stream condition for 41 sites during spring and summer (Fig. 5.4). Some sites had data from only one season in one year while other sites had data from all four years. Average stream condition ranged greatly among sites, with scores between 12 and 13 to <1. The changes between the highest and lowest scores were gradual – there was no apparent thresholds or clustering of sites around one or more scores. As was evident in the 2007 data, there was significant seasonal variation in MAIS Scores based on the 1967 – 1971 data. MAIS Scores were greater during summer vs spring at 34 sites, and less at five. The median MAIS Score for 1967-71 was 6.3 for spring, and 8.0 for summer, both on the lower portion of the Fair category. The average seasonal difference was 1.5 points across all sites. As a result of the seasonal variation, a greater proportion of the sites were classified as Fair during summer than spring (63 vs 50%) while more were classified as Poor during spring (50 vs 37%). No site was classified as Good during either spring or summer based on the 1967-71 data (although Pidcock was classified as Good in summer 1967 and spring 1968 but as Fair on four other occasions, and Paunacussing was classified as Good in Spring 1969 but as Fair on three other occasions).

We presently do not have land use data from the 1967-71 time period, but we do have population density from the 1970 census. Increases in population density are generally correlated with decreases in forest cover (the original land cover) and increases in land covers associated with anthropogenic activities (e.g., residential and commercial/industrial uses, impervious covers, road density, etc.). During 1967 – 1971, MAIS Scores decreased rapidly as population density increased (Fig. 5.5). Population densities greater than 300 people/km^2 were generally associated with Poor MAIS Scores, indicating that habitat and water quality in these watersheds are able to support few if any pollution sensitive species.

Long-term changes in stream conditions were examined directly at 11 sites where we have data from both 1967 – 1971 and 2007. Across these 11 sites, average MAIS Score increased 3.5 points for spring (from 6.7 to 10.2) and 4.1 points for summer (from 8.2 to 12.3) (Table 5.2, Fig. 5.6). The increase in MAIS Score was statistically significant at eight sites (Paunacussing, Tinicum, Upper N. Br. Neshaminy, Lower Tohickon, Neshaminy, Little Neshaminy, Upper Tohickon, W. Br. Neshaminy) whereas differences at three sites were not significant (Pidcock, County Line, Lower N. Br. Neshaminy), although the change at Lower N. Br. Neshaminy (I3) was a nearly significant ($p=0.07$) decrease in MAIS Score. The changes in MAIS Scores resulted in changes in the classification of stream condition at four sites in spring (Fair to Good at two sites, Poor to Good at one site, Poor to Fair at one site), and nine sites in summer (Fair to Good at five sites, Poor to Good at one site, Poor to Fair at two sites, Fair to Poor at one site). The classification of several sites as Good in either spring or summer 2007 is a noticeable improvement in stream condition relative to 1967 – 1971 when none of the 43 sites had an average classification of Good (Fig. 5.7). As was noted above, we do not presently have land use data from the 1967-71 period to compare to present conditions, but we do have population density from both 1970 and 2000 and impervious cover estimates from 1985 and 2000. Increases in population density are generally associated with increases in anthropogenic land and water uses, and water chemistry and tracer compounds characteristic of these uses as well as waste and storm water reaching the stream (cf Fig. 5.3). In both 1967 – 1971 and 2007, stream condition decreased as population density increased (Figs. 4.3 and 4.5). However, stream condition at several sites increased between 1967 – 1971 and 2007, even though population density increased (Figs. 4.8 and 4.9). As a result, comparable population densities supported better stream conditions in 2007 than in 1967-1971. This suggests that modern pollution control practices are able to address some of the negative effects of residential, industrial, and commercial land uses and concentrations of wastes and biproducts of anthropogenic activity such that similar population densities result in less stream degradation. However, the significant relationship between stream condition and population density and presence of numerous Fair and Poor sites indicates that the wastes and biproducts of anthropogenic activity are still negatively affecting these streams and limiting their ability to support macroinvertebrate communities characteristic of clean streams. Thus, improved land and water use have increased carrying capacity of the watershed, but there is still a negative relationship with increased land and water use from residential, industrial, and commercial development.

Individual Site Assessments

V1 Tinicum Creek

Tinicum Creek is a small watershed in northern Bucks County that drains directly into the Delaware River (Fig. 1.2, Chapter 1). The site was chosen in 1967 as a routine sampling station on a small watershed, and not associated with either a future flood control dam or major WWTP. Site V1 was classified as Good in both spring and summer 2007 (Table 5.2, Fig. 5.10). In contrast, it was classified at Poor in both spring and summer 1967-71. Thus, macroinvertebrates indicate that stream condition at this site in Tinicum improved markedly ($p<0.0001$) between 1967-1971 and 2007. The Tinicum watershed was one of the least developed (based on population density in 1970 and impervious cover in 1985) sampled in 1967-1971, and this remains true in 2007 (Table 1.3, Chapter 1). Population density was only 35 people/km^2 in 1970, and increased to only 57 people/km^2 in 2000). Land development (as impervious cover) increased from 0.12% in 1985 to 0.23% in 2000. We do not have estimates for past forest cover, but it was 69% in 2005. The relatively limited conversion of forest to agricultural or urban uses suggests that this watershed should support good streams, and that the impaired conditions observed in 1967-71 were possibly a local issue (at least in terms of the pollution source). In the 1960's a chemical company was discharging wastes containing chromic acid, copper sulfate, and other heavy metals, as well as sulfuric acid and ammonia into Rapp Creek, a headwater tributary well upstream of site V1 on Tinicum. This company has since closed and cleanup of the site began in 1972 and was considered completed in 1998 (Mid-Atlantic Superfund 2008). Our findings suggest that the former Superfund site is no longer impacting Tinicum and that the site has recovered from the prior chemical pollution. Based on our spring 2007 data (MAIS Score = 15), Tinicum deserves the Special Protection designation is as an Exceptional Value stream awarded by the Commonwealth of Pennsylvania (Table 5.4). The macroinvertebrate fauna is comparable to the faunas that we have observed at EV streams in the Schuylkill River basin.

II11 Upper Tohickon Creek

Tohickon Creek is a medium-sized watershed in northern Bucks County that drains into the Delaware River (Fig. 1.2, Chapter 1). Two sites on Tohicken were sampled in 2007, one upstream (II11) and one downstream (I11) of Lake Nockamixon, a 1,450 acre reservoir that was created in 1973 after the first study. Site II11 on Upper Tohickon was chosen in 1967 as a sampling station downstream of a major WWTP, and upstream of a proposed flood control reservoir (i.e., what became Lake Nockamixon). This site was classified as Fair in both spring and summer 2007 (MAIS Score = 8.1 and 10.8, respectively) (Table 5.2, Fig. 5.11), which is a significant improvement ($p<0.0001$) relative to the results from 1967-1971 when the site was classified as Poor during both spring and summer (i.e., MAIS Score = 3.7 and 5.7, respectively). The watershed upstream of site II11 is more densely populated and developed (19% of land cover, including Quakertown) than the overall watershed upstream of site I11 on the lower Tohickon, but still it remains relatively rural with extensive portions that are forested (49%) or agricultural (19%) (Table 1.3, Chapter 1). Population density was 156 people/km^2 in 1970, and increased to 253 people/km^2 in 2000; impervious cover increased from 3.3% in 1985 to 5.0 in 2000. This site was chosen in 1967 because it was downstream of a wastewater treatment facility that was believed to affect stream condition. This facility (either upgraded or replaced) is presumably still in use today (there is presently one standard and 1 industrial WWTP upstream of site II11). While we do not have records of the discharge of the WWTF, the relatively limited changes in population density and land use suggest that the significant improvement in stream condition between 1967-1971 and 2007 suggests that there was a major upgrade in the quality of the discharge from this facility. As a result, the stream is now able to support more pollution-sensitive species than in 1967-1971. Tohickon above Lake Nockamixon is designated as a Trout Stocking Fishery (Table 5.4), and the macroinvertebrate community at Station II11 in spring 2007 was clearly degraded compared to Exceptional Value and High Quality-Cold Water Fishery sites that we have sampled in the Schuylkill River basin. However, it is comparable to the Trout Stocking Fisheries we have sampled. In addition, PA-DEP considers this reach of the Upper Tohickon near Site II11 to be impaired and not supporting its designated aquatic life uses (Table 5.4). Our macroinvertebrate data do not support the conclusion that the site is impaired – most impaired sites in the Schuylkill River watershed, for example, have MAIS Scores of 7 or less (http://www.stroudcenter.org/schuylkill/basins/longterm.htm).

I11 Lower Tohickon Creek

Site I11 on the lower Tohickon Creek was chosen in 1967 as a sampling station downstream of a proposed flood control reservoir (i.e., what became Lake Nockamixon). The site was classified as Fair (MAIS Score = 12.4) in the spring and Good (MAIS Score = 15.1) in summer 2007 (Table 5.2, Fig. 5.12), which represents a significant ($P<0.0001$) increase in stream condition at this lower Tohickon site relative to being classified as Fair during spring and summer 1967-1971(MAIS Score = 8.0 and 10.7, respectively). The watershed upstream of the lower Tohickon site remains relatively rural with extensive portions (i.e., 59% in 2005) that are forested, especially with state game lands and Nockamixon State Park (Table 1.3, Chapter 1). Deforested areas are a combination of agricultural (15%) and urban (13%) uses. Population density was 95 people/km^2 in 1970, and increased to only 155 people/km^2 in 2000). Land development (as impervious cover) increased from 1.5% in 1985 to 2.5% in 2000. The extensive forest cover (only Tinicum had more) would suggest that this watershed should support good streams. However, this site is downstream of a reservoir, which can affect stream condition, and the stream upstream of Lake Nockamixon is not the highest quality stream in Bucks County (cf Site II11 on Upper Tohickon; Fig. 5.2). While we do not have records of the quality of water discharged from the reservoir, the relatively limited changes in population density and land use suggest that the improvement in stream condition between 1967-1971 and 2007 reflects, at least in part, the construction and operation of the reservoir. Reservoirs can trap nutrients and sediments that originate from upstream land and water use. They can also release water during summer that is cooler and well oxygenated relative to average summer conditions. Whatever the cause, the stream is now able to support more pollution-sensitive species than in 1967-1971. This is evidence that the construction and operation of the Lake Nockamixon reservoir has not had a negative impact on Lower Tohickon. Tohicken Cr. below Lake Nockamixon is designated as a Cold Water Fishery while Tohickon Cr. above Lake Nockasmixon is designated as a Trout Stocking Fishery (Table 5.4). This difference supports the conclusion that the reservoir is trapping pollutants from upstream (cf Site II11 on Upper Tohickon) and releasing cool, well oxygenated water during summer. The macroinvertebrates in summer 2007 indicated significantly better stream conditions downstream than upstream of Lake Nockamixon; spring differences were not statistically significant. The spring 2007 macroinvertebrates at Site I11 on Lower Tohickon are comparable to many sites with comparable designations (i.e., Cold Water Fisheries in the Schuylkill River basin have a mean MAIS Score = 12.0), and indicate better water quality than in most High Quality-Trout Stocking, Trout Stocking, and Warm Water Fisheries.

V4 Paunacussing Creek

Paunacussing Creek is a small watershed in central Bucks County that drains directly into the Delaware River (Fig. 1.2, Chapter 1). The site was chosen in 1967 as a routine sampling station on a small watershed, and not associated with either a dam or WWTP. It was one of the cleanest streams sampled in Bucks County in 1967-1971 (along with Pidcock), and in 2007 (Fig. 5.7). It was classified as Good based on the macroinvertebrates collected in both spring and summer 2007 (Table 5.2, Fig. 5.13), which was a slight improvement ($p=0.047$) relative to 1967-71 when it was classified as only Fair (Good in spring 1969 but as Fair on one other spring date and two summer dates in 1967-71). In 1967-71, the Paunacussing watershed was one of the least developed (based on population density in 1970 and impervious cover in 1985; Table 1.3, Chapter 1), which was presumably a major factor in maintaining the quality of the stream at that time. Since macroinvertebrates were collected in 1967-1971, there has been an increase in the number of people living in the watershed (62 to 201 people/km^2), and this was accompanied by an increase in land development (impervious cover increased from 0.04% in 1985 to 0.27% in 2000). As of 2005, forest cover is only 34% while agricultural cover is 38% and urban cover is 21%. This suggests that agriculture was also the dominant land use in this watershed in 1967-71. Relatively good water quality back in 1967-71 as well as in 2007 suggest that agricultural practices were not having a marked negative impact on Paunacussing. The increase in population density and developed land use does not appear to have had a negative effect on the macroinvertebrate communities in Paunacussing. One reason increased urbanization has not contributed the degradation of water quality is that there are no WWTP discharges upstream of our sampling site. Thus, residential and commercial wastes associated 201 people/km^2 (about 3500 people in the watershed) are not discharged directly into this small waterway. Based on our spring macroinvertebrate samples from 115 streams in the Schuylkill River basin, Paunacussing deserves the Special Protection awarded by the Commonwealth of Pennsylvania. However, its present Special Protection designation is as a High Quality – Cold Water Fishery (Table 5.4), but the spring 2007 MAIS Score of 15 for Paunacussing is more similar to an Exceptional Value stream (average MAIS Scores in the Schuylkill were 13.7 for EV streams and 12.6 for HQ-CWF streams).

V2 Pidcock Creek

Pidcock Creek is a small watershed in central Bucks County that drains directly into the Delaware River (Fig. 1.2, Chapter 1). The site was chosen in 1967 as a routine sampling station on a small watershed, and not associated with either a future flood control dam or major WWTP. It was one of the cleanest streams sampled in Bucks County in 1967-1971 (along with Paunacussing), and in 2007 (Fig. 5.7). It was classified as Good based on the macroinvertebrates collected in both spring and summer 2007 (Table 5.2, Fig. 5.14). This was not a statistically significant improvement relative to 1967-71 when it was classified as only Fair (Good in summer 1967 and spring 1968 but as Fair on two other spring dates and two summer dates in 1967-71). Like the nearby Paunacussing and Tinicum, the Pidcock watershed was still relatively rural and undeveloped in 1967-1971 (Table 1.3, Chapter 1). Population density from the 1970 census was 51 people/km^2 and land development (as impervious cover in 1985) was only 0.04%. By 2000, the number of people living in the watershed increased to 107 people/km^2, and land development (as impervious cover) increased to 0.17% in 2000. This is still low development relative to many other parts of Bucks County. Total forest cover in 2005 remained high (41%), as was agriculture (37%). The changes in land use and population density since the original 1967-1971 study do not appear to have had a negative effect on the macroinvertebrate communities in Pidcock. Pidcock is currently listed as a Warm Water Fishery (Table 5.4). However, the spring 2007 MAIS Score of 14 for Pidcock is similar to an Exceptional Value or High Quality-Cold Water Fishery stream among the 115 streams we sampled in the Schuylkill River basin (average MAIS Scores in the Schuylkill were 12.6 for HQ-CWF streams, and 13.7 for EV streams), and indicates better water quality characteristic than in most Trout Stocking and Warm Water Fisheries. Based on our spring macroinvertebrate samples, Pidcock deserves to be awarded Special Protection status from the Commonwealth of Pennsylvania, a significant upgrade from its present designation as a Warm Water Fishery.

I1 County Line Creek

County Line Creek is a small tributary that flows through portions of both Bucks and Montgomery Counties before joining the West Branch of Neshaminy (Fig. 1.2, Chapter 1). The site was chosen in 1967 as a sampling station downstream of a proposed flood control reservoir, but the dam was never constructed. County Line was among the cleanest streams sampled in the 1967-1971 study (4th out of 43), and still scored well in 2007 (Fig. 5.7). Based on macroinvertebrates, it was classified as Fair in both spring and summer 1967-71 (MAIS Score = 11.7 and 11.3, respectively) as well as 2007 (MAIS Score = 12.1 and 10.6, respectively) (Table 5.2, Fig. 5.15). Thus, macroinvertebrates do not show a statistically significant improvement or decline in stream conditions in the many years between studies. The watershed is only moderately developed relative to other parts of Bucks County: forest cover in 2005 was 46%, agricultural cover was 29%, urban cover was 15% (Table 1.3, Chapter 1). Population density from the 1970 census was 118 people/km^2 and land development (as impervious cover in 1985) was 0.37%. Since then, the number of people living in the watershed increased to 219 people/km^2, and land development (as impervious cover in 2000) increased to 0.72%. The changes in land use and population density since the original 1967-1971 study do not appear to have had a negative effect on the macroinvertebrate communities in the stream. County Line is currently designated a Warm Water Fishery stream by the Commonwealth of Pennsylvania (Table 5.4),. The macroinvertebrate community at site I1 in 2007 appears degraded relative to an Exceptional Value or High Quality-Cold Water Fishery stream. However, the spring 2007 MAIS Score of 12.1 is higher than we commonly observed among Trout Stocking and Warm Water Fisheries sampled in the Schuylkill River basin. County Line appears to deserve being considered for a designation upgrade to at least a Cold Water or High Quality-Trout Stocking Fishery (average MAIS Scores in the Schuylkill were 12.0 and 10.6, respectively). In addition, PA-DEP considers this reach of County Line to be impaired and not supporting its designated aquatic life uses (Table 5.4). Our macroinvertebrate data do not support the conclusion that the site is impaired – as noted earlier, most impaired sites in the Schuylkill have MAIS Scores of 7 or less.

II1 West Branch Neshaminy Creek

The West Branch of Neshaminy Creek drains the far western portion of the Neshaminy Creek watershed (Fig. 1.2, Chapter 1). This is the most urbanized portion of Bucks County, and defines the character of the land use and water quality in the West Branch. Site II1 was chosen in 1967 because it was downstream of a major wastewater treatment plant that was believed to be having a negative effect on stream condition (Table 1.3, Chapter 1). Presently, there is one standard and one industrial WWTP upstream of the site. Site II1 on the West Branch of Neshaminy was classified as Poor in spring and Fair in summer 2007 (MAIS Score = 2.7 and 8.8, respectively; Table 5.2, Fig. 5.16). This represents a significant improvement ($P<0.0001$) relative to conditions observed in 1967-1971 when the site was classified as Poor in both seasons (MAIS Scores = 0.0 and 0.2, respectively) and was one of the worst of the 43 sites sampled in Bucks County (Fig. 5.7). The watershed upstream of site II1 on the West Branch was primarily urban/suburban development (54%), with limited forest (19%) and agricultural (14%) land cover (Table 1.3, Chapter 1). Based on a population density of 464 people/km^2 in 1970, this site was one of the more urbanized sites sampled in 1967-1971. Population density increased to 721 people/km^2 in 2000, making it the most densely populated watershed sampled in 2007. This increase of 257 people/km^2 was accompanied by a doubling of developed land (impervious cover increased from 11.5 in 1985 to 22.2% in 2000). We do not know the fate of the WWTP of concern back in 1967 (either upgraded or replaced) or the have the discharge records for the two WWTPs present today. However, the increases in population density and urban/suburban land use suggest that the improvement in stream condition between 1967-1971 and 2007 reflects a significant upgrade in the quality of the discharge from this facility as well as implementation of other water pollution control measures. That said, the site is still experiencing significant environmental stress as it was still classified as Poor in spring 2007. West Branch Neshaminy is designated as a Warm Water Fishery (Table 5.4) and the macroinvertebrate community at site II1 in 2007 is clearly degraded relative to an Exceptional Value or High Quality-Cold Water Fishery stream. However, it is comparable to those in Warm Water Fisheries we have sampled in the Schuylkill River basin. The spring 2007 macroinvertebrates suggest the West Branch Neshaminy near Site II1 should be considered impaired, which agrees with the current assessment by PADEP (Table 5.4).

I3A Upper North Branch Neshaminy Creek

Two sites on the North Branch of Neshaminy Creek were sampled in 2007, one upstream (I3A) and one downstream (I3) of Lake Galena (Fig. 1.2, Chapter 1). Site I3A was chosen later than most sites (first sampled in 1970), presumably because the original researchers realized that they needed a site upstream of the future Lake Galena. Site I3A on the upper North Branch was classified as Fair (MAIS Score = 11.8) in the spring and Good (MAIS Score = 15.8) in summer 2007 (Table 5.2, Fig. 5.17), which represents a significant (P=0.007) improvement since the 1967-71 study when the site was classified as Poor and Fair during spring and summer (MAIS Score = 5.3 and 8.0, respectively). The North Branch Neshaminy watershed is one of the more agricultural watersheds in Bucks County, with relatively limited urban/suburban or industrial development (Table 1.3, Chapter 1). In 2005, agriculture represents 39% of the land cover upstream of Site I3A versus 35% forest cover and 15% urban cover. Population density was 66 people/km^2 in 1970, and increased to 162 people/km^2 in 2000. Land development (as impervious cover) increased from 0.6% in 1985 to 1.5% in 2000. We have no documentation of past or present environmental stressors that negatively impact the macroinvertebrates in the North Branch. However, based on present land use and our estimation that land use was similar 40 years ago, it appears that the upper North Branch was primarily impaired by agricultural activities during the 1967-71 study. Moreover, current and past agricultural activities may be of similar intensity, but present land and water uses are resulting in significantly less stream impairment, presumably because modern Best Management Practices (e.g., contour and no-till farming, crop rotation, livestock fences, and riparian buffers) have reduced the movement of nutrients, pesticides, sediments, and farm waste into the stream. In addition, the single WWTP upstream of I3A does not appear to be having a measurable effect on stream macroinvertebrates. As a result, the stream is now able to support more pollution-sensitive species than in 1967-71 (Fig. 5.17). The upper North Branch upstream of Lake Galena is designated as a Warm Water Fishery (Table 5.4) and the macroinvertebrate community is clearly degraded relative to an Exceptional Value or High Quality-Cold Water Fishery stream. However, the spring 2007 macroinvertebrates are comparable to many sites with better designations (i.e., Cold Water Fishery or High Quality-Trout Stocking Fisheries in the Schuylkill River basin have mean MAIS Scores = 12.0 and 10.6, respectively), and indicate Upper North Branch Neshaminy has better water quality than in most Trout Stocking and Warm Water Fisheries. This reach might warrant an upgrade of its current designated Aquatic Life Use based on aquatic macroinvertebrates.

I3 Lower North Branch Neshaminy Creek

Site I3 on the lower North Branch of Neshaminy Creek was chosen in 1967 as a sampling station downstream of a proposed flood control reservoir (i.e., Lake Galena, 365 acres, built in 1973) (Fig. 1.2, Chapter 1). Site I3 was classified as Fair (MAIS Score = 6.5) in the spring and Poor (MAIS Score = 4.7) in summer 2007 (Table 5.2, Fig. 5.18), versus Fair during spring and summer 1967-1971(MAIS Score = 8.4 and 9.4, respectively). It had the third lowest MAIS Score in spring and the lowest Score in summer 2007 (Fig. 5.2). The difference between 1967-1971 and 2007 represents a nearly significant (P=0.07) decrease in stream condition based on macroinvertebrates, the only site among the 11 sampled in 2007 that appeared to decline in water quality since 1967-71 (Figs, 4.6, 4.7). Overall, the macroinvertebrate community at Site I3 was degraded relative to the majority of sites sampled in 2007. The most comparable site was Site II1 on the West Branch of Neshaminy – the most developed and densely populated site sampled in 2007. Site I3 was chose to evaluate changes in stream condition that result from the future construction and operation of the dam forming Lake Galena. The data from 1967-1971 suggest that Sites I3A and I3 on the North Branch of Neshaminy were not statistically different. In 2007, MAIS Scores at Sites I3 and I3A were comparable in spring, but were significantly lower at Site I3 in summer.

The North Branch Neshaminy watershed upstream of Site I3 is similar to that upstream of Site I3A, except for the presence of Lake Galena. The watershed is one of the more agricultural watersheds in Bucks County, with relatively limited urban/suburban or industrial development (Table 1.3, Chapter 1). Agriculture upstream of this site represented 34% of the land cover versus 40% forest cover and 14% urban cover. Population density was 77 people/km^2 in 1970, and increased to 156 people/km^2 in 2000. Land development (as impervious cover) increased from 0.4% in 1985 to 1.1% in 2000. We have no documentation of past or present environmental stressors that negatively impact the macroinvertebrates in the lower North Branch. However, based on present land use and our estimation that land use was similar 40 years ago, it appears that the North Branch (Sites I3 and I3A) was impaired primarily by agricultural activities during the 1967-1971 study. Results from Site I3A on the upper North Branch suggest that current and past agricultural activities may be of similar intensity, but present activities are resulting in significantly less stream impairment. As a result, the upper North Branch at Site I3A is now able to support more pollution-sensitive species than in 1967-1971. The same cannot be said for Site I3 below Lake Galena. This suggests that discharge from Lake Galena is having a negative impact on macroinvertebrates downstream of the dam. This was most evident during summer 2007. The lower North Branch downstream of Lake Galena is designated as a Trout Stocking Fishery (Table 5.4). The macroivertebrate community is clearly degraded relative to Exceptional Value or High Quality-Cold Water Fishery streams we have sampled in the Schuylkill River basin; however, it is comparable to those in Warm Water or Trout Stocking Fisheries. The spring and summer 2007 macroinvertebrates suggest the North Branch near Site I3 should be considered impaired, but PADEP presently lists it as supporting its designated use for aquatic life.

II7 Little Neshaminy Creek

Little Neshaminy Creek is the largest single tributary to Neshaminy Creek, draining the southwestern portion of the watershed (Fig. 1.2, Chapter 1). Site II7 was chosen in 1967 because it was downstream of a major wastewater treatment plant that was believed to be having a negative effect on stream condition. Presently, there are five WWTPs upstream of the site (Table 1.3, Chapter 1). Site II7 on Little Neshaminy was classified as Poor in spring and Good in Summer 2007 (MAIS Score = 5.8 and 13.6, respectively; Table 5.2, Fig. 5.19). This 7.8-point range was the greatest seasonal difference observed among the 11 sites sampled in 2007, and this was the only site that was classified as both Poor and Good (Fig. 5.2). While this wide seasonal range is a challenge to interpret with only one year of data, it represents a significant improvement ($p<0.0001$) over conditions observed in 1967-1971 when the site was classified as Poor in both seasons (MAIS Scores = 1.9 and 4.6, respectively; Figs. 4.6, 4.7). The 1967-1971 MAIS Scores for Site II7 on Little Neshaminy were low, but there were several other sites in Bucks County with lower MAIS Scores (i.e., < 1) and apparently lower water quality (Fig. 5.4). The Little Neshaminy watershed is the second most urbanized watershed sampled in 2007 (Table 1.3, Chapter 1). The watershed upstream of the site has a mixture of urban/suburban development (48%), agriculture (14%), and forests (17%). Based on a population density of 321 people/km^2 in 1970, this site was one of the more urbanized sites sampled in 1967-1971. Population density increased to 561 people/km^2 in 2000, and this increase of 240 people/km^2 was accompanied by a more than doubling of developed land (impervious cover increased from 8.0 in 1985 to 17.1% in 2000). This facility (either upgraded or replaced) is presumably still in use today. While we do not have records of WWTP discharges, the changes in population density and land use suggest that the improvement in stream condition between 1967-1971 and 2007 reflects a significant upgrade in the quality of the discharge from the facility of concern in 1967 as well as effective implementation of other water pollution control measures. That said, the site is still experiencing significant environmental stress as it was still classified as Poor in spring 2007. Little Neshaminy is designated as a Warm Water Fishery (Table 5.4) and the macroinvertebrate community at Site II7 in 2007 is clearly degraded relative to an Exceptional Value or High Quality-Cold Water Fishery stream. However, it is comparable to those Warm Water Fisheries we have sampled in the Schuylkill River basin. The spring 2007 macroinvertebrates suggest the Little Neshaminy near Site II7 should be considered impaired, which agrees with the current assessment by PADEP (Table 5.4).

III6 Neshaminy Creek

Neshaminy Creek is the largest watershed in Buck County, draining much of the central and southern portions of the county (Fig. 1.2, Chapter 1). Site III6 is on the lower main stem of Neshaminy. The site was chosen as a routine monitoring station in 1967, integrating land and water use along the main stem as well as associated with upstream tributaries. This includes five upstream tributary sites that were also sampled in 2007 (i.e., Sites I1 on County Line , I3A on the North Branch of Neshaminy above Lake Galena, I3 on the N. Br. of Neshaminy below Lake Galena, II1 on the West Branch of Neshaminy, and II7 on Little Neshaminy). Site III6 was classified as Fair in spring and summer 2007 (MAIS Score = 9.0 and 12.8, respectively; Table. 4.2, Fig. 5.20). It was also classified as Fair during spring and summer 1967-71(MAIS Score = 6.4 and 9.0, respectively), however, the 2007 data represent a significant (P=0.008) increase in stream condition based on macroinvertebrates. The watershed upstream of the site has a mixture of urban/suburban development (40%), agricultural (20%), and forests (25%) (Table 1.3, Chapter 1). It is one of the most urbanized sites sampled in 2007, with over 250,000 people presently (2000 census) living upstream. This is almost double the number in the 1970 census, and translates into a population density of 241 people/km^2 in 1970 and 480 people/km^2 in 2000. The doubling of population density is paralleled by an almost doubling of development (as impervious cover), which increased from 4.6% in 1985 to 10.9% in 2000. Presently, there are 15 standard WWTPs discharging into Neshaminy Ck or its tributaries upstream of Site III6 (Table 1.3, Chapter 1). We do not have the data to know if the increase in urban land use represented a loss of forest or agricultural land, or if WWTPs have been upgraded or added (presumably both since 1967). Based on macroinvertebrates in 2007, water quality at Site III6 on the Lower Neshaminy was better than at two upstream sites (II1 on the W. Br. Neshaminy, and I3 on the N. Br. of Neshaminy below Lake Galena), and not statistically better or worse than at the other three sites. Given the doubling of population density and impervious cover to a level higher than at all but two sites among the 11 we sampled in Bucks County, the significant increase in water quality suggests that changes in land use and the implementation of best management practices for land and water use over the last 40 years have reduced the pollutants reaching Site III6. The lower main stem of Neshaminy is designated as a Warm Water Fishery (Table 5.4) and the macroinvertebrate community at Site III6 in 2007 is clearly degraded relative to an Exceptional

Value or High Quality-Cold Water Fishery stream. However, this section of the lower main stem of Neshaminy supports a macroinvertebrate community that is comparable to or better than most Trout Stocking and Warm Water Fisheries we have sampled in the Schuylkill River basin. The spring 2007 macroinvertebrates suggest the Lower Neshaminy near Site III6 should not be considered impaired, which disagrees with the current assessment by PADEP (Table 5.4).

Summary

Bucks County was one of the three original counties in Pennsylvania, and was named by William Penn in 1682. The county has a total area of 1,611 km² (622 square miles), and spans portions of the Piedmont and Atlantic Coastal Plain. Bucks County was for many decades a productive rural farming community just north of Philadelphia, but it has become more urbanized and suburbanized over the last 60 years. For example, population size was 82,476 in 1920, and it increased to only 107,715 in 1940. However, population size increased rapidly after that, reaching 410,056 in 1970 and 597,635 in 2000. Based on recent census estimates, Bucks County is now the fourth most populous county in Pennsylvania (after Philadelphia, Allegheny, and Montgomery counties) and is now considered part of the Philadelphia Metropolitan Area. We used aquatic macroinvertebrates collected in spring and summer 2007 to assess the condition of streams at 11 Bucks County locations. These data indicate that the condition of streams ranges greatly across Bucks County, from clean streams that support numerous pollution-sensitive species (e.g., Paunacussing, Tinicum, and Pidcock Creeks) to degraded streams that support few if any pollution-sensitive species (e.g., Little Neshaminy Creek and West Branch of Neshaminy Creek). The degree of stream degradation across sites is positively correlated with the degree of residential, commercial, and industrial development (as measured by land covers, population density, and various chemical concentrations and tracer compounds). Thus, the most degraded sites are downstream of the watersheds with the greatest population densities, greatest proportion of developed land covers, and greatest concentrations of wastes and biproducts of anthropogenic land and water use.

Unlike almost all assessments of current stream conditions, our study benefited from having historic macroinvertebrate data that resulted from the insightful decision of Bucks County officials to assess stream sites back in 1967-71. These historic data allow us to evaluate changes in stream condition at 11 sites between 1967-71 and 2007, a four-decade time period that included increased suburbanization as well as the implementation of important water protection and management regulations. Macroinvertebrates from 1967-71 and 2007 indicate that stream condition improved at 10 sites over the last 40 years - the increase was statistically significant at eight sites but not at the two remaining sites (Table 5.5). Macroinvertebrates at only one site suggested that conditions had degraded between 1967-71 and 2007, but the decrease was not quite statistically significant ($p=0.07$). This site (I3) on Lower North Branch Neshaminy may be impaired by the outflow from Lake Galena, a reservoir that was constructed in 1973. The increase in stream condition across most sites is evidence that current land and water uses are resulting in significantly less stream impairment than in 1967-71, even though there are more people using the land and water upstream of every site. This indicates that improved residential and industrial waste-water treatment and implementation of modern Best Management Practices (e.g., contour and no-till farming, crop rotation, livestock fences, and riparian buffers) have reduced the movement of nutrients, toxins, pesticides, sediments, and farm waste into the stream. However, the significant relationship between stream condition and population density and presence of several Fair and Poor sites indicates that the wastes and byproducts of anthropogenic activity are still negatively affecting these streams and limiting their ability to support macroinvertebrate communities characteristic of clean streams. Thus, improved land and water use have increased carrying capacity of the watershed, but there is still a negative relationship with increased land and water use from residential, industrial, and commercial development.

Literature Cited

Broadfoot, D. W., J. C. Mertz and J. R. Powell, Jr. 1969. Water Quality Monitoring Project: Year End Report June 1969. A report to the Natural Resources Division, Bucks County Planning Commission, PA.

Broadfoot, D. W., J. C. Mertz and J. R. Powell, Jr. 1971. Water Quality Monitoring Project: Supplemental Report I – data update 1971. A report to the Natural Resources Division, Bucks County Planning Commission, PA.

Broadfoot, D. W., J. C. Mertz and J. R. Powell, Jr. 1972. Water Quality Monitoring Project: Supplemental Report II – data update 1972. A report to the Natural Resources Division, Bucks County Planning Commission, PA.

Mankelwicz, J. M., D.W. Broadfoot, B.E. Conroy, and J. C. Mertz.1972. Water Quality Monitoring Project: Supplemental Report III (Data Update 1972). A report to the Natural Resources Division, Bucks County Planning Commission, PA.

Mid-Atlantic Superfund. 2008. http://www.epa.gov/reg3hscd/npl/PAD051395499.htm Accessed 15 Feb 2008.

Table 5.1a. Macrinvertebrate density (individuals/m^2) collected in spring 2007 from 11 sites (arranged north to south) in Bucks County, PA.

Site	Stream name	Total Macro.	Non-insect	Oligo-chaeta	Total Insects	Ephem-eroptera	Pleco-ptera	Tricho-ptera	Diptera	Coleo-ptera
V1	Tinicum Ck	4665	383	100	4282	864	772	495	1973	108
II11	Upper Tohickon Ck	23325	3896	2741	19429	359	38	1323	12146	5498
I11	Lower Tohickon Ck	5025	384	68	4642	670	97	434	2606	789
V2	Pidcock Ck	706	104	82	602	154	39	43	333	25
V4	Paunnacussing Ck	1057	61	39	996	233	97	169	448	47
I1	County Line Ck	4294	341	319	3953	86	677	265	2660	251
I3A	Upper N. Br. Neshaminy Ck	11108	1376	1183	9732	391	303	1477	4538	2880
I3	Lower N. Br. Neshaminy Ck	20674	7666	5458	13008	0	38	7799	3422	1443
II1	W. Br. Neshaminy Ck	14478	8292	7921	6186	0	0	289	5608	208
II7	Little Neshaminy Ck	14758	5073	4657	9685	34	0	280	8210	1106
III6	Neshaminy Ck	1129	462	416	667	14	4	79	448	115

Table 5.1b. Macrinvertebrate density (individuals/m^2) collected in summer 2007 from 11 sites in Bucks County, PA.

Site	Stream name	Total Macro.	Non-insect	Oligo-chaeta	Total Insects	Ephem-eroptera	Pleco-ptera	Tricho-ptera	Diptera	Coleo-ptera
V1	Tinicum Ck	45075	3364	1434	41711	5563	57	17893	12540	2676
II11	Upper Tohickon Ck	31694	7732	191	23962	3030	0	4617	5830	10246
I11	Lower Tohickon Ck	21529	5787	201	15742	1835	57	5556	4031	4112
V2	Pidcock Ck	5269	409	72	4860	452	0	2115	1333	638
V4	Paunnacussing Ck	12871	583	90	12288	1969	0	7176	2290	824
I1	County Line Ck	2229	950	147	1280	32	4	276	681	276
I3A	Upper N. Br. Neshaminy Ck	3301	128	31	3173	945	0	557	364	965
I3	Lower N. Br. Neshaminy Ck	32975	4645	1319	28330	0	0	12817	14366	746
II1	W. Br. Neshaminy Ck	28502	11556	488	16946	344	0	7140	6337	1893
II7	Little Neshaminy Ck	18796	1563	29	17233	2065	0	7871	2480	3742
III6	Neshaminy Ck	25266	2107	46	23159	1569	0	9684	6872	2414

Table 5.2. Average MAIS Score for the11 stream sites (arranged approximately north to south) sampled in spring and summer 2007 and spring and/or summer 1967-71.

Site	Stream Name	2007		1967-71	
		Spring	Summer	Spring	Summer
V1	Tinicum Ck	14.6	14.3	3.0	6.1
II11	Upper Tohickon Ck	8.1	10.8	3.7	5.7
I11	Lower Tohickon Ck	12.4	15.1	8.0	10.7
V2	Paunnacussing Ck	15.0	14.1	12.9	11.8
V4	Pidcock Ck	14.0	14.4	12.1	13.1
I1	County Line Ck	12.1	10.6	11.7	11.3
I3A	W. Br. Neshaminy Ck	2.7	8.8	0.0	0.2
I3	Upper N. Br. of Neshaminy Ck	11.8	15.8	5.3	8.0
II1	Lower N. Br. of Neshaminy Ck	6.5	4.7	8.4	9.4
II7	Little Neshaminy Ck	5.8	13.6	1.9	4.6
III6	Lower Neshaminy Ck	9.0	12.8	6.4	9.0

Table 5.3. Correlation coefficients for selected independent variables (GIS, water chemistry, tracers) that had significant relationships with MAIS Scores from either spring (April) or summer (September) 2007. P value for significant measures is in parentheses.

Variable	MAIS Score Spring	MAIS Score Summer
Watershed Variables		
1970 population density	-0.83 (0.002)	-0.21
2000 population density	-0.76 (0.006)	-0.18
1985 % impervious	-0.85 (0.001)	-0.12
2000 % impervious	-0.86 (0.001)	-0.13
Change in % impervious (2000-1985)	-0.84 (0.001)	-0.13
% Deciduous 2005	0.67 (0.024)	0.14
% Evergreen 2005	0.66 (0.027)	0.32
Road density 2009	-0.77 (0.006)	-0.03
# WWTP/km^2 (2007)	-0.62 (0.042)	-0.04
Stream Chemistry - Anions		
Chloride	-0.76 (0.006)	-0.18
Nitrite-N	-0.69 (0.019)	-0.24
Stream Chemistry - Cations		
Potassium	-0.84 (0.001)	-0.18
Sodium	-0.78 (0.005)	-0.12
Stream Chemistry – In-situ		
Conductivity	-0.73 (0.011)	-0.05
Stream Temperature	-0.68 (0.022)	-0.66 (0.026)
Stream Chemistry - Isotopes		
$\delta^{13}C$	-0.60 (0.050)	-0.15
% Carbon	-0.64 (0.035)	-0.39
% Nitrogen	-0.67 (0.025)	-0.59
Stream Chemistry - Nutrients		
Particulate Nitrogen	-0.23	-0.74 (0.010)
Particulate Organic Nitrogen	-0.34	-0.81 (0.002)
Soluble Kjeldahl Nitrogen	-0.85 (0.001)	-0.28
Total Kjeldahl Nitrogen	-0.88 (0.000)	-0.54
Total Nitrogen	-0.64 (0.033)	-0.11
Total Dissolved Phosphorus	-0.70 (0.015)	0.09
Total Phosphorus	-0.85 (0.001)	-0.16
Stream Chemistry – Organic Carbon		
Dissolved Organic Carbon (DOC)	-0.72 (0.012)	-0.33
Biodegradable DOC	-0.74 (0.010)	-0.26
Total Organic Carbon	-0.71 (0.015)	-0.51
Particulate Organic Carbon	-0.18	-0.73 (0.010)

Table 5.3. (continued).

Variable	MAIS Score Spring	MAIS Score Summer
Stream Chemistry – Molecular Tracers (Fragrances/Caffeine)		
Caffeine	-0.74 (0.010)	-0.18
AHTN – Fragrance material	-0.79 (0.004)	-0.02
HHCB – Fragrance material	-0.82 (0.002)	-0.07
Sum of Fragrance materials	-0.82 (0.002)	-0.06
Stream Chemistry – Molecular Tracers (PAH concentrations)		
1 Methyl Phenanthrene (1MP)	0.68 (0.022)	0.05
2 Methyl Phenanthrene (2MP)	0.68 (0.020)	0.45
Phenanthrene (PHE)	0.71 (0.014)	0.18
sum of volatile PAHs	0.68 (0.022)	0.14
Stream Chemistry – Molecular Tracers (PAH ratios)		
ANT/(ANT + PHE)	-0.66 (0.027)	-0.02
BAA/(BAA + CHR)	0.61 (0.046)	0.07
(1MP + 2MP)/PHE	0.78 (0.004)	0.4
PHE/(PHE + 1MP + 2MP)	-0.81 (0.003)	-0.44
ratio of high to low mol wt PAHs	-0.68 (0.021)	-0.23
Stream Chemistry – Predicted Fecal Sources		
predicted human fecal sources	-0.91 (0.000)	-0.29
Stream Chemistry – Molecular Tracers (Fecal Steroid concentrations)		
Cholesterol (CHO)	-0.74 (0.010)	-0.86 (0.001)
Epi-Coprostanol (EPI)	-0.88 (0.000)	-0.54
Cholestanol (aCOP)	-0.74 (0.009)	-0.76 (0.007)
Cholestanone (aONE)	-0.67 (0.024)	-0.68 (0.021)
Coprostanol (bCOP)	-0.84 (0.001)	-0.46
24-Ethyl-Cholesterol (eCHO)	-0.61 (0.044)	-0.65 (0.032)
24-Ethyl-Coprostanol (eCOP)	-0.63 (0.038)	-0.01
Sum of fecal steroids	-0.69 (0.018)	-0.85 (0.001)
Stream Chemistry – Molecular Tracers (Fecal Steroid ratios)		
bCOP/(bCOP + aCOP + EPI)	0.84 (0.001)	0.15
bCOP/(bCOP + aCOP)	-0.84 (0.001)	-0.12
bCOP/(bCOP + CHO)	-0.79 (0.004)	-0.08
bCOP/(bCOP + eCOP)	-0.87 (0.001)	-0.48
(bCOP+EPI+eCOP+eEPI)/ (bCOP+EPI+CHO+aCOP+eCOP+eEPI+eCHO+SNOL)	-0.83 (0.002)	-0.14
(bCOP+EPI+CHO+aCOP)/ (bCOP+EPI+CHO+aCOP+eCOP+eEPI+eCHO+SNOL)	-0.80 (0.003)	-0.49
CHO/(CHO + eCHO)	-0.72 (0.012)	-0.51
eCOP/(eCOP + eCHO)	-0.84 (0.001)	-0.13
eCOP/(eCOP + SNOL)	-0.95 (0.000)	-0.42
EPI/(EPI + eEPI)	-0.92 (0.000)	-0.41

Table 5.4. Stream sites (arranged approximately north to south) sampled in 1967-71 and 2007, showing designated aquatic life uses (Exceptional Value, High Quality – Cold Water Fishery, Cold Water Fishery, High Quality – Trout Stocking Fishery, Trout Stocking Fishery, Warm Water Fishery), recent MAIS Scores, and current status (impaired or sustaining all designated uses) assessed by Pennsylvania Department of Environmental Protection.

Site	Site Name	Aquatic Life Designated Use	MAIS [1]	Current Status [2]	Problems [3]
V1	Tinicum Ck	EV	14.6	Attaining	
II11	Upper Tohickon Ck	TSF	8.1	Not attaining	2002, Agriculture - nutrients; Removal of vegetation - siltation
I11	Lower Tohickon Ck	CWF	12.4	Attaining	
V4	Paunnacussing Ck	HQ – CWF	15.0	Attaining	
V2	Pidcock Ck	WWF	14.0	Attaining	
I1	County Line Ck	WWF	12.1	Not attaining	2002, Ag - excessive algal growth and siltation; Urban runoff/storm sewers – flow variability
II1	W. Br. Neshaminy Ck	WWF	2.7	Not attaining	2002, Ag - excessive algal growth and siltation, Municipal point source – nutrients (1996); Urban runoff/storm sewers - flow variability
I3A	Upper N. Br. Neshaminy Ck	WWF	11.8	Attaining	
I3	Lower N. Br. Neshaminy Ck	TSF	6.5	Attaining	
II7	Little Neshaminy Ck	TSF	6.5	Attaining	
II7	Little Neshaminy Ck	WWF	5.8	Not attaining	2002, Municipal point source - nutrients; Urban runoff/storm sewers - siltation and flow variability
III6	Lower Neshaminy Ck	WWF	9.0	Not attaining	1996, Municipal point source – Nutrients, organic enrichment, low D.O., pH; unknown causes

[1] Corresponds to current sampling, spring 2007 samples only
[2] Current status reflects PA-DEP evaluation of aquatic life (macroinvertebrate and habitat assessment) designated use, although human health was referenced at Lower N. Br. Neshaminy Ck.
[3] identified by PA-DEP of significance in order

Table 5.5. Summary of temporal changes in stream condition based macroinvertebrates collected in 1967-71 and 2007. Stream condition classification based on MAIS Scores from spring 2007.

Site	Stream Name	MAIS Score	2007 Classification
Sites that improved significantly			
V1	Tinicum Ck	14.6	Good
II11	Upper Tohickon Ck	8.1	Fair
I1	Lower Tohickon Ck	12.4	Fair
V4	Paunacussing Ck	15.0	Good
II1	West Branch Neshaminy Ck	2.7	Poor
I3A	Upper North Branch Neshaminy Ck	11.8	Fair
II7	Little Neshaminy Ck	5.8	Poor
III6	Lower Neshaminy Ck	9.0	Fair
Sites that did not change significantly			
V2	Pidcock Ck	14.0	Good
I1	County Line Ck	12.1	Fair
Sites that may have degraded			
I3	Lower North Branch Neshaminy Ck	6.5	Fair

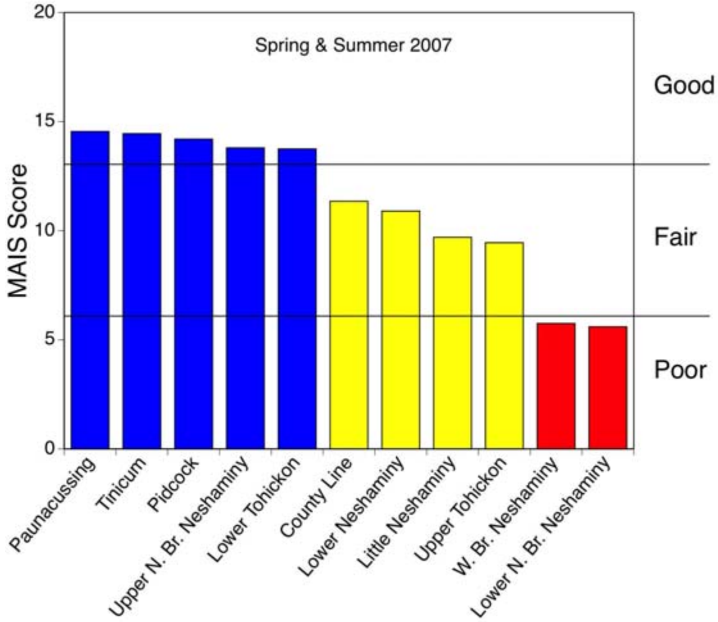


Figure 5.1. MAIS Scores for 11 sites in Bucks County, PA averaged across spring and summer 2007, sorted by descending order of MAIS Score. Bar color indicates site classification as Good, Fair, or Poor based on MAIS Score.

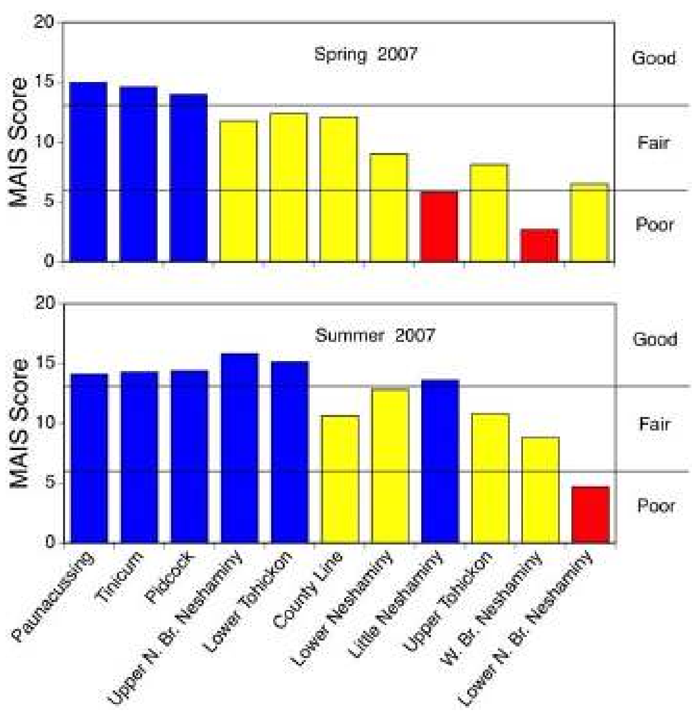


Figure 5.2. Seasonal MAIS Scores for 11 sites in Bucks County, PA from spring and summer 2007, sorted by descending order of average MAIS Score (Fig. 5.1). Bar color indicates site classification as Good, Fair, or Poor based on MAIS Score.

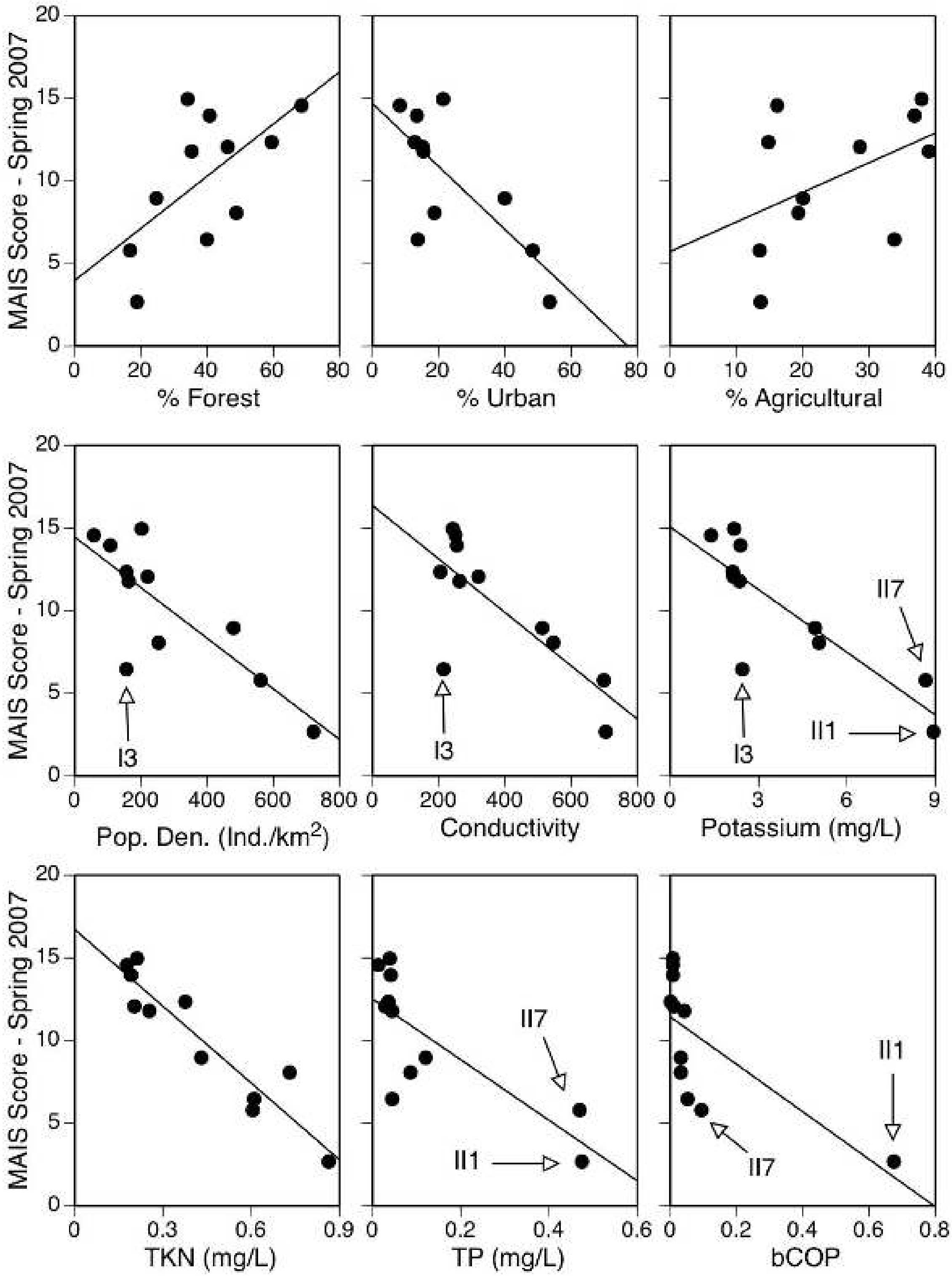


Figure 5.3. Plots of selected independent variables (i.e., land covers, water chemistry characteristics, trace compounds associated with water use and/or contamination) versus MAIS Scores from spring 2007. All correlations were significant ($p \leq 0.05$).

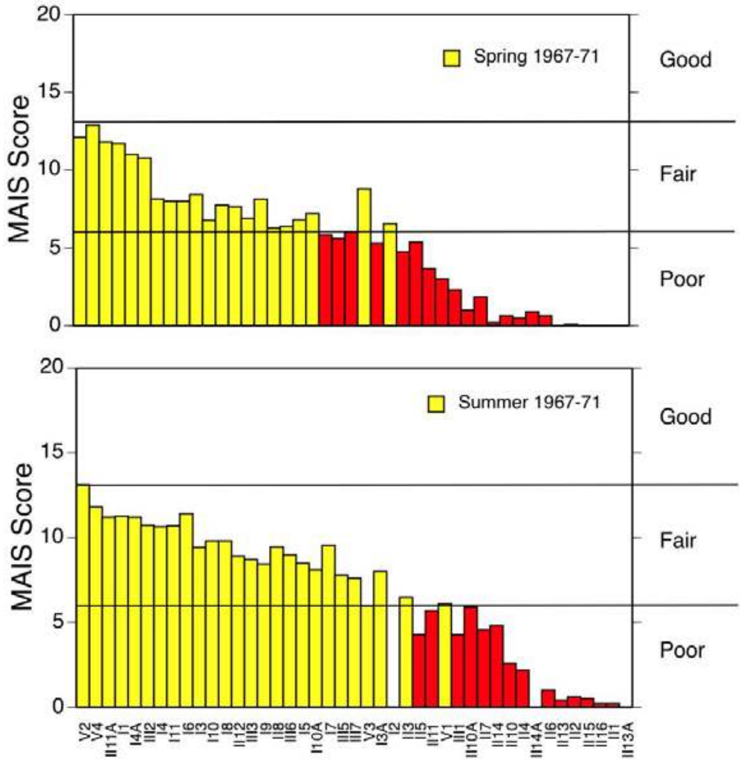


Figure 5.4. Seasonal MAIS Scores for 43 sites in Bucks County, PA from spring and summer 1967-71, sorted by descending order of average MAIS Score. Bar color indicates site classification as Good, Fair, or Poor based on MAIS Score.

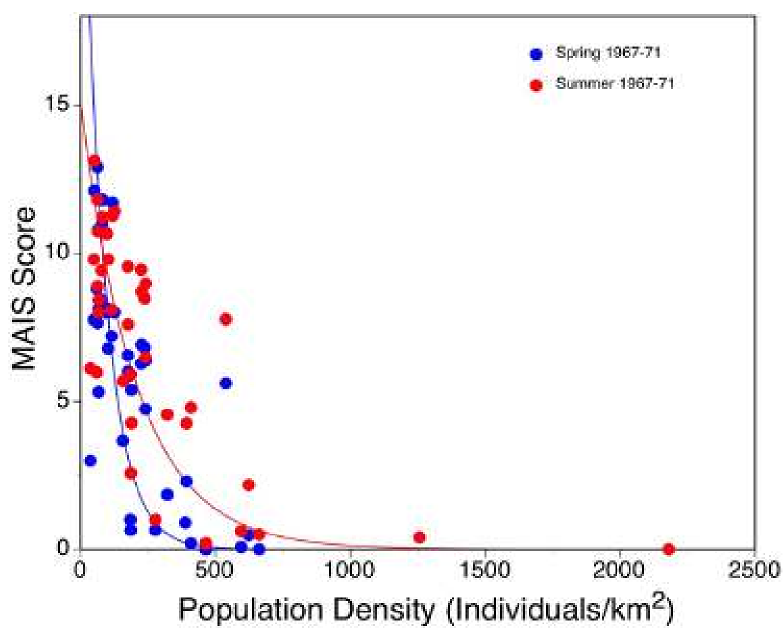


Figure 5.5. Plot of population density from 1970 census (individuals/km^2 in watershed upstream of site) versus seasonal MAIS Scores from spring and summer 1967-71.

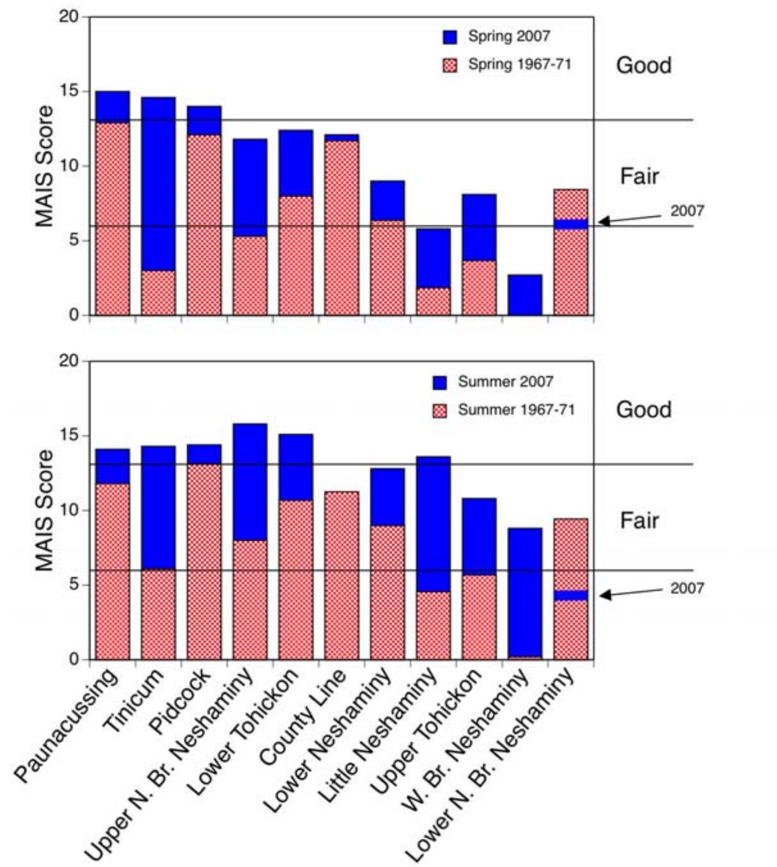


Figure 5.6. Changes in seasonal MAIS Scores for 11 stream sites in spring and summer 2007 (blue) and 1967-71 (red pattern), sorted by descending order of MAIS Score in Fig. 5.3.

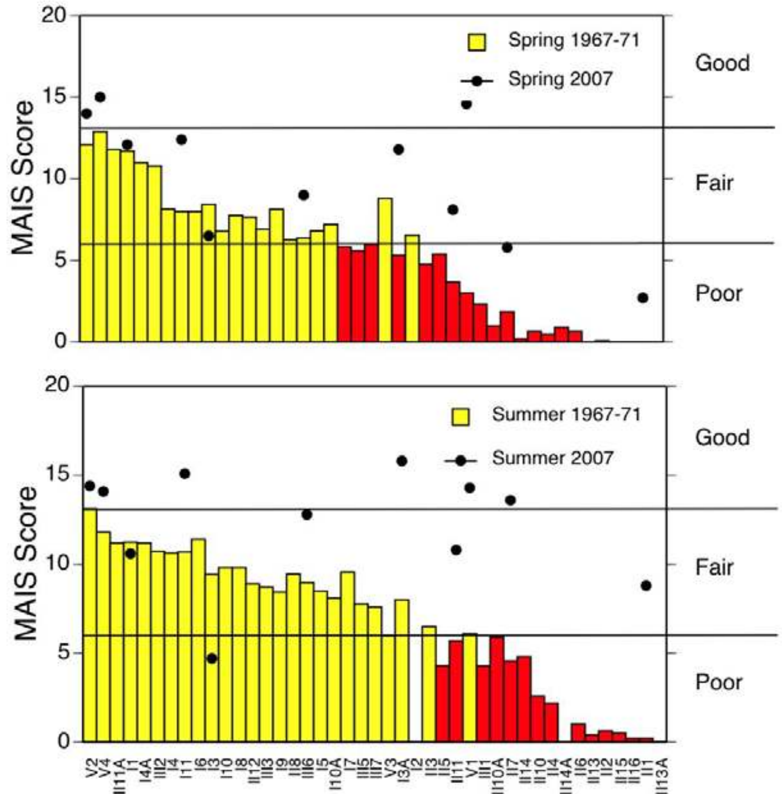


Figure 5.7. Seasonal MAIS Scores for 43 sites from spring and summer 1967-71 (bars) and 11 sites from spring and summer 2007 (circles), sorted by descending order of average 1967-71 MAIS Score. Bar color indicates site classification as Good, Fair, or Poor based on MAIS Score.

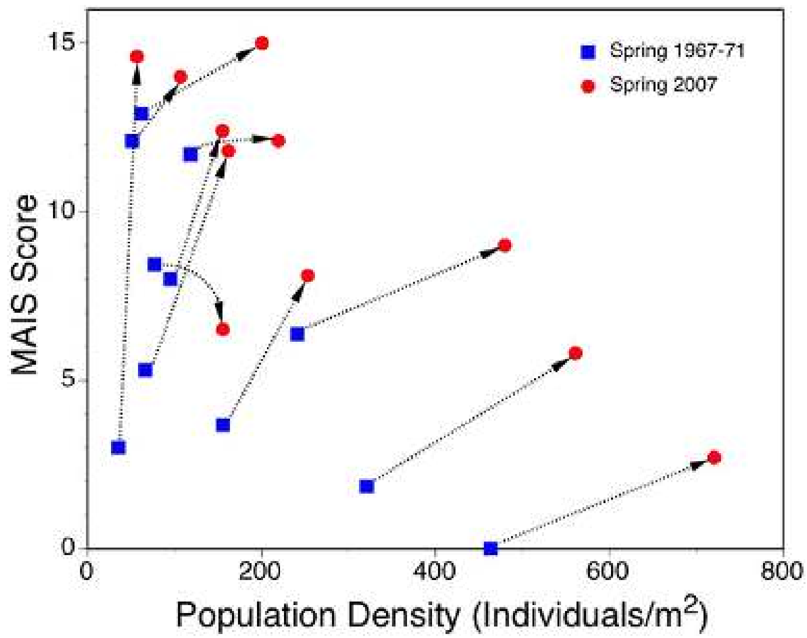


Figure 5.8. Changes in population density from 1970 and 2000 censuses (individuals/km^2 in watershed upstream of site) and spring MAIS Scores for 11 sites with macroinvertebrate data from both 1967-71 and 2007.

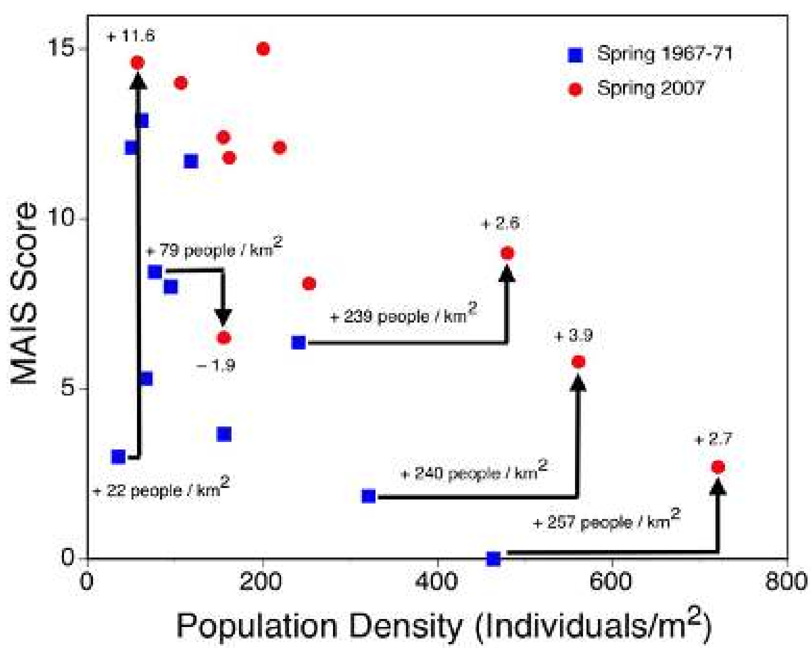


Figure 5.9. Details highlighting specific changes in population density and spring MAIS Scores for selected sites with data from both 1967-71 and 2007.

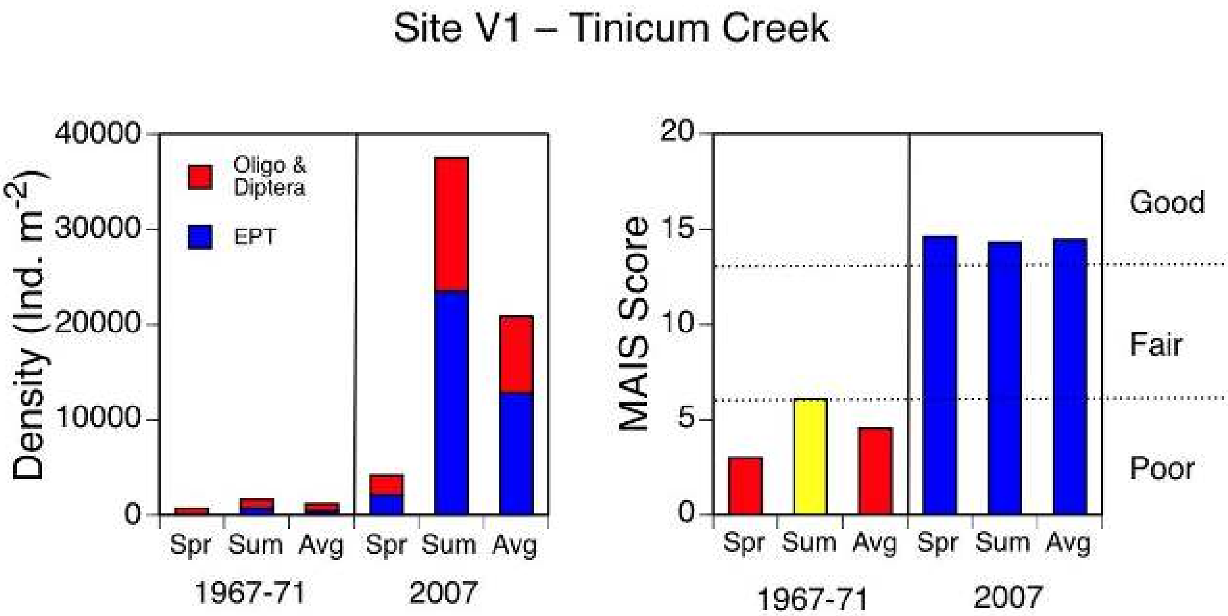


Figure 5.10. for Tinicum Creek (Site V1), average density (individuals m^{-2}) of pollution-sensitive Ephemeroptera, Plecoptera, and Trichoptera (i.e., EPT) and the pollution-tolerant Oligochaeta and Diptera macroinvertebrates, and average MAIS Scores for spring, summer and the average of spring and summer in 1967-71 and 2007

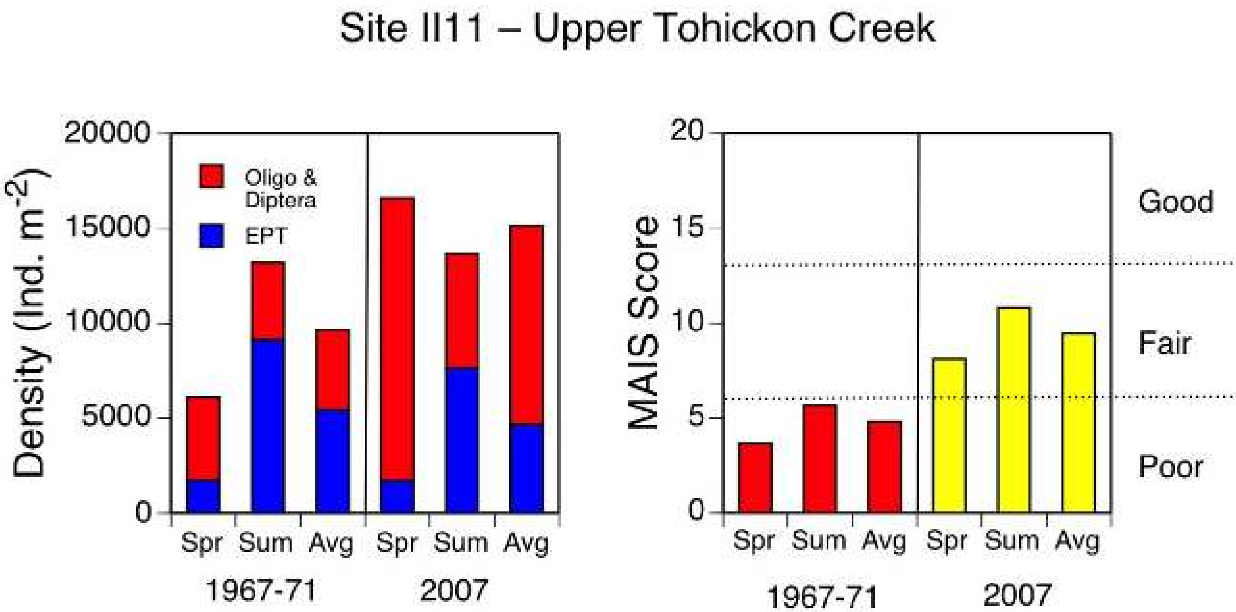


Figure 5.11. For Upper Tohickon Creek (Site II11), average density (individuals m^{-2}) of pollution-sensitive Ephemeroptera, Plecoptera, and Trichoptera (i.e., EPT) and the pollution-tolerant Oligochaeta and Diptera macroinvertebrates, and average MAIS Scores for spring, summer and the average of spring and summer in 1967-71 and 2007

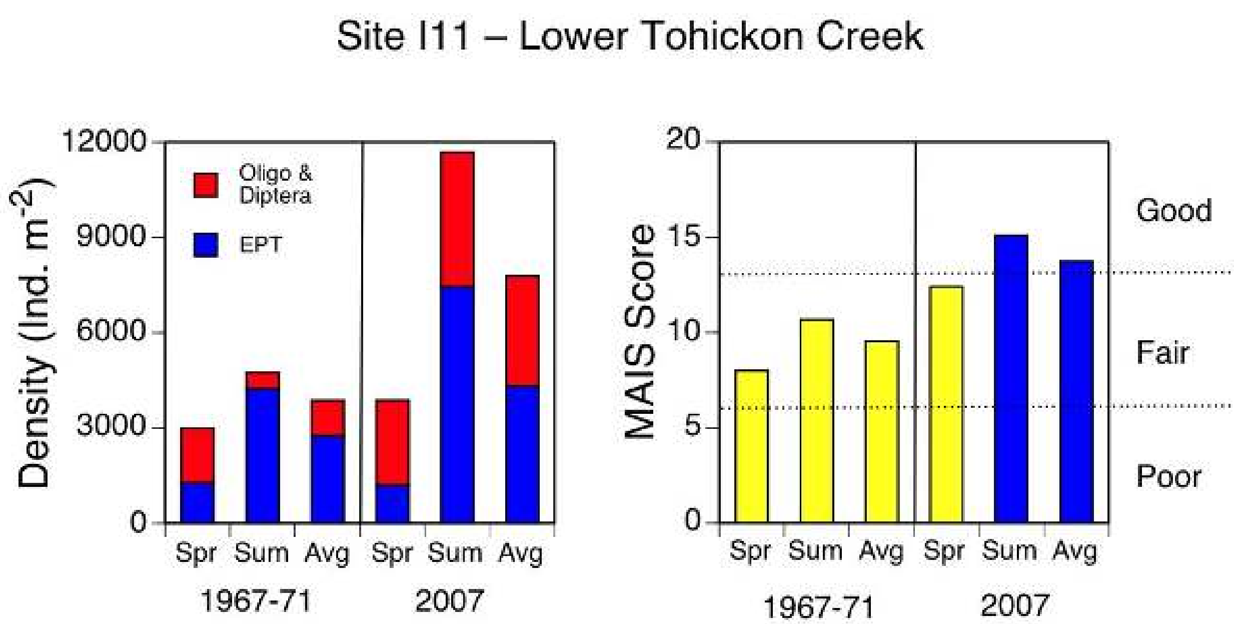


Figure 5.12. For Lower Tohickon Creek (Site I11), average density (individuals m^{-2}) of pollution-sensitive Ephemeroptera, Plecoptera, and Trichoptera (i.e., EPT) and the pollution-tolerant Oligochaeta and Diptera macroinvertebrates, and average MAIS Scores for spring, summer and the average of spring and summer in 1967-71 and 2007

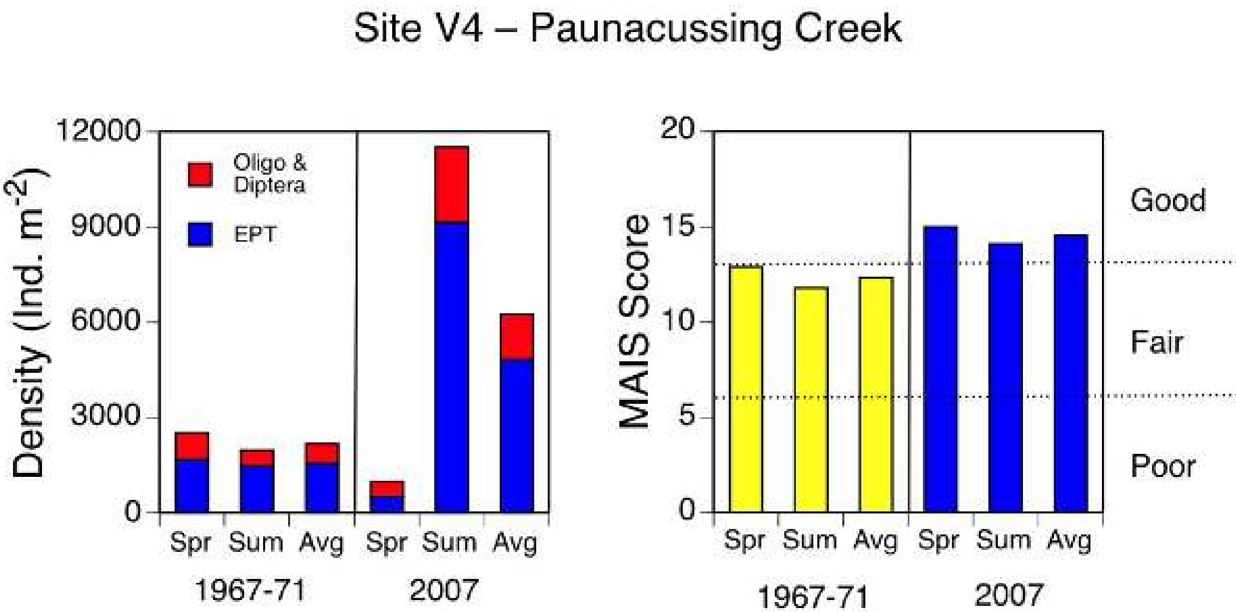


Figure 5.13. For Paunnacussing Creek (Site V4), average density (individuals m^{-2}) of pollution-sensitive Ephemeroptera, Plecoptera, and Trichoptera (i.e., EPT) and the pollution-tolerant Oligochaeta and Diptera macroinvertebrates, and average MAIS Scores for spring, summer and the average of spring and summer in 1967-71 and 2007

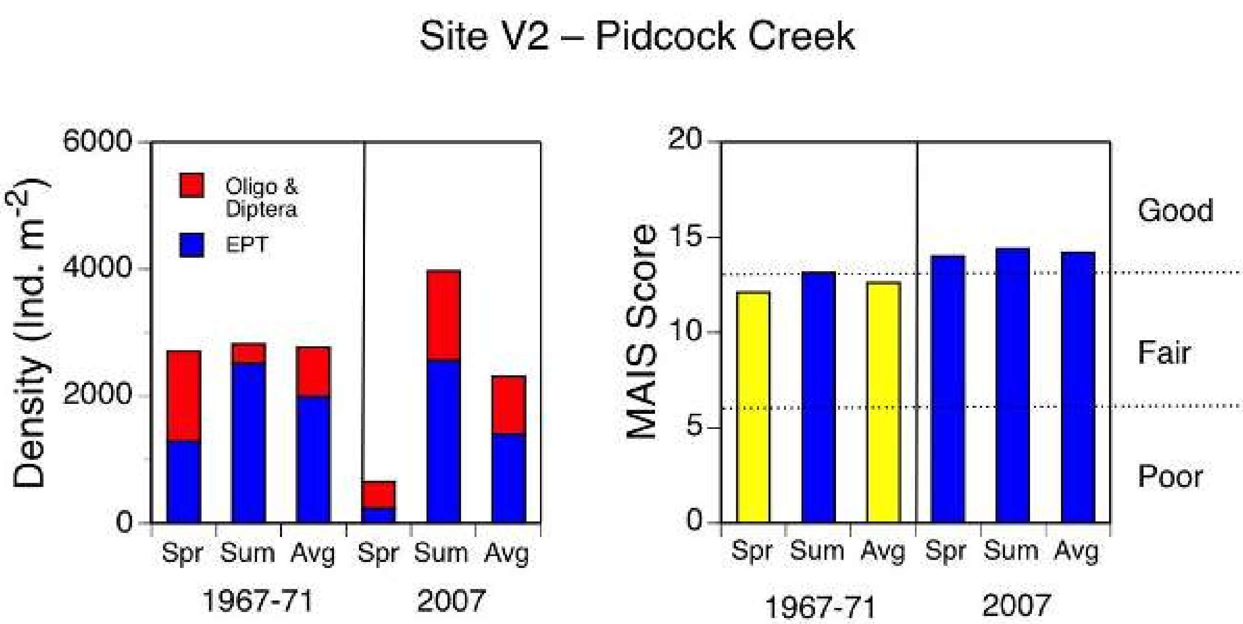


Figure 5.14. For Pidcock Creek (Site V2), average density (individuals m^{-2}) of pollution-sensitive Ephemeroptera, Plecoptera, and Trichoptera (i.e., EPT) and the pollution-tolerant Oligochaeta and Diptera macroinvertebrates, and average MAIS Scores for spring, summer and the average of spring and summer in 1967-71 and 2007

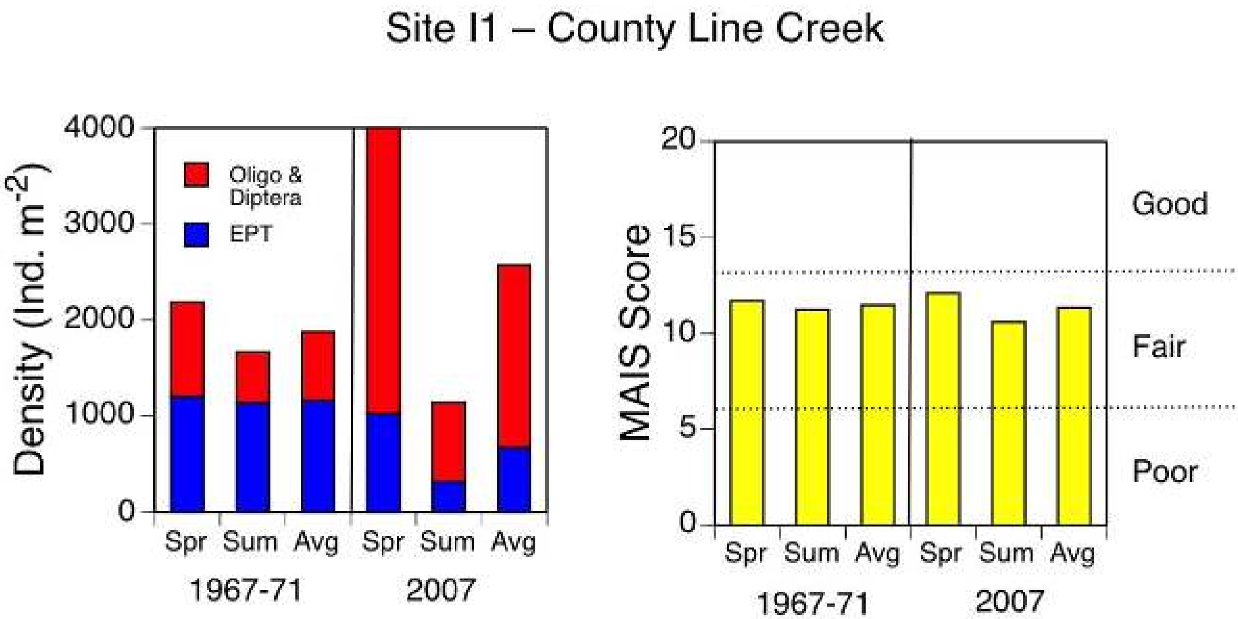


Figure 5.15. For County Line Creek (Site I1), average density (individuals m^{-2}) of pollution-sensitive Ephemeroptera, Plecoptera, and Trichoptera (i.e., EPT) and the pollution-tolerant Oligochaeta and Diptera macroinvertebrates, and average MAIS Scores for spring, summer and the average of spring and summer in 1967-71 and 2007

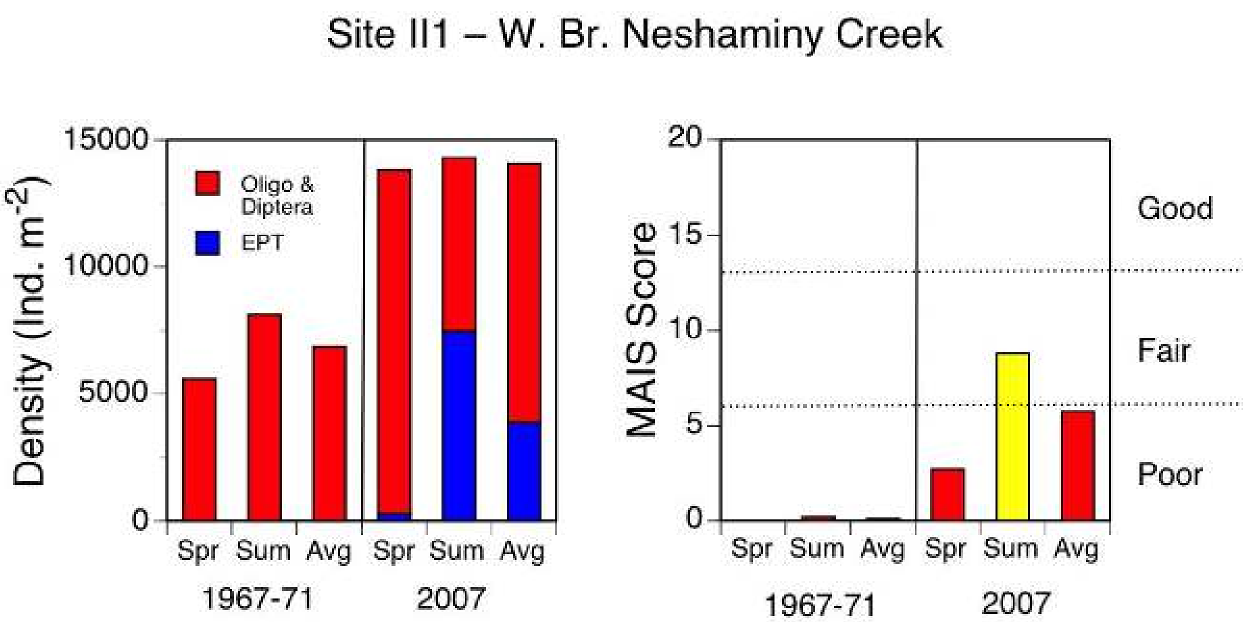


Figure 5.16. For West Branch of Neshaminy Creek (Site II1), average density (individuals m^{-2}) of pollution-sensitive Ephemeroptera, Plecoptera, and Trichoptera (i.e., EPT) and the pollution-tolerant Oligochaeta and Diptera macroinvertebrates, and average MAIS Scores for spring, summer and the average of spring and summer in 1967-71 and 2007

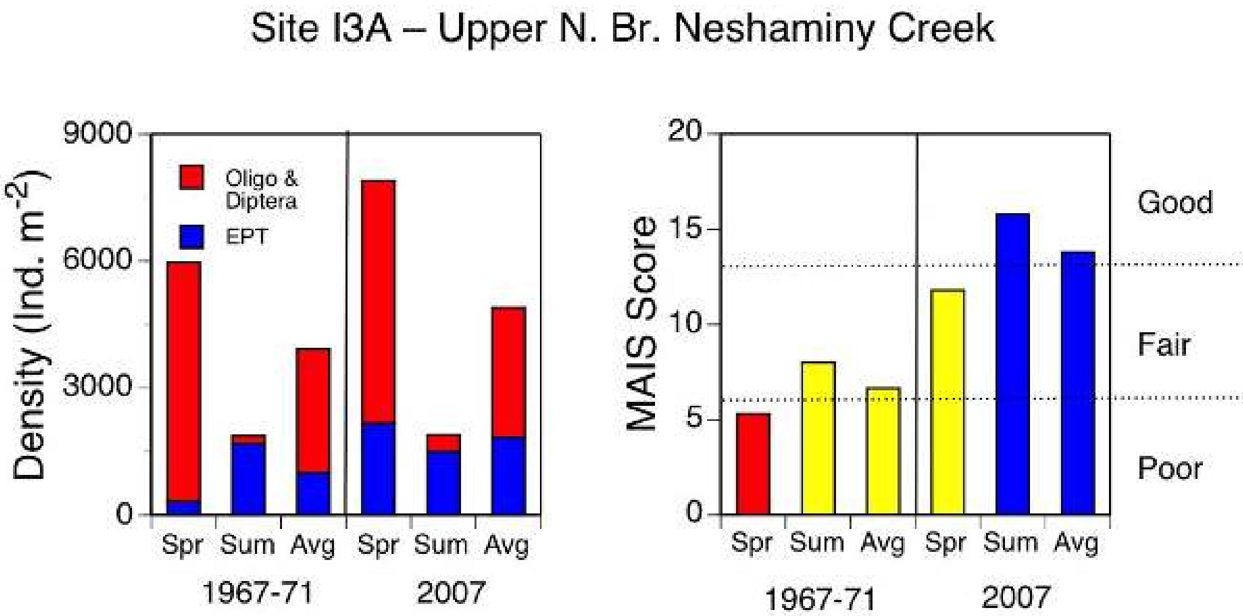


Figure 5.17. For Upper North Branch of Neshaminy Creek (Site I3A), average density (individuals m^{-2}) of pollution-sensitive Ephemeroptera, Plecoptera, and Trichoptera (i.e., EPT) and the pollution-tolerant Oligochaeta and Diptera macroinvertebrates, and average MAIS Scores for spring, summer and the average of spring and summer in 1967-71 and 2007

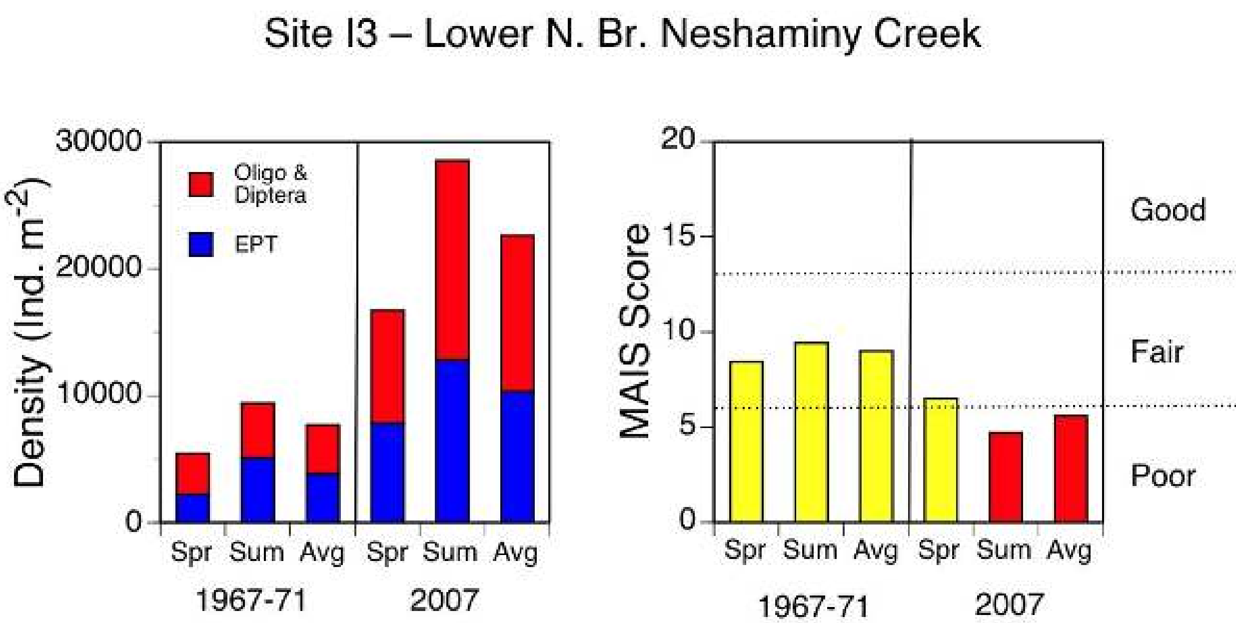


Figure 5.18. For Lower North Branch of Neshaminy Creek (Site I3), average density (individuals m^{-2}) of pollution-sensitive Ephemeroptera, Plecoptera, and Trichoptera (i.e., EPT) and the pollution-tolerant Oligochaeta and Diptera macroinvertebrates, and average MAIS Scores for spring, summer and the average of spring and summer in 1967-71 and 2007

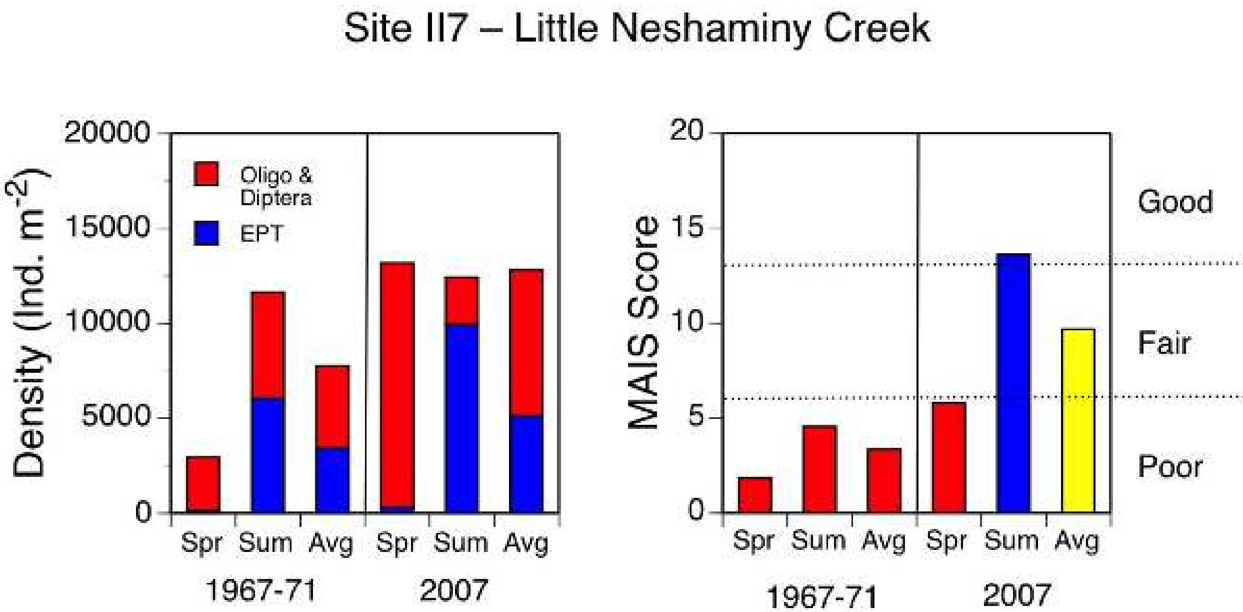


Figure 5.19. For Little Neshaminy Creek (Site II7), average density (individuals m^{-2}) of pollution-sensitive Ephemeroptera, Plecoptera, and Trichoptera (i.e., EPT) and the pollution-tolerant Oligochaeta and Diptera macroinvertebrates, and average MAIS Scores for spring, summer and the average of spring and summer in 1967-71 and 2007

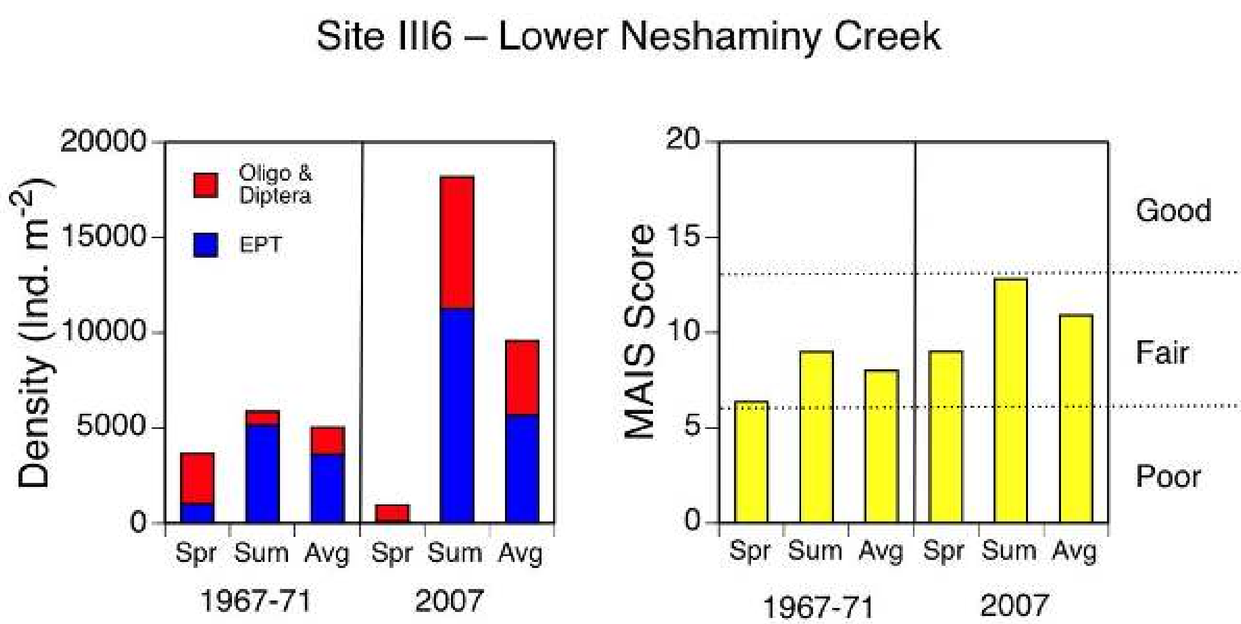


Figure 5.20. For Lower Neshaminy Creek (Site III6), average density (individuals m^{-2}) of pollution-sensitive Ephemeroptera, Plecoptera, and Trichoptera (i.e., EPT) and the pollution-tolerant Oligochaeta and Diptera macroinvertebrates, and average MAIS Scores for spring, summer and the average of spring and summer in 1967-71 and 2007

Appendix

Appendix 4.1. Taxa collected in the spring and summer 2007 from 11 streams in Bucks County, PA. Asterisks indicates unique taxon that was used to calculate a total of 194 taxa for the study.

Taxa	I1	I3A	I3	I11	II1	II7	II11	III6	V1	V2	V4
Planariidae *	X	X	X	X	X	X	X	X	X	X	X
Nemertea *	X	X	X	X	X		X	X	X	X	X
Nematoda *		X	X			X	X	X	X	X	X
Oligochaeta *	X	X	X	X	X	X	X	X	X	X	X
Hirudinea *	X			X		X					X
Isopoda *				X		X	X				
Amphipoda	X	X	X	X	X	X	X	X	X	X	
Gammaridae											
Gammarus *	X	X			X	X	X				
Decapoda *		X									
Acari *	X	X	X	X	X	X		X	X	X	X
Gastropoda	X		X	X			X	X	X		X
Ancylidae *	X		X	X	X			X	X	X	
Planorbidae *							X	X	X		
Bivalvia *	X	X	X	X	X	X	X	X	X	X	X
Corbicula *		X		X	X	X	X				
Sphaerium *			X		X						
Plecoptera	X	X					X		X	X	
Nemouridae											
Amphinemura	X	X	X	X				X	X	X	X
Amphinemura delosa *	X	X	X						X	X	X
Prostoia *	X										
Leuctridae											
Leuctra *											X
Perlidae		X		X					X	X	
Neoperla *		X									
Agnetina *				X							
Paragnetina media *									X		
Eccoptura xanthenes *	X										
Perlodidae	X	X							X		
Isoperla	X	X		X					X		
Isoperla namata *	X										
Chloroperlidae	X										X
Alloperla *		X									
Sweltsa *	X			X					X		X
Haploperla brevis *											X

Taxa	I1	I3A	I3	I11	II1	II7	II11	III6	V1	V2	V4
Perlidae/Perlodidae	X			X					X	X	X
Capniidae/Leuctridae									X		
Odonata	X										
Gomphidae *	X										X
Coenagrionidae *							X		X	X	X
Argia	X	X			X			X	X	X	
Argia moesta/translata *		X									
Ephemeroptera	X	X		X				X	X		X
Leptohyphidae								X			X
Tricorythodes *		X				X	X	X	X		X
Caenidae										X	
Caenis *		X		X	X	X	X		X	X	
Ephemerellidae		X		X					X	X	
Ephemerella									X		
Ephemerella dorothea *									X	X	X
Ephemerella invaria grp. *								X	X		X
Eurylophella									X		
Eurylophella verisimilis *										X	X
Serratella		X		X						X	
Serratella deficiens *		X							X		
Leptophlebiidae	X	X		X					X		
Paraleptophlebia *				X					X		
Baetidae	X	X		X	X	X	X	X	X	X	X
Acentrella		X						X	X		X
Acentrella cho ous *									X		
Acerpenna macdunnoughi *	X			X							
Baetis	X	X		X	X	X	X	X	X	X	X
Baetis flavistriga *							X	X	X	X	X
Baetis intercalaris *							X	X	X		X
Baetis nr. Tricaudatus *										X	X
Baetis intercalaris/flavist *		X				X	X	X			
Diphetor hageni *	X										
Heterocloeon *				X				X			
Heptageniidae	X	X		X	X	X		X	X	X	X
Epeorus *									X		
Stenonema	X	X		X				X	X	X	X
Stenonema terminatum *		X								X	
Stenonema modestum *				X						X	X
Stenonema vicarium *	X								X	X	
Stenonema cho o *											X
Stenacron										X	
Stenacron interpunctatum *		X		X		X	X	X	X	X	

Taxa	**I1**	**I3A**	**I3**	**I11**	**II1**	**II7**	**II11**	**III6**	**V1**	**V2**	**V4**
Ameletidae											
Ameletus									X		
Ameletus ludens *	X										
Isonychiidae											
Isonychia		X		X					X	X	X
Isonychia bicolor *				X							
Hemiptera											
Gerridae											
Gerris remigis *	X										
Metrobates *								X			
Microveliidae											
Microvelia *											X
Rhagovelia *							X				
Trichoptera	X	X		X		X		X	X	X	X
Glossosomatidae								X	X	X	X
Agapetus *										X	X
Glossosoma *											X
Protoptila *						X		X			
Philopotamidae				X	X	X	X	X	X	X	X
Chimarra	X	X	X	X		X	X	X	X	X	X
Chimarra aterrima *	X	X				X				X	X
Chimarra nr. Obscura *		X		X			X	X	X	X	X
Dolophilodes *		X		X							X
Wormaldia *									X		
Psychomyiidae		X	X						X	X	
Psychomyia		X		X							
Psychomyia flavida *		X	X								
Hydropsychidae	X	X	X	X	X	X	X	X	X	X	X
Cheumatopsyche *	X	X	X	X	X	X	X	X	X	X	X
Diplectrona modesta *									X		
Hydropsyche	X	X	X	X	X	X	X	X	X	X	X
Hydropsyche betteni *	X	X	X	X	X	X	X	X	X	X	X
Hydropsyche slossonae *									X		X
Hydropsyche bronta *		X			X	X		X	X	X	X
Hydropsyche cho o *		X						X	X	X	
Hydropsyche sparna *								X	X	X	X
Hydropsyche leonardi *				X				X	X		
Macrostemum zebratum *										X	
Hydroptilidae		X			X	X	X	X	X		X
Hydroptila *					X	X	X	X	X		
Leucotrichia		X	X	X	X	X				X	X
Leucotrichia pictipes *		X	X		X	X		X	X	X	X

Taxa	I1	I3A	I3	I11	II1	II7	II11	III6	V1	V2	V4
Stactobiella *								X			
Limnephilidae											
Pycnopsyche guttifer *										X	
Leptoceridae	X		X	X		X	X	X	X	X	
Ceraclea *				X					X		
Mystacides sepulchralis *	X							X			
Oecetis							X		X		
Oecetis persimilis *							X				
Lepidostomatidae				X							X
Lepidostoma *				X				X	X		
Brachycentridae			X	X					X		
Micrasema *									X		
Helicopsychidae											
Helicopsyche borealis *						X		X		X	X
Polycentropodidae	X			X				X	X	X	X
Neureclipsis *										X	
Nyctiophylax *	X									X	
Polycentropus *				X					X	X	X
Uenoidae											
Neophylax	X			X			X		X	X	
Neophylax fuscus *										X	
Neophylax oligius *										X	
Corydalidae											
Corydalus cornutus *		X							X		
Nigronia serricornis *										X	
Pyralidae											
Petrophila *		X	X	X	X	X	X	X	X	X	
Diptera			X							X	
Simuliidae	X	X	X	X	X	X	X	X	X	X	
Prosimulium *				X			X		X	X	X
Simulium		X	X	X	X	X	X	X	X		X
Simulium tuberosum *							X				
Simulium venustum/verecundum *		X									
Simulium vittatum cmplx. *	X		X				X				
Psychodidae								X			
Tipulidae	X						X		X		
Antocha *	X	X		X		X	X	X	X	X	X
Dicranota *	X										
Hexatoma *		X									
Tipula *	X						X				
Ceratopogonidae	X								X		
Atrichopogon *		X									

Taxa	**I1**	**I3A**	**I3**	**I11**	**II1**	**II7**	**II11**	**III6**	**V1**	**V2**	**V4**
Chironomidae											
Tanypodinae				X						X	X
Ablabesmyia *	X										
Natarsia *		X								X	X
Nilotanypus	X										
Nilotanypus fimbriatus *	X							X			
Pentaneura *						X					
Thienemannimyia grp. *	X	X	X			X		X	X	X	X
Zavrelimyia *	X										
Diamesinae								X			
Diamesa *	X	X	X	X	X	X		X	X	X	X
Potthastia gaedii grp. *									X		
Sympotthastia *	X	X							X		
Orthocladiinae	X	X	X	X	X	X	X	X	X	X	X
Cardiocladius obscurus *		X	X	X				X			X
Chaetocladius *				X							
Corynoneura *	X	X		X		X	X	X	X	X	X
Cricotopus	X	X	X	X	X	X	X	X	X	X	X
*Cricotopus albiforceps/vierriensis**		X				X	X	X	X		
Cricotopus annulator cmplx. *	X	X		X	X	X	X	X		X	
Cricotopus bicinctus grp. *	X	X	X	X	X	X	X	X	X	X	X
Cricotopus politus *				X				X	X	X	
Cricotopus triannulatus *	X	X	X	X	X		X	X	X		X
Cricotopus trifascia grp. *		X		X	X		X		X	X	X
Cricotopus tremulus *		X		X	X	X	X		X		
Cricotopus/Orthocladius	X	X	X	X	X	X	X	X	X	X	X
Eukiefferiella	X	X		X	X				X		X
Eukiefferiella brevicalcar grp. *	X	X		X				X	X	X	
Eukiefferiella claripennis grp. *	X			X							
Eukiefferiella gracei grp. *				X							
*Eukiefferiella pseudomontana grp.**		X									
Euryhapsis *	X										
Hydrobaenus *	X	X	X	X	X	X		X	X	X	X
Krenosmittia *											X
Limnophyes *				X							
Nanocladius		X	X								
Nanocladius alternantherae *		X									
Nanocladius crassicornis *			X								
Nanocladius distinctus/minimus *			X								
Orthocladius	X	X	X	X	X	X	X	X	X	X	X
Orthocladius carlatus *	X			X							
Orthocladius clarkei *	X	X									

Taxa	**I1**	**I3A**	**I3**	**I11**	**II1**	**II7**	**II11**	**III6**	**V1**	**V2**	**V4**
*Orthocladius dorenus **	X	X	X	X	X	X	X	X	X	X	X
*Orthocladius oliveri **		X		X			X	X	X		
*Orthocladius obumbratus **	X					X	X			X	X
*Orthocladius rivicola **		X		X		X			X	X	X
*Orthocladius rivulorum **				X					X		
*Orthocladius robacki **	X	X							X	X	X
*Paracricotopus **			X								
*Parametriocnemus **	X	X									
*Paratrichocladius **											X
Rheocricotopus											X
*Rheocricotopus nr. Robacki **	X								X		
*Rheocricotopus unidentatus **							X				
*Synorthocladius **				X	X	X		X		X	
Thienemanniella		X		X	X	X	X	X	X		X
*Thienemanniella boltoni **							X				
Thienemanniella sp. B (Epler) *							X	X	X		
*Thienemanniella lobapodema **				X							
*Thienemanniella nr. Xena **	X						X				
*Thienemanniella taurocapita **		X							X	X	
*Thienemanniella cho ou **						X		X			
Tvetenia	X	X						X	X		
*Tvetenia paucunca **	X	X	X	X						X	
*Tvetenia vitracies **				X				X			X
Chironominae	X	X	X		X	X	X	X			
Chironomini	X		X		X	X			X		
*Cryptotendipes **		X									
*Dicrotendipes **	X	X	X	X	X	X	X	X	X	X	
*Endochironomus **		X									
*Glyptotendipes **			X								
*Microtendipes pedellus grp. **	X	X	X			X		X	X	X	X
*Parachironomus **			X		X						
*Paratendipes **		X									
*Phaenopsectra **	X						X				
Polypedilum	X	X	X	X	X		X	X	X	X	X
*Polypedilum aviceps **	X								X		X
*Polypedilum convictum grp. **	X	X	X	X	X	X	X	X	X	X	X
*Polypedilum scalaenum grp. **	X										
*Polypedilum tritum **						X	X	X	X	X	
Rheotanytarsus		X	X	X	X	X	X	X	X	X	X
*Rheotanytarsus cho ous grp. **	X	X	X	X	X	X	X	X	X	X	X
*Saetheria **								X			
*Stenochironomus **	X	X						X			

Taxa	**I1**	**I3A**	**I3**	**I11**	**II1**	**II7**	**II11**	**III6**	**V1**	**V2**	**V4**
Tanytarsini	X	X	X	X	X	X		X	X	X	X
Cladotanytarsus *	X							X	X	X	X
Micropsectra	X	X				X		X			
Micropsectra nr. Polita *									X		X
Micropsectra sp. D (Epler) *	X					X					
Paratanytarsus *	X										X
Stempellinella *	X	X				X		X	X	X	X
Sublettea *	X								X	X	X
Tanytarsus	X	X		X	X	X	X	X		X	X
Tanytarsus glabrescens grp. *	X	X		X	X	X	X	X	X	X	X
Tanytarsus guerlus grp. *	X		X			X	X	X	X	X	X
Tanytarsus sp.1 (Funk) *	X	X		X		X			X	X	
Tanytarsus sp. 2 (Funk) *								X			
Tanytarsus/Micropsectra	X	X						X			
Rhagionidae											
Atherix *									X		
Empididae	X	X	X	X			X		X	X	
Chelifera *		X	X	X			X	X			
Clinocera *	X	X		X		X	X		X	X	X
Hemerodromia *	X	X	X	X	X	X	X	X	X	X	
Ephydridae *		X									
Chaoboridae											
Chaoborus *			X	X							
Coleoptera	X										
Elmidae	X	X	X	X	X	X	X	X	X	X	X
Ancyronyx variegata *							X				
Dubiraphia *		X									
Macronychus glabratus *		X		X							
Microcylloe puspusillus *		X					X	X	X		X
Optioservus		X		X				X			
Optioservus ovalis *											X
Optioservus trivittatus *		X		X			X				
Oulimnius latiusculus *		X									X
Optioservus/Oulimnius		X		X							X
Stenelmis	X	X	X	X	X	X	X	X	X	X	X
Stenelmis crenata *	X	X	X	X	X	X	X	X	X	X	X
Stenelmis sandersoni *							X				
Psephenidae	X					X	X			X	X
Ectopria *					X	X	X		X		
Psephenus herricki *	X	X	X	X	X	X	X	X	X	X	X

----------------------Intentionally Blank----------------------

Chapter 6. Algal Communities: Phytoplankton and Periphyton

Overview

The studies of Bucks County streams conducted between 1967 – 1971 included microscopic examination of phytoplankton samples for algal identification. That work was repeated in the present study and additional phytoplankton samples were analyzed for concentrations of chlorophyll *a*, a marker of biomass. However, planktonic algae are transient in a particular reach. Furthermore, in small to mid-sized streams an extensive periphyton community (i.e., algae attached to surfaces) can develop and more biomass is found on the streambed than in the water column. The study streams were relatively shallow and considerable light reached the streambed in all of them, especially where they were wide enough to bring about a separation of the tree canopy or where the riparian zone had been cleared of trees at some point in time. Therefore, we added measurements of periphyton biomass and community composition to the algal community programmatic element, in order to provide additional baselines of periphyton chlorophyll, organic mass and community composition for future reference. We included analyses of the tree canopy and characterization of benthic substrata with those assessments because those factors, along with nutrient concentrations, influence the development of periphyton communities.

Methods

Photographs of each study site, the tree canopy, and streambed (including predominant substrata) are presented in the Appendix at the end of this chapter. Information on study sites, including location and watershed conditions, can be found in Chapter 2.

Phytoplankton

Sampling. Water samples were collected at the bottom, middle and top of each stream reach on the dates shown in Table 6.1. Samples for algal identification were collected into 250-mL Nalgene bottles previously rinsed with stream water. The samples were shaken and two 100-mL aliquots were poured into 125-mL Nalgene bottles and fixed with 1% (final concentration) gluteraldehyde. The samples were placed on ice in a cooler and stored at 4°C until examination.

Other water samples were collected in 500 ml Nalgene bottles for analysis of chlorophyll *a*, an index of algal biomass. A field duplicate was collected at the bottom station and a 500 ml field blank was performed at each stream. Samples were placed on ice in a cooler. That evening, an aliquot from each sample was filtered at 0.5 atmospheres onto a Whatman GF/F filter. The filter was folded in half, transferred to a small plastic zip-lock bag and frozen on dry ice. From 100 to 500 ml were filtered, the volume depending on phytoplankton density and expected chlorophyll concentration. On return to the laboratory the following day, filters were transferred to a -20°C freezer.

Chlorophyll determinations. Chlorophyll concentrations were determined fluorometrically (Arar and Collins 1997). The frozen filters were macerated in 4 ml of 90% acetone (made basic with 0.1 ml NH_4OH/L acetone) at 4°C. The volume was brought to 10 ml with additional acetone solution and samples were extracted -20°C for 16 to 24 h in darkness. The filters were compressed using a Teflon pestle and the supernatant fluids were transferred to centrifuge tubes. The samples were centrifuged (10,000 x *g*, 20 min, 4°C) after which the supernatant fluids were transferred to test tubes in an ice bath and covered with aluminum foil. Manipulations were performed in subdued light. An aliquot of the supernatant fluid (4 ml) was analyzed fluorometrically by making an appropriate dilution (between 1:2 and 1:32) in a 9 ml cuvette and measuring fluorescence intensity before and after acidification in a Model 10-AU fluorometer (Turner Design, Sunnyvale, CA). A lab control standard of 10 µg chlorophyll *a*/ml (Sigma-Aldrich, St. Louis, MO) was assayed with each set of filters. A solid standard calibrated against a fluorometrically-determined chlorophyll standard (Turner Design) was assayed with samples on a daily basis. Concentrations were determined using the equation found in Arar and Collins (1997), which included correction for pheophytin (a chlorophyll degradation product), the concentrations of which are also reported.

Community composition. Each phytoplankton sample was concentrated on a cellulose nitrate membrane filter (25 mm diameter, 0.2 µm pore size) by filtration at 0.5 atmospheres. Each filter was placed in a small conical funnel and cells were washed into an amber vial by directing a stream of 1 % gluteraldehyde from a 5 ml syringe with an attached 25-gauge needle over the filter, thus concentrating the cells from 100 ml into a final volume of 4 ml. Samples were stored at 4°C. Counts of phytoplankton were performed using a Palmer-Maloney counting chamber. Samples were held on a vortex mixer for 90 s after which an aliquot (0.1 ml) was loaded into the counting chamber. Samples were examined using an Olympus BX61 differential interference contrast microscope equipped with a 40x long-working-distance water immersion objective (Olympus America, Melville, NY). Two samples from each reach were counted. From 1 to 4 aliquots from each sample were counted with the goal of enumerating 300 taxonomic units (defined as a filament or colony of Cyanobacteria or a cell of other algal groups). This approach prevents the overweighting of small cyanobacterial cells as components of community structure. Parenthetically, cell numbers for each filament or colony were noted. Only data for live cells, i.e, cells containing a chloroplast, are reported. Phytoplankton were identified to genus (as in the 1967 - 1971 study) whenever possible using keys listed in Table 6.2 and sometimes using photomicrographs from reputable sources available on the Internet. Occasionally separate subsamples were examined under 1000x magnification to assist in identification. Frank Acker of the Phycology Section at the Academy of Natural Sciences served as consultant concerning taxonomic matters related to both phytoplankton and periphyton identification. Numerous photomicrographs were taken to create a taxonomic archive that is available on request.

Periphyton

Sampling. From 4 to 10 equidistant transects were set between the top and bottom of each reach (Table 6.3). Stream width was measured at each transect, and 10 equidistant lateral sampling points were designated. At each point, water depth was measured and the predominant types of substrata and periphyton "cover" were assessed (field mapping). Substratum categories followed those of Hynes (1970), e.g., silt, sand, pebble, cobble, and boulder. Examples of cover types were: filamentous green algae, diatoms (brown velvet appearance), black and green covers (a thin slime on rock that yielded color when rubbed with a finger), silt, and moss.

Replicate samples (2 – 5) for periphyton chlorophyll *a* and organic matter were collected for cover types constituting ≥10% of encounters during the field mapping effort. Soft substrata were sampled by inserting a plastic tube (11.28 cm id) into the streambed and suctioning surface sediments with a meat baster. Periphyton on rocks were scraped, brushed and washed into a jar and the rock outline was traced onto a piece of paper for determination of surface area. Samples were placed on ice. That evening, each sample was homogenized and filtered onto a 250 µm mesh screen. One-quarter of the recovered biomass was transferred to a jar with one quarter of the filtrate for determination of organic weight (AFDM) and refrigerated. One quarter of biomass and filtrate were transferred to a jar and fixed with formaldehyde (3% final concentration) for algal identifications. The remaining half of each sample was transferred to an Oak Ridge tube and centrifuged, and recovered pellets were frozen (on dry ice, then at -20°C after return to the laboratory) for chlorophyll *a* analyses. The remaining half of 250 µm filtrate from each sample was filtered (Whatman GF/F) and the filter was frozen for chlorophyll determination.

Chlorophyll and organic matter assays. Pellets from centrifugation and filters were thawed and extracted overnight in 90% acetone (made basic with NH_4OH) at –20°C in darkness. Following centrifugation (14,000 x *g*, 20 min, 4°C), absorbencies of the supernatant fluids were determined spectrophotometrically at 665 nm and 750 nm before and after acidification with 2 drops of 1 N HCl (prepared biweekly). Pellets were extracted repeatedly until chlorophyll *a* absorbance was either 10% of the value obtained in the 1st extraction or <0.1 absorbance units at 665 nm. Concentrations were determined using the equation of Lorenzen (1967), which include correction for pheophytin.

For determination of organic matter as ash-free dry mass (AFDM), samples were dried at 100°C, weighed, ashed (500°C for 6 h), cooled, and reweighed.

Rock outlines were digitized and planar surface area was determined using the public domain NIH Image software (developed by the U.S. National Institutes of Health and available at hhtp://rsbweb.nih.gov). This allowed expression of chlorophyll and organic matter on an areal basis

Community composition. Counts of periphyton algae were performed in order to assess community composition associated with each cover type. Samples were shaken vigorously for 90 s after which an aliquot (0.1 ml) was loaded into a Palmer-Maloney counting chamber. Samples were examined using an Olympus BX61 differential interference contrast microscope equipped with a 40x long-working-distance water immersion objective (Olympus America, Melville, NY). From 1 to 4 aliquots from each sample were counted with a goal of enumerating 300 taxonomic units (Cyanobacterial filaments or colonies; cells of other algal groups). The goal of 300 units was occasionally relaxed if a small number of taxa occurred in the cover type because there were usually multiple samples of each cover type. Periphyton were identified to genus or major group using keys listed in Table 6.2 and photomicrographs on the Internet from reputable sources as needed. Sometimes separate subsamples were examined under 1000x magnification to assist in identification. Photomicrographs were taken to create a taxonomic archive.

Tree canopy density

The tree canopy over each stream was photographed at 2 to 3 locations evenly spaced along the reach, using a digital camera (Fujifilm S 5100) equipped with a fisheye lens (Opteka 0.22x AF Fisheye). The camera was positioned 0.67 m above the water surface at the center of the stream. Each photograph captured the canopy for a distance of ~25 m. Tree canopy photos were processed using Image-Pro Plus 5.0 software. Color photos were segmented to black and white images of sky and tree canopy. The proportion of total area accounted for by the canopy was determined using the Image J v.1.38 software (US NIH, public domain available at http://rsb.info.nih.gov/ij/). The %canopy values from the photos were averaged to generate a mean % canopy cover for each stream.

Data analysis

Chlorophyll and organic matter estimates. Phytoplankton chlorophyll values for each sample were averaged to generate a number for the stream. Periphyton chlorophyll concentrations for each cover type were matched with the percentage of total reach area of that cover type to generate a weighted periphyton chlorophyll concentration/m^2. Chlorophyll was assayed for the most important cover types. These accrued to between 82 and 100% of the cover type point assessments in all streams but Lower Tohickon where only 68% of encounters were matched with chlorophyll. However 21.7% of encounters in that reach were categorized as "bare" with low chlorophyll concentration and if only substrata with a visible cover are considered, ~90% of point assessments would have been matched with a chlorophyll value. Elsewhere, bare cover type never accounted for more than 10% of substrata encounters except in Paunacussing (55%). Organic matter data were treated similarly to generate a weighted estimate of organic mass/m^2 for each stream.

Phytoplankton densities. Phytoplankton counts were generated for total number of live units and live cells of each taxon/100 ml according to equation (1):

$$\text{total live units or cells/100ml } = \sum_{n=1}^{t} \frac{\text{units or cells of taxon}_t}{\text{fields counted}} \times \frac{2092 \text{ fields}}{1} \times \frac{4 \text{ ml}}{0.1 \text{ ml}} \qquad (1)$$

where:
cells or live units are the sum from all aliquots for a given taxon "t",
fields equals the total number of fields counted
2092 is the number of fields per Palmer Cell at 40xW magnification
4 ml is the total sample volume
0.1 ml is the Palmer Cell volume

Periphyton densities. Periphyton counts were generated for total number of live units and live cells/100 ml according to equation (2):

$$\text{total live units or cells/100ml} = \sum_{n=1}^{t} \frac{\text{units or cells of taxon}_t}{\text{fields counted}} \times \frac{2092 \text{ fields}}{1} \times \frac{\text{sample volume}}{0.1 \text{ ml}} \times \frac{4}{1} \times \frac{1}{\text{area (cm}^2)} \qquad (2)$$

where:
cells or live units are the sum from all aliquots for a given taxon "t",
fields equals the total number of fields counted
2092 is the total number of fields per Palmer Cell at 40xW magnification

sample volume is the total volume of sample (50 or 100 ml)
0.1 ml is the volume of the Palmer Cell
4 corrects for the portion of the filtered sample used for taxonomy
cm^2 is the area of the rock or sediment (100 cm^2) sampled

Biovolume data available for numerous species (Lowe and Pan 1996) were averaged by genus to generate means for genera encountered in our samples. The value for *Achnanthidium* was applied to *Achnanthes* as well, and values for *Cymbella*, *Gomphonema*, *Navicula*, and *Nitzschia* were applied to the categories Pennate with those genera appended as adjectives (e.g., Pennate – naviculoid). A biovolume for *Melosira* was averaged from data compiled for several stations on Tenmile Lake, OR, on June 26, 2006 by J. Kann of Aquatic Ecosystem Sciences, Ashland OR available on the Internet at www.tlbp.presys.com and in Hill (2002) yielding a mean biovolume of $3146 \pm 1527\ \mu m^3$/cell. Biovolumes of 10 μm^3 and 40 μm^3 were used for unicellular and filamentous Cyanobacteria, respectively.

Percent similarity in community composition was determined for (i) phytoplankton communities between streams, (ii) periphyton communities between streams, (iii) phytoplankton and periphyton communities in each stream, and (iv) phytoplankton composition in 1967-71 and 2007 using equation (3).

$$PS_c = 100 - 0.5\sum_{i=1}^{s} |a_i - b_i| = \sum_{i=1}^{s} \min(a_i, b_i) \qquad (3)$$

where:
a_i = percentage of species i in stream A or community A
b_i = percentage of species i in stream B or community B

The % relative abundances for these computations were based on the proportion of the species in the total number of either diatoms or soft algae as appropriate, not the entire community, and thus are called “alternative relative abundances”. Certain taxa were grouped before making these computations for the following reasons. *Hantzschia* (present in historical data set but probably called *Nitzschia* in 2007) was designated *Nitzschia*. *Achnanthes* (present in historical data set and a few in 2007) was designated *Achnanthidium* (frequently encountered in 2007). Cells designated “araphid with straight striae”, “unidentified diatom”, “pennate/gomphonemoid” were all designated Bacillariophyta to be consistant with historical grouping of unspecified Bacillariophyta. Cells designated “Pennate/nitzschioid” in 2007 were included as *Nitzschia.* Cells designated “Pennate/naviculoid” were included with *Navicula.* Cells designated “Pennate/cymbelloid” were included with *Cymbella.* Cells called in 2007 “coccoid green”, “colonial green”, “unidentified green”, “unidentified green # 1, #2, or #3”, and “spined desmid” all were classified as Chlorophyta. Likewise, units called “coccoid blue green”, “colonial blue green” and “Cyanobacteria – CB” in the 2007 data were all grouped as Cyanobacteria.

Data were $\log_{10}$(x)-transformed or arcsine$\sqrt{(x)}$-transformed (for % data) with a constant added before transformation before statistical analyses. Differences between streams were determined using analysis of variance (ANOVA) followed by Tukey’s test when the ANOVA was significant ($p \leq 0.05$).

Non-metric Multidimensional Scaling (NMS) ordination technique was used to examine how genus-level phytoplankton and periphyton taxa differed among streams (PC-ORD Version 4.41, MjM Software, Gleneden Beach, OR). Each analysis was performed under the Autopilot mode using the slow and thorough option. The phytoplankton analysis was based on "alternative' relative abundance" values and rare taxa (occurring < 1%) within a site were removed from the analysis. The periphyton analysis was based on "alternative relative abundance" values converted to presence/absence data and rare taxa (<1%) within a site were removed. NMS ordinations used Sorenson (Bray-Curtis) distance with a step length of 0.2. For both analyses, a 2-dimensional solution (axes) was used based on results of a Monte Carlo test that compared the proportion of randomized runs having a stress value ≤ the observed stress (desired p-value of ≤ 0.05; p = 0.0196 for both phytoplankton and periphyton). The axis scores for each ordination, which describe the separation of sites in two dimensions, were then examined for correlations with chemical, biological, tracer and watershed variables in order to explain the distribution of sites in each ordination.

Results and Discussion

Relevant site characteristics

Tree canopy density. Tree canopy densities ranged from 43.9% (Lower Neshaminy, to 89.2% (County Line; Table 6.3). Canopy density was greater than 60% for all streams but Lower Neshaminy, Upper Tohickon, and W. Br. Neshaminy. As expected, density was a function of width (Fig. 6.1). The percentage at W. Br. Neshaminy was lower than expected for a stream of its size and the one most different from the predicted value, suggesting that the riparian zone may have experienced greater disturbance than at other streams of similar size.

Streambed substrata. The study streams were dominated by hard substrata. The % of encounters classified as cobble, boulder and bedrock ranged from 49.2% (W. Br. Neshaminy) to 93.8% (Lower Tohickon), and when the pebble category was included in this summation the percentages increased to between 84.5% (Upper Tohickon) and 99.9% (Tinicum; Fig. 6.2). The highest percentage of soft substrata (clay, silt and sand) was 15.4% and occurred in Upper Tohickon.

Phytoplankton

Phytoplankton chlorophyll. With two exceptions, phytoplankton chlorophyll concentrations did not differ substantially between the 3 samples (bottom, mid, top of reach), and CVs of these samples from ranged from 5.6 to 12.3%. The exceptions were Paunacussing and Tinicum where CVs were 16.9% and 63.5%, respectively. There was no obvious explanation for the much higher variability at Tinicum.

The mean concentration of phytoplankton chlorophyll *a* in each stream ranged from 0.56 µg/L (Paunacussing) to 2.46 µg/L (Lower Neshaminy), except for the extraordinarily high concentration of 8.24 µg/L in Lower N. Br. Neshaminy (Fig. 6.3). The high value at Lower N. Br. Neshaminy is presumably related to its location downstream of Lake Galena (an impoundment completed in 1973). The suspended algal biomass measured there was most likely phytoplankton discharged from the reservoir. Lower Tohickon was also located downstream of an impoundment (Lake Nockamixon) but phytoplankton chlorophyll was much lower there.

Presumably conditions promoting phytoplankton development in Lake Galena were substantially different from those in Lake Nockamixon. While we did not perform studies in the reservoirs, nutrients related to algal growth such as total N, total P, nitrate, and ammonium, were 1.45, 1.25, 1.28 and 1.21- fold greater, respectively, at Lower N. Br. Neshaminy downstream of Lake Galena than at Lower Tohickon below Lake Nockamixon.

If the phytoplankton chlorophyll concentrations that are used to categorize the trophic status of lakes and reservoirs are applied our data, all streams would be considered oligotrophic (< 3 µg/L) with the exception of Lower N. Br. Neshaminy, which would be considered mesotrophic (3 – 10 µg/L).

Pheophytin concentrations were approximately equal to or greater than the chlorophyll concentrations in 7 streams and significantly elevated in 5 of them: Upper N. Br. Neshaminy, Lower Tohickon, W. Br. Neshaminy, Little Neshaminy, and Pidcock (paired sample *t* tests, df = 2; Fig. 6.3). This suggests that much of the suspended biomass was in less than optimal physiological condition. Chlorophyll concentrations were significantly greater than pheophytin in 2 streams: Lower N. Br. Neshaminy, and County Line, but the differences in Lower Neshaminy and Upper Tohickon were non-significant statistically.

Phytoplankton chlorophyll was significantly correlated with only one chemical variable, PO_4-P (Table 6.4). That negative correlation presumably reflects a greater uptake of nutrient where biomass was higher. Phytoplankton chlorophyll was positively correlated with % water in the watershed, undoubtedly a consequence of the high biomass downstream of Lake Galena. Phytoplankton chlorophyll was negatively correlated with the molecular tracer anthracene, positively with cholesterol, and negatively with the ratio of the tracers (bCOP/bCOP+eCOP). Chlorophyll was low at County Line, a site where several PAH tracer hydrocarbons were in high concentrations.

Quality Assurance/Quality Control checks substantiate the reliability of phytoplankton chlorophyll measures. Phytoplankton chlorophyll averaged 2.02 ± 2.08 µg/L across all samples (n=43, including field duplicates) and 95% of the samples exceeded 0.49 µg/L. The averages of 8 field blanks (1 per sampling day) and of 6 lab blanks (2 per measurement day) were both 0.01 µg/L, or only 0.5% of the average sample, and only 3% of the lowest sample. The field blanks serve as a check on cross contamination at the filtering step, which clearly was not a problem. The relative percent difference (RPD) between field duplicates ranged from 0.6 % (Lower Neshaminy) to 27.9% (Little Neshaminy), with the exception of one very high value (91.4%) for Paunacussing and averaged 13.8% (excluding the data for Paunacussing). There was no field duplicate sample for Tinicum. The laboratory control standard was measured on each of the three days of measurement and the RPD between days was 0.5%, which indicates that the fluorometer was stable and working properly.

<u>Phytoplankton community composition</u>**.** Of the 22 samples counted, between 300 and 456 units were counted in 12 of them, and >266 units in another 5 samples. Lower cell densities were enumerated in samples from County Line (145 and 166 units based on 4 and 3 aliquots, respectively), Paunacussing (208 and 220 units in 3 and 4 aliquots, respectively) and Little Neshaminy (170 units, although that count was paired with one of 285 taxonomic units).

The number of algae genera (or higher taxonomic grouping)/100 ml ranged from 39 in Lower Neshaminy and County Line to 51 in Paunacussing (Table 6.5). Several genera were found in all streams including the diatoms *Achnanthidium*, *Cocconeis, Melosira, Navicula, Nitzschia* and the soft algal genera *Ankistrodesmus, Chlamydomonas, Chlorella, Cosmarium, Selenastrum*, and *Trachelomonas*. Unidentified green algal taxa, unicellular coccoid Cyanobacteria, colonial Cyanobacteria, Chryptomonadales, and small (< 10 µm diameter) centric diatoms also occurred in all streams. The community in Lower N. Br. Neshaminy downstream of Lake Galena differed noticeably in composition from the one in Upper N. Br. Neshaminy above the reservoir. Total densities were 1,010,070 and 190,435 units per 100 ml, respectively, a 10-fold difference. Densities of the following taxa were at least 10-fold greater downstream of the impoundment: *Aulacoseira, Melosira, Chlamydomonas,* and *Leptolyngbya*. Some taxa that were undetected above the reservoir were found at extraordinarily high densities below the reservoir, e.g., *Limnothrix and Phormidium*. These differences in densities and taxa were less pronounced at the stations above and below Lake Nockamixon (Upper and Lower Tohickon, respectively) where total densities differed less than 2-fold. Phytoplankton chlorophyll *a* was well correlated with the number of taxonomic units in plankton samples (Fig. 6.4).

The percent similarity in phytoplankton community composition between streams (after combining taxa data as described) ranged from 24.8% (Lower N. Br. Neshaminy vs. Tinicum) to 71.7% (Pidcock vs. Paunacussing) and averaged 50.6 ± 13.2 (x ± SD, n = 55, Table 6.6). The community in Little Neshaminy was > 63.7% (x + SD) similar to 7 other streams while the one in Tinicum was < 37.4 % (x + SD) similar to 5 other streams. Most notably, phytoplankton composition in Lower N. Br. Neshaminy had low similarity with all other streams (24.5 – 34.6% except for 41.3% with Lower Neshaminy), not just its companion station upstream of the impoundment. The communities upstream and downstream of Lake Nockamixon were ~54% similar.

The phytoplankton communities in 2007 were compared with summertime communities present in 1968 – 1971 using the data for dates in the historical data set (Table 6.7) that were closest to our sampling dates. The average densities for taxa present on those dates in the historical data set are shown in Table 6.8. The distribution of live phytoplankton units between soft algae and diatoms in the historical data set and the 2007 data set are contrasted in Fig. 6.5. The total number of units was similar between studies in three streams, Upper N. Br. Neshaminy, Lower Tohickon, and Pidcock. Decreases occurred in six streams (County Line, W. Br. Neshaminy, Little Neshaminy, Upper Tohickon, Lower Neshaminy and Paunacussing) and 2007 values were approximately one-third of historic values at County Line, W. Br. Neshaminy and Upper Tohickon. Reaches placed historically in category II (Upper Tohickon, W. Br. Neshaminy and Little Neshaminy) were located below wastewater treatment plants. The decreases at those points most likely reflect improvements in treatment processes and decreased nutrient loading. The lower cell density in County Line may reflect toxicity affecting algal growth since the concentrations of several hydrocarbon tracers were higher there than elsewhere. Some hydrocarbons and their degradation products are known to suppress plant photosynthesis, and these molecular tracers may also serve as proxies for other toxic substances that would reduce plant biomass (Marwood et al. 1999, Warshawsky et al. 1995). The 5-fold increase in cell density at Lower N. Br. Neshaminy, largely among soft algal taxa, reflects the impact on water quality of the Lake Galena impoundment. In contrast, the increase in taxa in Tinicum is attributed to clean up of a superfund site on a tributary stream and recovery from toxic pollution. Where differences in the distribution of algae have occurred the trend is for the number of units of soft algae to increase to a greater extent than the units of diatoms. This was most obvious at Lower N. Br. Neshaminy, Lower Neshaminy, Pidcock and Paunacussing.

The % similarity in phytoplankton generic composition between the historical and 2007 studies was ≤30% for every stream (Table 6.9). This could be the result of differences in method (cell counts on acetone cleared filters vs. Palmer-Maloney cell), microscopy (light or phase microscopy vs. differential interference contrast microscopy), taxonomic capabilities, and changes in algal taxonomy during the nearly 40-y time span. Nevertheless, it is noteworthy that the streams with the lowest % similarity (7.66 – 14.99) are those that have undergone a major change in the intervening years such as the impoundment of a formerly free-flowing stream (Lower N. Br. Neshaminy and Lower Tohickon) or the clean up of a superfund site (Tinicum).

The number of algal genera has been used as one index of stream condition, with a greater number expected in streams of good condition, and fewer where sensitive genera are stressed. The number of phytoplankton operational taxonomic units (genus or higher group) increased between 1967-71 and 2007 in every stream but Upper Tohickon, which changed little and had the greatest number of genera (45) historically (Fig. 6.6). The greatest increase (nearly 3-fold) occurred in Tinicum, confirming the improvement in water quality there. Four streams in 2007 had 45 or more operational taxonomic units (Lower Tohickon, Tinicum, Pidcock and Paunacussing) and only 2 streams had fewer than 40 (County Line and Lower Neshaminy). Except for Upper Tohickon, all streams in 1967-71 had fewer than 35 genera reported and Tinicum had only 16, suggesting that there has been a general improvement in water quality during the intervening years, although there are still issues in some streams as noted elsewhere in this report.

The results of the examination of spatial variability across phytoplankton taxa using non-metric Multidimensional Scaling (NMS) are shown in Fig. 6.**7**. The NMS for phytoplankton required 53 iterations, the final stress was 7.93 and the final instability was 0.00001. The first two axes accounted for 91% of the variance in the ordination. Scores on Axis 1 were most strongly positively correlated with % water in the watershed in 2005, and to a lesser extent with particulate organic nitrogen (PON), and chlorophyll *a*. Axis 1 scores were negatively correlated with ethyl-cholestanol (SNOL), *E. coli* densities, and tracers or tracer ratios related to fecal pollution. Axis 2 scores were positively correlated with chlorophyll a and to a lesser extent with water in the watershed, bedrock, NH_4-N and low impervious surface in industrial, commercial and residential area; and negatively with anthracene, and two tracer ratios. The community in Lower N. Br. Neshaminy (I 3) below Lake Galena clearly separated from the other stations on both axes (related to % water in watershed and high chlorophyll) and stations affected by wastewater treatment plant discharges (series II) clustered to the lower mid-left of figure. County Line (I 1) had the highest concentrations of hydrocarbon related molecular tracers and separated to the most lower left portion of the figure. Tinicum (V 1) had the highest amount of bedrock of any stream (Fig. 6.2).

Periphyton

Periphyton chlorophyll and organic mass. Weighted estimates of benthic chlorophyll *a* were extraordinarily high (720 mg/m^2) in W. Br. Neshaminy but in the remaining streams ranged from 177 mg/m^2 in Lower Neshaminy to a low of 13.7 mg/m^2 in Paunacussing (Fig. 8). Most chlorophyll was associated with algae in all streams but Upper Tohickon where moss amounted to 16.3% of encounters. Organic mass associated with the benthic substrata followed a pattern similar to chlorophyll *a* (Fig. 6.9) and periphyton organic mass was highly correlated with periphyton chlorophyll *a* ($r = 0.94$, $p < 0.001$). Thus, organic matter on the beds of the streams at the time they were studied was primarily algae or algal-derived detritus.

Both periphyton chlorophyll *a* and organic mass were negatively correlated with tree canopy cover, $r = -0.80$, $p = 0.003$ and $r = -0.70$, $p = 0.016$, respectively, but none of the correlations with the different types of substrata were significant statistically (Table 6.4). Periphyton chlorophyll was significantly positively correlated with several nutrients known to affect algal growth; the most important of which were total P ($r = 0.67$, $p = 0.024$), and total Kjeldahl N ($r = 0.65$, p = 0.031; Table 6.4). The positive correlations of periphyton chlorophyll *a* with several tracer molecules associated with human activities and wastes, notably fragrance materials and coprostanol (bCOP), suggest that sewage effluents and septic drainage are important sources of nutrients that promote algal growth. Other support for this reasoning comes from the positive correlation of chlorophyll *a* with the density of wastewater treatment plants ($r = 0.6$, $p = 0.049$), road density (r = 0.68, p = 0.02), and high percent impervious surfaces in industrial, commercial and residential areas (2005) (r = 0.87, p <0.001), and negatively with row crops and low impervious surface in industrial, commercial, and residential areas (2005 data). As for phytoplankton chlorophyll, periphyton chlorophyll was negatively correlated with several hydrocarbon molecular tracers, and the chlorophyll concentration was very low in County Line.

There are no established standards for characterizing stream reach trophic status using periphyton. However, Dodds (2002) proposed that reaches with periphyton chlorophyll concentrations < 20 mg/m^2 and > 70 mg/m^2 might be considered oligotrophic and eutrophic, respectively, with reaches between these limits considered mesotrophic. On this basis, two streams, County Line and Paunacussing, would be designated oligotrophic; Lower Tohickon, Lower N. Br. Neshaminy, and Pidcock would be considered mesotrophic; and the remaining streams (Tinicum, Upper Tohickon, Lower Neshaminy, Upper N. Br. Neshaminy, Little Neshaminy and W. Br. Neshaminy) eutrophic. This classification is probably more realistic than the one based on phytoplankton chlorophyll because the periphyton community develops over time on the streambed whereas the phytoplankton are transient in the reach. The relationship between periphyton chlorophyll (including moss chlorophyll for Upper Tohickon II 11) and total N and total P are shown in Fig. 6.10. Total P concentrations were exceptionally high in W. Br. Neshaminy and Little Neshaminy (II 1 and II 7, both downstream of wastewater treatment plants). Concentrations of total N, while exhibiting a less extreme break between stations below wastewater treatment plants and other sites, also were highest at those two stations below sewage treatment plants.

Quality Assurance/Quality Control checks substantiate the reliability of periphyton chlorophyll measures. Periphyton chlorophyll averaged 58.6 ± 123.7 µg in the first extract of all samples (n=81, including field duplicates) and 95% of the samples exceeded 0.32 µg. The average of 69 lab blanks (2 or more per measurement day) was 0.019 µg, or only 0.03% of the average sample, and only 5.9% of the lowest sample. A laboratory control standard was measured at the beginning and end of each of the 32 series of measurements on the spectrophotometer. Four lab control standard solutions were used during these chlorophyll measurements. The concentration of each was determined immediately after its preparation. The relative percent difference between those measurements and the concentrations measured at the beginning and end of each sample run averaged 1.5, 2.5, 1.6 and 1.1 for the four standards. This, coupled with the data for the lab blanks, indicates that the spectrophotometer was stable and working properly over the several weeks during which measurements were being made and that there was no deterioration of chlorophyll in the standard employed.

<u>Periphyton cover types and community composition</u>. Of the 29 samples counted, 13 were counted to >300 units, 4 exceeded 260, 8 had between 200 – 259 units counted and 4 had <200 units counted. Filamentous algae predominated in W. Br. Neshaminy, accounting for 79% of the cover types encountered there. Filaments or filaments with silt mixed in contributed more than 50% of algal cover in Tinicum, Lower Neshaminy and Little Neshaminy (Fig. 6.11). Mats of diatoms were a significant cover type at the upper and lower stations on the N. Br. Neshaminy, and silt (which usually contains a significant number of diatoms) was a relatively important cover in County Line, Lower N. Br. Neshaminy, Pidcock and Paunacussing. Green and black covers occurred most frequently in Lower Tohickon and in both stations on N. Br. Neshaminy. Bare substrata were predominant in Paunacussing, even more so than the silt cover. Exposed substrata, i.e., above the water surface, were significant in Upper Tohickon as well as in County Line and Pidcock. The only station where moss made a significant contribution to benthic biomass was at Upper Tohickon.

A complete listing of genera and groups is given in Table 6.10. The following diatom genera were found in all streams: *Achnanthidium, Amphora, Cocconeis, Cyclotella, Eunotia, Gomphonema, Navicula, Nitzschia,* and *Rhoicosphenia*. None of the genera of soft algae occurred in every stream although *Scenedesmus* was present in all but County Line and *Leptolyngbya* in all but Pidcock.

The greatest number of periphyton OTUs (63) occurred in Upper N. Br. Neshaminy above Lake Galena (Fig. 6.12). Only 38 OTUs were recorded in W. Br. Neshaminy, where *Cladophora* dominated the community and the highest chlorophyll concentration occurred. The percent similarity in periphyton genera (after combining taxa as described) ranged from 32.1% (Lower N. Br. Neshaminy vs. W. Br. Neshaminy) to 67.1% (Little Neshaminy vs. Lower Neshaminy) and averaged 47.6 ± 8.2 (x ± SD, n = 55, Table 6.11). In contrast to phytoplankton similarity indices, no stream had a periphyton community that stood out as different from the ones in all other streams. Most (87% of the 55 comparisons) periphyton % similarities were within 1 SD of the mean % similarity or greater. Periphyton composition in Lower N. Br. Neshaminy had low similarity with 4 other streams. Lower Tohickon had low similarity with 3 other streams. In general, the number of taxa and % similarity in taxonomic composition of periphyton appeared to be less useful in characterizing these streams than chlorophyll distribution among cover types (Fig. 6.7). This is probably because cell biovolume is not considered when dealing with taxonomic units. As is seen in Fig. 6.13, variability in chlorophyll *a* was only 40% explained by periphyton units, but 75 % explained by periphyton biovolume, even though we had biovolume values for only ~75% of the taxa.

There was a moderately strong relationship ($R^2 = 0.36$) between % motile species and % silt cover (Fig. 6.14) when silt cover type was adjusted by adding to it one-half of the percentages of algal cover types that contained silt, e.g., silt + filamentous algae, silt + diatoms, silt + green algae. The relationship was less robust if the % motile diatoms was regressed on the silt cover type alone ($R^2 = 0.16$) or on % soft substrata ($R^2 = 0.20$). For this analysis, the following diatom genera were considered motile taxa: *Gyrosigma, Navicula, Nitzschia, Surirella*, and the groups pennate-naviculoid and pennate-nitzschioid. Addition of the taxa *Diploneis, Frustulia, Mastogloia, Nedium, Pinnularia,* and *Placoneis* changed the percentages negligibly and so were not included in the estimates of motile taxa.

The spatial variability across periphyton taxa, resulting from non-metric Multidimensional Scaling is displayed in Fig. 6.15. The NMS for periphyton required 92 iterations, the final stress was 10.11 and the final instability was <0.000001. The first two axes accounted for 79% of the variance in the ordination. The communities clustered spatially along gradients predominated by human impacts. The three stations downstream of sewage effluents (II series) clustered to the lower left of the figure. Axis 1 scores were negatively correlated with numerous tracer molecules such as fragrance materials and bCOP, high ionic strength water containing ions indicative of nutrient enrichment, *E. coli* densities, population density, road density and % impervious surfaces roads, all consistent with a gradient of urbanization. Axis 1 scores were positively correlated with % deciduous forest and % water in the watershed. Thus the two stations downstream of reservoirs were located toward the middle right of the figure. Axis 2 scores were negatively correlated with chlorophyll *a* (greatest periphyton chlorophyll occurred in W. Br. Neshaminy (II 1), tracers associated with human fecal sources (bCOP/[bCOP+aCOP], caffeine and fragrance materials), the number of wastewater treatments plants, total P and TKN concentrations. The positive correlations with phenanthrene and volatile PAHs help explain the separation of the County Line (I 1) community, to the top of the figure. An additional factor, silt, might also be involved in the separation of County Line (I 1) and Pidcock (V 2) toward the top of the Fig. 6.15 because highest percentages of silt occurred in these streams.

These findings concerning algae are consistent with those of other programmatic elements. Figure 16 highlights the dramatic difference of phytoplankton chlorophyll at Lower N. Br. Neshaminy and of periphyton chlorophyll at W. Br. Neshaminy from all other streams. Lower N. Br. Neshaminy was impacted by the upstream impoundment (Lake Galena) and the Macroinvertebrate Aggregated Index for Streams (MAIS) score was Poor although fecal contamination appeared to be minimal. In contrast, W. Br. Neshaminy was impacted by fecal contamination and had highest coliform and *E. coli* densities of any stream along with high nutrient concentrations and a MAIS score of Poor. Chlorophyll concentrations were slightly elevated in Lower Neshaminy, Little Neshaminy, Upper Tohickon, all streams with a Fair MAIS score, and the latter two downstream of sewage treatment plants. Little Neshaminy had evidence of fecal contamination in June. County Line also had a Fair MAIS score but chlorophyll was lower there, perhaps due to toxicity (high concentrations of hydrocarbon molecular tracers) and both *E. coli* and total coliform densities were high there. The remaining five streams all had MAIS scores of Good. Algal biomass (chlorophyll) was low in two of them (Pidcock and

Paunacussing), but slightly elevated at the other stations in this category (Lower Tohickon and Upper N. Br. Neshaminy), and especially at Tinicum. *E. coli* densities were slightly elevated in Tinicum and Upper N. Br. Neshaminy, suggesting some impact remains. Obviously, the causative factors for the observed effects will differ with the group of organisms being analyzed, but there is a relative consistency in results concerning the ecosystem condition of the study streams using different study elements.

Literature Cited

Arar, E. J. and G. B. Collins. 1997. *In vitro* determination of chlorophyll *a* and pheophytin *a* in marine and freshwater algae by fluorescence. Method 445.0-1. U. S. Environmental Protection Agency, Cincinnati, OH.

Hynes, H. B. N. 1970. **The ecology of running waters**. University of Toronto Press, Toronto. 555 pages.

Lorenzen, C. J. 1967. Determination of chlorophyll and pheo-pigments: spectrophotometric equations. Limnology and Oceanography 12:343-346.

Lowe, R. L. and Y. Pan. 1996. Benthic algal communities as biological monitors, pp. 705 – 739. In: R. J. Stevenson, M. L. Bothwell and R. L. Lowe, eds. **Algal Ecology, Freshwater Benthic Systems**. Academic Press, New York.

Marwood, C. A., r. E. H. Smith, K. R. Solomon, M. N. Charlton and B. M. Greenberg. 1999. Intact and photo-modified polycyclic aromatic hydrocarbons inhibit photosynthesis in natural assemblages of Lake Erie phytoplankton exposed to solar radiation. Ecotoxicology and Environmental Safety 44: 322-327.

Warshawsky, D., T. Cody, M. Radike, R. Reilman, B. Schumann, K. LaDow and J. Schneider. 1995. Biotransformation of benzo[a]pyrene and other polycyclic aromatic hydrocarbon heterocyclic analogs by several green algae and other algal species under gold and white light. Chemico-Biological Interactions 97:131-148.

Table 6.1. Sampling dates for phytoplankton and periphyton, summer 2007.

Site No.	Site Name	Sampling Location	2007 Sampling date
VI	Tinicum	Near Frankenfield Covered Bridge	13-Jun
II11	Upper Tohickon	Near Sheards Mill Covered Bridge	26-Jun
I11	Lower Tohickon	Creamery Road below Lake Nockamixon	26-Jun
V4	Paunacussing	Upstream of Old Carversville Road	12-Jun
V2	Pidcock	Bowmans Hill Wildflower Preserve	19-Jun
I1	County Line	Downstream of County Line Road	2-Jul
III1	W. Br. Neshaminy	Upstream of County Line Road near Nursery	2-Jul
I3A	Upper N. Br. Neshaminy	Near Silo Hill Road	27-Jun
I3	Lower N. Br. Neshaminy	Callowhill Road below Lake Galena	7-Jun
II7	Little Neshaminy	Near Almshouse Road	12-Jun
III6	Lower Neshaminy	Downstream of Maple Avenue West	19-Jun

* Stations arranged in an approximate North to South order in tables and figures presenting site means for indicated parameters in this chapter.

Table 6.2. Taxonomic keys used in algal identification work.

Cox, E. J. 1996. **Identification of freshwater diatoms from live material**. Chapman & Hall, London. 158 pp.
Dillard, G. E. 1999. **Common freshwater algae of the United States**. J. Cramer, Berlin. 173 pp.
Patrick, R. and C. W. Reimer. 1966. **The diatoms of the United States. V. 1**. Monographs of the Academy of Natural Sciences, No. 13. 688 pp.
Prescott, G. W. 1970. **How to know the freshwater algae**. Wm. C. Brown, Dubuque. 348 pp.
Prescott, G. W. 1951. **Algae of the Western Great Lakes area, Bulletin 31**. Cranbrook Inst., Bloomfield Hills. 946 pp.
Smith, G. M. 1950. **The freshwater algae of the United States, 2nd ed**. McGraw-Hill, New York. 719 pp.
Wehr, J. D. and R. G. Sheath. 2003. **Freshwater algae of the United States**. Academic Press, New York. 918 pp.

Web based materials:

http://diatom.acnatsci.org/AlgaeImage/selectedThumbnails
www.environment-agency.gov.uk and
www.lucidcentral.com River diatoms: a multi-access key.

Table 6.3. Selected stream reach morphological attributes, percent riparian canopy and number of transects equally spaced over the reach length.

Site No.	Site Name	Reach length (m)	No. periphyton transects	Reach width (m)	% Canopy
V I	Tinicum	40	5	8.30	60.2
II 11	Upper Tohickon	38*	4	26.20	49.6
I 11	Lower Tohickon	50	6	16.22	63.0
V 4	Paunacussing	50	6	5.03	73.8
V 2	Pidcock	40	5	7.86	80.2
I 1	County Line	45	5	5.64	89.2
II 1	W. Br. Neshaminy	40	5	11.40	46.5
I 3A	Upper N. Br. Neshaminy	68*	5	9.92	69.0
I 3	Lower N. Br. Neshaminy	72	10	14.03	73.1
II 7	Little Neshaminy	80	9	17.04	60.9
III 6	Lower Neshaminy	80	9	22.67	43.9

* Includes estimated bridge width, no transects under or within 5 m of bridge

Table 6.4. Correlations of phytoplankton and periphyton chlorophyll *a* with chemical, biological, molecular tracer and geographical data.

	Significant correlation with density of			
	Total coliforms		*E. coli*	
Class of Variable and variable	*r*	*p* value	*r*	*p* value
CHEMICAL				
Total alkalinity			0.67	0.024
Calcium			0.65	0.029
Magnesium			0.61	0.046
Particulate P			-0.67	0.023
BIOLOGICAL				
Total coliforms			0.71	0.014
MOLECULAR TRACERS				
Anthracene/phenanthrene	0.62	0.043		
Benzo(a)anthracene/Chrysene			-0.60	0.049
24-ethyl-cholestanol (SNOL)			0.67	0.024
EPI (Epicoprostanol)			0.74	0.009
bCOP/(bCOP+aCOP) [Coprostanol/(Coprostanol+Cholestanol)]			0.61	0.045
aCOP/(aCOP+bCOP+EPI) [Cholestanol/(Cholestanol+Coprostanol+Epicoprostanol)]			-0.60	0.051
Coprostanol (bCOP)			0.59	0.054
sum(betas)/sum(c27,c29)			0.58	0.059
bCOP/(bCOP+EPI) [Coprostanol/(Coprostanol+Epicoprostanol)]	0.58	0.064		
GEOGRAPHY				
% Water in watershed 2005			-0.67	0.024
% Emergent wetlands in watershed 2005	-0.61	0.044	-0.56	0.073
> 74% impervious surface in residential area 2005			0.60	0.05
High density urban land use 2000			0.64	0.033
Deciduous forest cover 2005			-0.56	0.076

Table 6.5. Phytoplankton taxa present in study streams, June – July 2007.

Taxa	No. Live Units/100 ml in Indicated Stream (Site Number)										
	Tinicum V1	Upper Tohickon III11	Lower Tohickon I11	Paunacussing V4	Pidcock V2	County Line I1	W. Br. Neshaminy III1	Upper N. Br. Neshaminy I3A	Lower N. Br. Neshaminy I3	Little Neshaminy II7	Lower Neshaminy III6
Diatoms											
Achnanthes	951	221				136	1,754				
Achnanthidium	9,841	1,339	1,279	790	1,757	2,136	2,506	3,614	1,073	1,950	1,510
Amphora	1,902	221						239		612	664
Araphid with straight striae				263							
Asterionella			3,458								
Aulacoseira	1,902	1,329	7,885		1,222		1,941	332	46,142	370	10,568
Bacillariophyta				375							
Centric (>10 µm)	279	1,111	2,616	639	386	635		332		1,595	
Centric (<10 µm)	2,739	4,000	16,633	1,540	3,151	1,864	2,506	5,753	1,073	2,963	1,087
Cocconeis	8,497	1,107	2,586	3,721	3,089	2,313	6,984	4,956	1,073	2,192	3,442
Cyclotella	837	2,661	10,035	2,179	1,736			5,088	7,511	2,819	9,843
Cymbella	951		717								
Denticula				375			251				
Diatoma	279			526	429		423	717		484	
Diploneis			281								
Eunotia	2,511			188		136	251				
Fragilaria		225	2,616	526			423		1,073		
Gomphonema	1,674		717	375	600		752	332		1,338	
Melosira	25,287	889	562	1,389	644	2,221	423	1,196	31,119	2,933	9,723
Meridion	9,511	221								741	
Navicula	4,084	4,450	1,870	3,456	2,037	6,717	1,926	4,623	1,073	1,580	1,510
Neidium		225									
Nitzschia	18,160	3,568	2,150	3,341	4,694	2,859	2,521	6,669	7,780	5,609	4,529
Pennate	558	443			579	1,592		664		3,333	
Pennate - cymbelloid	558				215		251			242	
Pennate - gomphonemoid				188							
Pennate - naviculoid	5,529	664	717	3,419	2,252	544	673	903		1,353	423
Pennate - nitzschioid				263							
Reimeria	4,527						501	664		242	
Rhoicosphenia	1,230		717	563	1,652	227	1,769	1,050		4,883	4,590
Sellaphora						136		239		242	
Stephanodiscus	558	2,664	872	563	386	136	1,002	332		1,353	2,114
Surirella	279					910					
Synedra	1,788			526					14,486		
Tabellaria	1,902	886		375					4,292		
Thalassiosira				188				239			
Unidentified diatom	13,924	1,332	436	639	1,630	136	2,364	3,056		854	5,073

Table 6.5. (continued - 2).

Taxa	Tinicum V1	Upper Tohickon III11	Lower Tohickon I11	Paunacussing V4	Pidcock V2	County Line I1	W. Br. Neshaminy II1	Upper N. Br. Neshaminy I3A	Lower N. Br. Neshaminy I3	Little Neshaminy II7	Lower Neshaminy III6
	No. Live Units/100 ml in Indicated Stream (Site Number)										
Soft Algae											
Actinastrum			2,150								
Anabaena									3,219		
Ankistrodesmus	2,853	671	436	977	4,762	136	251	2,763	3,219	2,676	4,529
Apatococcus	1,674	886				1,137	2,757			370	
Carteria			1,404								
Cerasterias staurastroides			281								
Chlamydomonas	11,515	32,185	11,905	4,582	2,659	4,862	12,434	7,480	96,844	14,052	44,084
Chlorella	18,452	17,250	30,802	14,549	27,160	3,181	19,182	20,792	8,853	12,269	35,690
Chlorococcum			281								
Chlorophyta		675	2,247		1,717			717	3,219	968	
Closterium	951		1,279		215						
Coccoid bluegreen	6,696	12,457	44,998	6,985	18,395	8,731	108,670	47,217	24,412	18,881	22,404
Coccoid green	1,902		436	375	386	818	501	2,006		968	
Coelastrum									2,146		
Colonial blue green	279	889	3,487	639	579	227	8,816	2,139	17,437	370	4,288
Colonial green	39,998		23,827	1,053	2,575		1,002	5,925	18,242	7,861	40,461
Cosmarium	837	896	1,434	1,767	2,401	682	501	13,578	9,121	242	2,536
Crucigenia					858						10,628
Cryptomonadales	2,460	11,389	3,932	639	1,823	1,043	3,696	3,760	34,606	3,288	13,286
Cyanobacteria						136					
Cyanobacterium-cb									4,292		
Euglena				263	407			717	2,146	968	664
Euglenophyta		675		263	1,073	136	251	478	3,219	1,451	845
Flagellated green	279	4,457	436	1,053	1,008	998	2,020	810		1,466	423
Gongrosira	3,348										5,918
Kirchneriella				2,627	2,488				4,292		
Lagerheimia		889	1,153		1,630	727		571		968	5,858
Leptolyngbya		2,475	6,548	1,277	215	1,043	6,655	2,338	301,263	3,432	6,824
Limnothrix			1,744						100,332		
Lyngbya							423		3,487		
Mallomonas		671		188	407		845		8,048		
Microspora			562								
Mougeotia											9,964
Oocystis	2,853	446	12,990	4,211	1,481	1,817	2,114		4,292	242	7,066

Table 6.5. (continued – 3).

Taxa	No. Live Units/100 ml in Indicated Stream (Site Number) Tinicum V1	Upper Tohickon III11	Lower Tohickon I11	Paunacussing V4	Pidcock V2	County Line I1	W. Br. Neshaminy II1	Upper N. Br. Neshaminy I3A	Lower N. Br. Neshaminy I3	Little Neshaminy II7	Lower Neshaminy III6
Pediastrum								4,517			
Phacus		450									
Phormidium			436	263			1,769		74,310	242	
Planktothrix		221				227	924		26,022		
Pseudanabaena	4,806		872	563		136	4,306	239	37,557		2,657
Rhabdogloea		450									
Roya				714							
Scenedesmus	166,447	1,996	10,103	5,744	8,451		5,073	17,032	70,822	5,140	53,021
Selenastrum	1,395	1,107	1,279	2,518	5,748	136	423	5,367	1,073	968	2,114
Sphaerocystis									10,731		
Spined desmid											1,329
Staurastrum			436		386						
Staurodesmus (cuspidatus?)		221									
Synechococcus	1,116		436	375	5,207	815	251				
Tetraedron	279		2,150		793	227	251		1,073		2,174
Tetrastrum					858						5,314
Trachelomonas	2,625	4,043	1,123	2,932	3,969	3,128	5,495	717	18,242	3,999	1,691
Unidentified green	12,073	5,793	6,510	9,622	6,286	1,406	9,535	7,400	8,853	10,734	8,273
Unidentified green #1				1,316							
Unidentified green #2				526							
Unidentified green #3		2,025	562	1,579	771	1,087		2,870		2,661	3,321
Total Diatoms	282,839	103,220	176,237	67,601	104,709	32,837	198,143	149,436	901,374	94,214	295,362
Total Soft algae	120,260	27,557	56,145	26,409	26,458	22,697	29,221	40,999	116,696	37,688	55,075
algae)	403,100	130,777	232,381	94,010	131,167	55,535	227,364	190,435	1,018,070	131,902	350,437
Diatom Taxa Count	21	24	31	27	29	23	25	22	29	23	26
Soft algae Taxa Count	26	19	18	24	17	16	19	20	11	21	13
Total No. Taxa	47	43	49	51	46	39	44	42	40	44	39

Table 6.6. Percent similarity of phytoplankton communities in the study streams, June – July 2007. The mean % Similarity was 50.6 ± 13.1 (n = 55). Similarity indices within the range of 37.4 – 63.7 (x ± SD) are not color coded. Percent similarities out of that range are color coded as indicated.

		V1	**III11**	**I11**	**V4**	**V2**	**I1**	**II1**	**I3A**	**I3**	**II7**	**III6**
Tinicum	**V1**	-	31.71	37.00	47.95	41.34	36.43	30.48	45.04	**24.75**	45.67	51.58
Upper Tohickon	**III11**		-	54.36	58.86	57.82	56.68	47.57	55.03	33.10	**65.23**	56.71
Lower Tohickon	**I11**			-	64.65	59.55	52.26	56.17	**66.09**	31.26	**65.21**	60.97
Paunacussing	**V4**				-	**71.69**	57.67	47.05	**65.53**	31.39	**67.74**	62.08
Pidcock	**V2**					-	54.81	49.67	**69.60**	**26.65**	**66.01**	53.82
County Line	**I1**						-	52.37	54.32	**29.60**	63.89	45.09
W. Br. Neshaminy	**II1**							-	60.31	**29.46**	54.00	41.89
Upper N. Br. Neshaminy	**I3A**								-	**27.47**	**65.88**	57.12
Lower N. Br. Neshaminy	**I3**									-	34.60	41.25
Little Neshaminy	**II7**										-	**66.13**
Lower Neshaminy	**III6**											-

Color coding:

<30
<35
<37.4
>63.7
>65
>70

Table 6.7. Dates from historical data set used in comparisons with present study (2007).

Site Name	Site No.	Date(s) of data used in comparisons		
Tinicum	V 1	20-Aug-68	27-May-69	
Upper Tohickon	II 11	20-Aug-68	27-May-69	17-Jun-69
Lower Tohickon	I 11	20-Aug-68	17-Jun-69	
Paunacussing	V 4	28-Aug-68	27-May-69	17-Jun-69
Pidcock	V 2	3-Sep-68	1-Jul-69	
County Line	I 1	23-Aug-68	19-Jun-69	11-Sep-69
W. Br. Neshaminy	II 1	23-Aug-68	19-Jun-69	11-Jun-70
Upper N. Br. Neshaminy	I 3A	7-Jul-70		
Lower N. Br. Neshaminy	I 3	27-Aug-68	24-Jun-69	7-Jul-70
Little Neshaminy	II 7	30-Aug-68	26-Jun-69	9-Jun-70
Lower Neshaminy	III 6	12-Jun-69	2-Jun-70	

Table 6.8. Phytoplankton taxa present in study sites on selected summer dates in historical data set (1968 – 1970).

Taxa	No. Cells/100 ml in Indicated Stream (Site Number)										
	Tinicum V1	Upper Tohickon III11	Lower Tohickon I11	Paunacussing V4	Pidcock V2	County Line I1	W. Br. Neshaminy II1	Upper N. Br. Neshaminy I3A	Lower N. Br. Neshaminy I3	Little Neshaminy II7	Lower Neshaminy III6
Diatoms											
Achnanthes	49,183	7,175		16,152	7,476	20,737	4,717		10,100	15,148	7,743
Amphora	344	1,170	2,595	623		890		1,068	356	2,492	801
Anomoeneis			865								
Asterionella		76		267			178				
Biddulphia		76	1,730								
Caloneis		76				89					
Camplylodiscus		76									
Cocconeis	1,145	7,506	12,522	9,199	21,915	5,639		3,204	5,069	89	10,547
Cyclotella	8,752	47,357	85,860	1,912	19,753	34,226	68,015	2,670	8,277	88,340	173,016
Cymatopleura		1,908		844	267	534		5,607	2,485	3,649	267
Cymbella		76		1,776	2,398	2,492	890			534	1,202
Denticula		305									
Diatoma		441		445	700	288	577				1,068
Diatomella		2,824									
Diploneis		76				178			534		267
Epithemia		882	2,595					267			
Fragilaria	1,260	15,716	10,252	3,738	2,163	2,378	1,730		7,411	2,068	10,547
Gomphoneis		305		89							
Gomphonema		4,733	2,537	5,251	3,605	8,366	8,010	5,340	3,026	17,109	5,073
Hantzschia	865	2,595	1,730	1,242	700	1,378	41,161	26,166	12,460	38,181	4,539
Melosira		76									
Meridion	916	2,044	2,595	2,357	401	7,319	89	801	1,819	466	401
Navicula	59,769	15,190	3,338	31,406	24,452	17,754	6,358	44,856	19,484	41,250	62,612
Neidium		76		844							134
Nitzschia	2,188	6,107	2,601	20,722	19,625	17,309	42,580	5,874	9,523	19,843	12,683
Pennales	802	4,885	1,997	89	2,804	7,565	4,094	18,690	12,816	17,088	4,406
Pinnularia		2,061		979	401	89		801	178	445	401
Pleurosigma				89	267			1,068			
Rhoicosphenia	115	840	1,068	7,472	3,129	4,603	534	4,272	445	733	4,272
Surirella	115	2,426		1,068	267	644	178	1,602	577	466	
Synedra		1,221		534	534	623	1,730	4,539	1,200	733	267
Tabellaria								534			

Table 6.8. (continued – 2).

Taxa	Tinicum V1	Upper Tohickon III11	Lower Tohickon I11	Paunacussing V4	Pidcock V2	County Line I1	W. Br. Neshaminy II1	Upper N. Br. Neshaminy I3A	Lower N. Br. Neshaminy I3	Little Neshaminy II7	Lower Neshaminy III6
	No. Cells/100 ml in Indicated Stream (Site Number)										
Soft algae											
Actinastrum				1,157							
Anabaena		763	865							644	
Ankistrodesmus		458		178			1,246	11,214	5,785	979	801
Arachnochloris									12,110		
Chlamydomonas		1,527		1,424			218,762		89	178	4,005
Chlorella		5,496		2,047	11,481	1,424	159,933	67,017	20,648	51,086	86,241
Chlorococcum		3,817			668	178	4,895	801	1,246	2,937	8,544
Chlorophyta		1,832	1,730	1,979	4,406	1,780	11,926	18,690	4,717	19,313	3,338
Chrysophyta	107,516	46,105	22,428								124,289
Coelastrum	229										267
Cosmarium						178			2,663		
Crucigenia							178				134
Euglena			865	178			140,887			534	1,736
Euglenophyta	2,595		3,460	577					1,153	577	
Lagerheimia		2,137		1,157		178				2,670	134
Lepocinclis		7,573	31,140	5,767	267	17,656	12,125		8,073	466	
Merismopedia						89			2,136		
Microspora		2,214		89	1,869	979	1,246	1,335	534	623	668
Oscillatoria		534	134	356		267	3,204			178	
Pediastrum		1,493	134	178					712		134
Scenedesmus		3,935		712	668	555	7,832	2,937	12,948	4,183	45,257
Selenastrum		1,756			935				1,513	1,157	2,270
Staurastrum		1,951				844			267		
Tetradesmus							890	267	801	356	534
Trachelomonas							1,068	1,602	178	178	668
Ulothrix							1,246				
Volvocales	2,595	153	3,460								
Total Diatoms	125,452	128,227	132,283	107,097	110,852	133,101	180,840	127,359	95,759	248,636	300,242
Total Soft Algae	112,935	81,820	64,215	15,799	20,292	24,128	565,438	103,863	75,573	86,059	279,015
Total cells	238,386	210,046	196,498	122,896	131,144	157,229	746,278	231,222	171,332	334,695	579,257
Diatom Taxa Count	12	28	14	22	18	20	15	17	17	17	19
Soft algae taxa count	4	17	9	13	7	11	14	8	17	16	16
Total No. Taxa	16	45	23	35	25	31	29	25	34	33	35

Table 6.9. Percent similarity between phytoplankton communities present in study streams during the summers of 1968 – 1971 and 2007.

Site Name	Site No.	Percent similarity
Tinicum	V 1	7.7
Upper Tohickon	II 11	18.8
Lower Tohickon	I 11	10.1
Paunacussing	V 4	25.4
Pidcock	V 2	27.4
County Line	I 1	27.2
W. Br. Neshaminy	II 1	20.2
Upper N. Br. Neshaminy	I 3A	31.9
Lower N. Br. Neshaminy	I 3	15.0
Little Neshaminy	II 7	30.3
Lower Neshaminy	III 6	27.1

Table 6.10. Periphyton taxa present in study streams, June – July 2007.

Taxa	No. Live Units/cm^2 in Indicated Stream (Site Number)										
	Tinicum V1	Upper Tohickon III11	Lower Tohickon I11	Paunacussing V4	Pidcock V2	County Line I1	W. Br. Neshaminy II1	Upper N. Br. Neshaminy I3A	Lower N. Br. Neshaminy I3	Little Neshaminy II7	Lower Neshaminy III6
Diatoms											
Achnanthes	1,914	3,401	708	1,532	3,206		4,549	1,216	6,905	706	
Achnanthidium	26,308	3,114	8,773	5,590	6,697	2,054	11,707	26,408	19,178	9,167	6,593
Amphora	3,627	964	910	909	1,762	387	1,193	5,673	6,117	2,313	734
Asterionella								608			
Aulacoseira		14,348	6,834	236	2,398				65,500		4,544
Bacillaria			725		532						
Biddulphia		3,750									
Campylodiscus		2,050									
Centric (>10 µm diameter)		17,730	10,828	642	3,016	1,078	4,764	319	10,987	13,076	30,756
Centric (<10 µm diameter)	4,584	5,861	17,798	523	1,940	159	5,321	7,986	18,782	4,388	10,637
Cocconeis	53,579	27,071	11,823	11,951	10,628	8,594	436,473	36,463	9,778	64,434	108,936
Cyclotella	3,962	12,962	2,501	1,113	11,208	1,556	8,480	3,856	10,062	37,637	77,291
Cymbella	17,789				1,649	3,227		1,376	5,754	3,305	1,384
Denticula			242			221					
Diadesmis		10,699								2,313	
Diatoma	1,422	1,025	2,345	639	254	476		7,582	1,194	4,626	1,280
Diploneis					266	482					
Encyonema								5,376			
Eunotia	8,720	964	3,223	4,561	1,877	1,317	18,462	9,460	6,763	9,105	9,681
Fragilaria	22,402	750	14,319		21,504	92	8,352		25,960	353	
Fragilariaforma							1,193				
Frustulia		15,656	427			300					2,922
Gomphonema	20,945	750	2,845	951	8,063	159	35,828	6,801	7,690	11,330	4,002
Gyrosigma			427		797			911			174
Martyana	1,813					203					
Mastogloia			427					608			
Melosira	19,052	84,042		4,668	51,526	8,226	102,118	8,860	3,091	46,476	26,517
Meridion	1,117		2,075				32,822		336	1,408	
Navicula	10,099	124,280	36,630	6,759	48,742	13,102	7,366	61,664	27,746	23,703	78,641

Table 6.10 (continued – 2).

Taxa	No. Live Units/cm^2 in Indicated Stream (Site Number)										
	Tinicum V1	Upper Tohickon III11	Lower Tohickon I11	Paunacussing V4	Pidcock V2	County Line I1	W. Br. Neshaminy II1	Upper N. Br. Neshaminy I3A	Lower N. Br. Neshaminy I3	Little Neshaminy II7	Lower Neshaminy III6
Neidium	957	4,660	3,954	929	2,666	264		2,401	2,248	1,408	696
Nitzschia	25,331	20,754	25,249	5,953	24,788	20,104	45,846	45,331	15,113	38,546	83,564
Pennate		3,228	845	3,524	660	92	4,549	928	4,452		
Pennate - cymbelloid	4,293	10,248	1,108	789	4,531	1,074	3,467	6,193	3,362	4,011	12,295
Pennate - gomphonemoid		2,008	4,992	174	6,114	791	1,193	681		706	
Pennate - naviculoid	31,575	33,066	8,891	4,603	31,941	3,750	29,489	15,538	24,226	24,761	30,319
Pennate - nitzschioid		6,795					12,450				
Pinnularia		2,050	552								
Placoneis						159					
Planothidium						159					
Reimeria	16,365	589	1,625	917	2,830	407	1,193	1,952	7,388	706	
Rhoicosphenia	28,562	27,342	4,043	1,649	36,077	6,037	238,140	42,969	9,134	156,083	211,471
Sellaphora				95		60		1,792			
Skeletonema		2,675									5,645
Staurosira			933			79					
Stephanodiscus	4,744	29,600	347	851	673	882		1,560	12,840	21,426	8,982
Surirella	3,063	1,258	1,810		2,190	610	1,193	3,008	2,716	1,984	1,751
Synedra	957	2,827		379	774				1,194		
Tabellaria	7,254								46,747		
Tryblionella (accuminata)		750									
Unidentified diatom	4,267		618	1,462	413	60		2,423	2,769		584
Soft Algae											
Anabaena									3,207		
Ankistrodesmus	7,472		1,340		789		2,274		274	2,400	4,842
Apatococcus	39,104		56,564	1,219				10,751	13,761	56,770	
Borzia			3,270					136			
Chlamydomonas	17,069		845	285			2,386	2,842	1,644	6,945	584
Chlorella	29,276	589	870		4,531	60	5,966	3,097	21,940	3,969	11,087
Chrysophyta									2,740		
Cladophora	33,186	13,073					31,778	5,229	5,833	14,526	32,316

Table 6.10. (continued – 3).

Taxa	No. Live Units/cm2 in Indicated Stream (Site Number)										
	Tinicum	Upper Tohickon	Lower Tohickon	Paunacussing	Pidcock	County Line	W. Br. Neshaminy	Upper N. Br. Neshaminy	Lower N. Br. Neshaminy	Little Neshaminy	Lower Neshaminy
	V1	III11	I11	V4	V2	I1	II1	I3A	I3	II7	III6
Closteridium	1,813										
Closterium			93							5,132	13,210
Coccoid bluegreen	30,581	38,308	59,798	553	9,452	120	132,341	46,262	38,182	12,344	56,938
Coccoid green		9,902	1,382	2,585	448	2,168	31,229	43,877	822	98,013	82,774
Colonial blue green	21,854	2,783	3,231		2,045	945	13,435	16,094	6,093	1,157	20,324
Colonial green	80,740	7,893	27,813	9,526	2,127	713	80,976	125,049	51,412	112,705	227,399
Cosmarium			483					160	14,115		758
Cryptomonadales					557		1,193		336		584
Cyanobacteria									1,682		
Draparnaldia			1,005								
Euglena											584
Euglenophyta											584
Filamentous green		17,914	2,175			1,752	4,549			7,043	522
Flagellated	18,492							673	1,194		
Gongrosira	8,443	4,875	25,519	871	1,726	2,974		59,278	48,520		60,260
Heteroleibleinia								5,712			
Jagerinema			18,540								
Kirchneriella									822	992	
Lagerheimia							1,193		274		
Leibleinia								26,368			
Leptolyngbya	12,659	589	4,216	95		203	11,415	6,007	13,099	1,862	584
Limnothrix			5,904					136	3,723		
Lyngbya	2,845	375	8,081	523				924	8,370		15,558
Mallomonas									3,362		
Microcystis											584
Microspora									2,927		
Oocystis	1,422						4,773	1,895	3,896	7,937	
Oscillatoria		375	1,045	174		487		5,600	5,125	1,764	2,413
Pediastrum			1,933					1,090	1,682		49,797

Table 6.11. Percent similarity of periphyton communities in the study streams, June – July 2007. The mean % Similarity was 47.6 ± 8.2 (n = 55). Similarity indices within the range of 39.4 – 55.8 (x ± SD) are not color coded. Percent similarities out of that range are color coded as indicated.

		V1	**II11**	**I11**	**V4**	**V2**	**I1**	**III1**	**I3A**	**I3**	**II7**	**III6**
Tinicum	**V1**	-	40.06	52.77	46.72	46.82	40.12	46.80	53.87	59.67	49.05	51.56
Upper Tohickon	**II11**		-	41.66	45.17	65.17	58.38	40.65	44.97	38.47	43.94	42.22
Lower Tohickon	**I11**			-	41.60	46.40	38.25	36.00	54.04	59.04	38.17	45.34
Paunacussing	**V4**				-	47.64	54.70	45.60	61.39	42.02	57.47	51.41
Pidcock	**V2**					-	57.09	40.92	42.51	41.37	43.18	46.86
County Line	**I1**						-	40.44	48.16	34.69	45.33	41.50
W. Br. Neshaminy	**III1**							-	45.10	32.10	58.34	47.96
Upper N. Br. Neshaminy	**I3A**								-	54.13	60.39	60.64
Lower N. Br. Neshaminy	**I3**									-	35.92	45.67
Little Neshaminy	**II7**										-	67.12
Lower Neshaminy	**III6**											-

Color coding: <35
<39.4
>55.8
>60

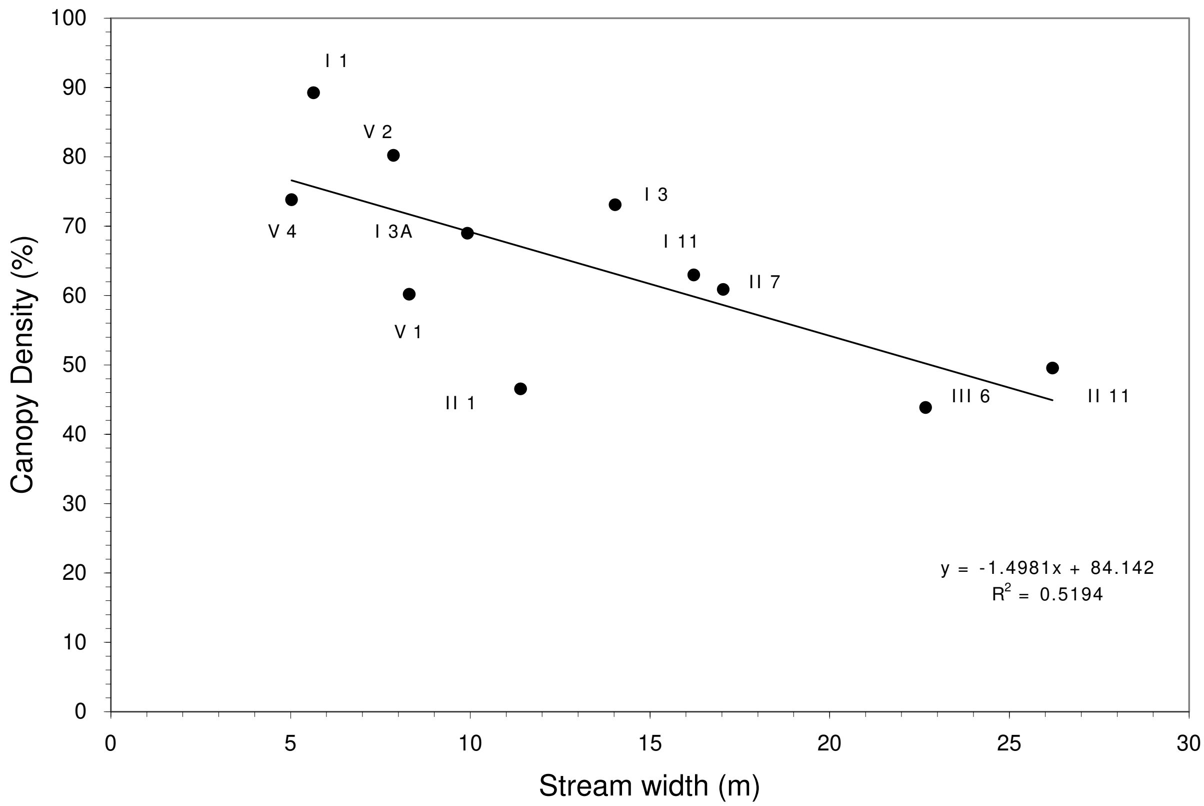


Figure 6.1. Tree canopy density at each stream reach as a function of stream width, June – July 2007.

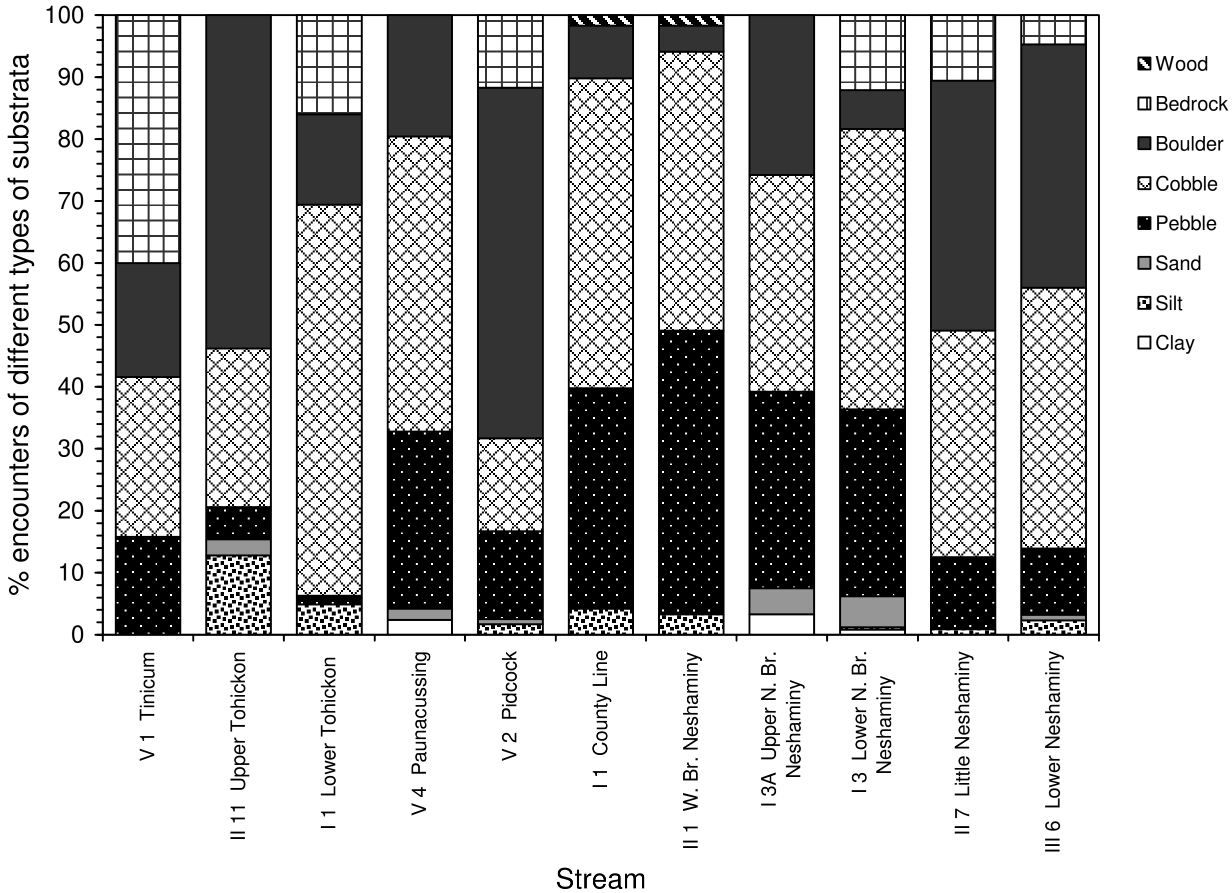


Figure 6.2. Percentages of different types of benthic substrata found in each study stream, June – July 2007.

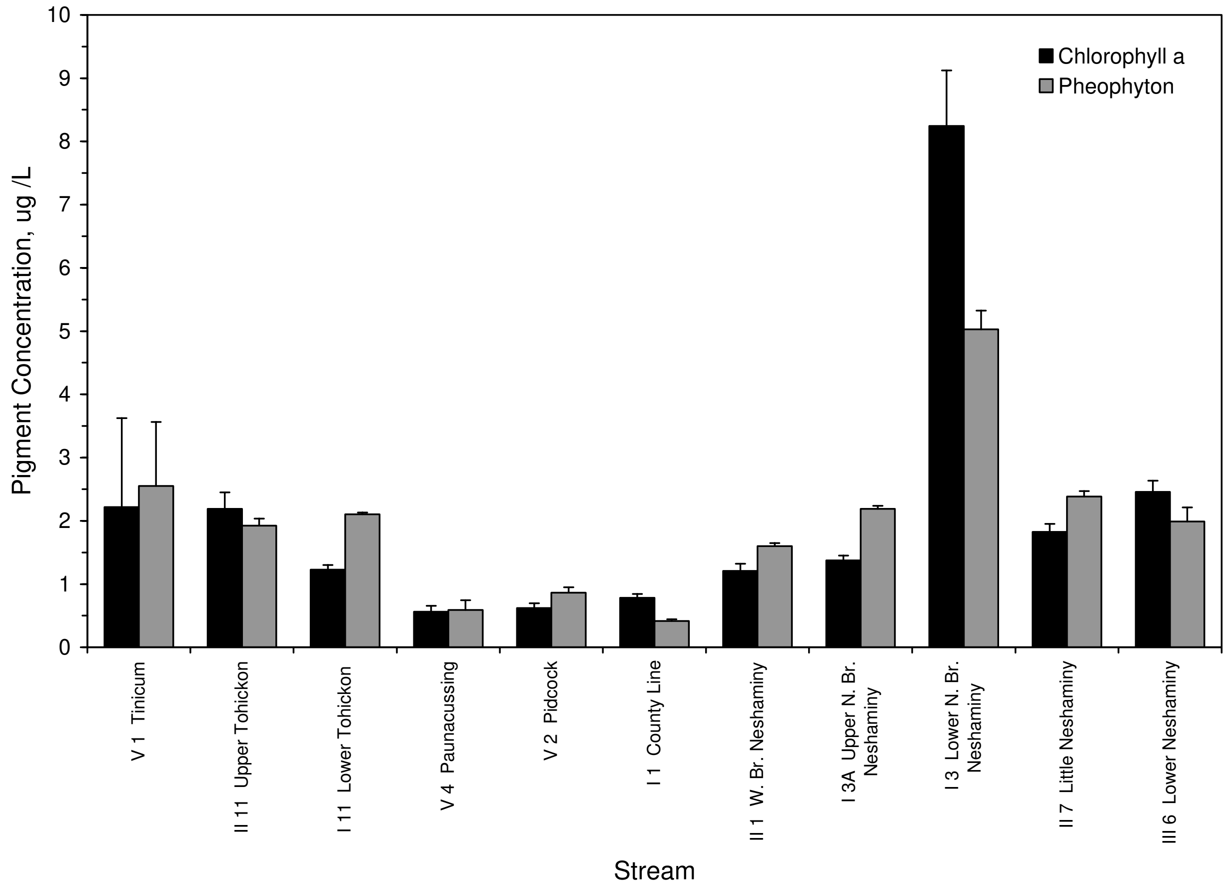


Figure 6.3. Phytoplankton chlorophyll *a* and pheophytin *a* concentrations.

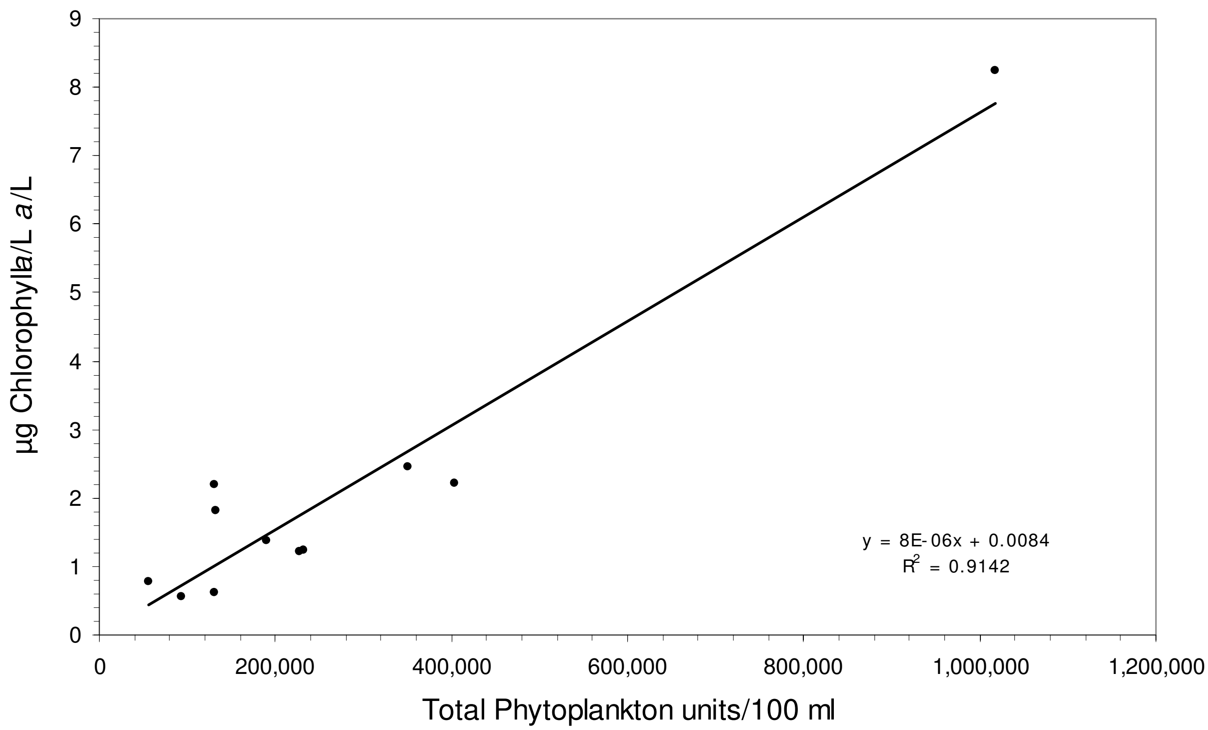


Figure 6.4. Relationship between chlorophyll *a* and live units of phytoplankton.

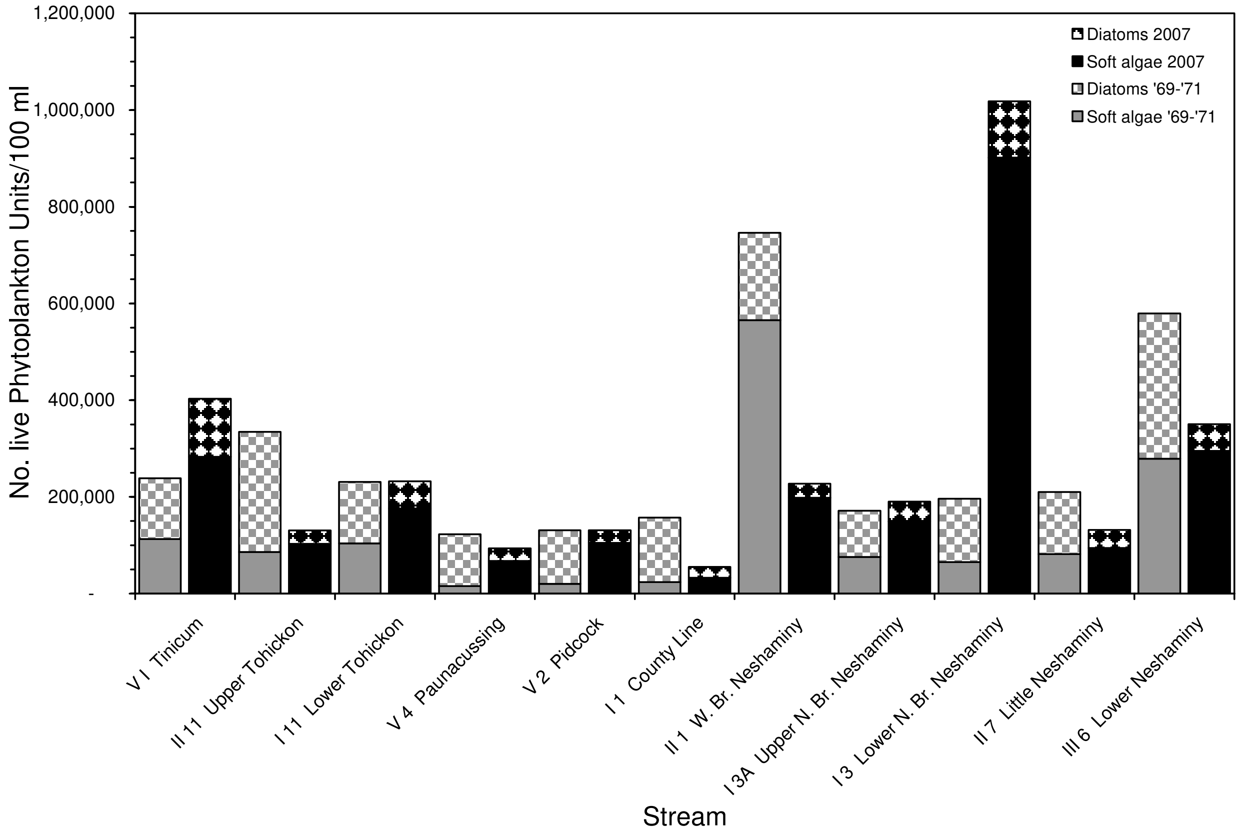


Figure 6.5. Number of live units of phytoplankton in study streams during summers of 1969 – 1971 and in 2007 categorized as soft algae and diatoms.

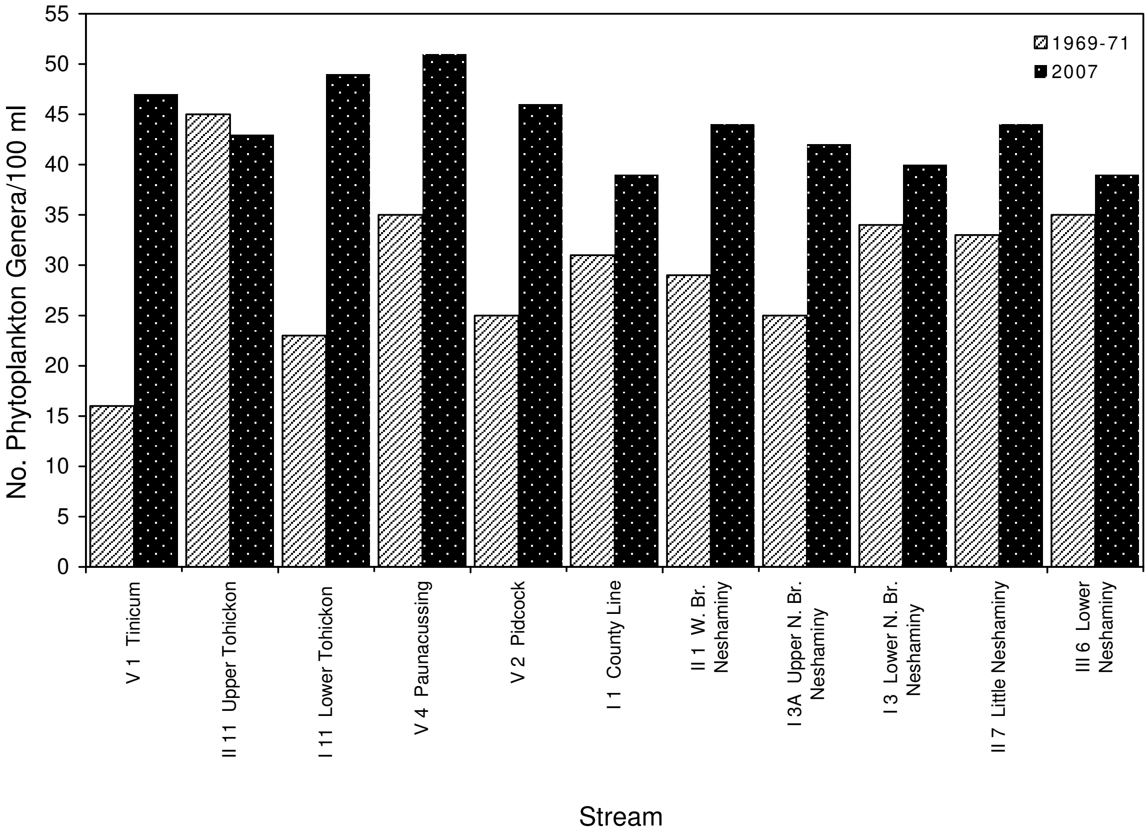


Figure 6.6. Number of phytoplankton operational taxonomic units (OTUs, genus or higher grouping) in samples from the study streams during the summers of 1969-1971 and 2007.

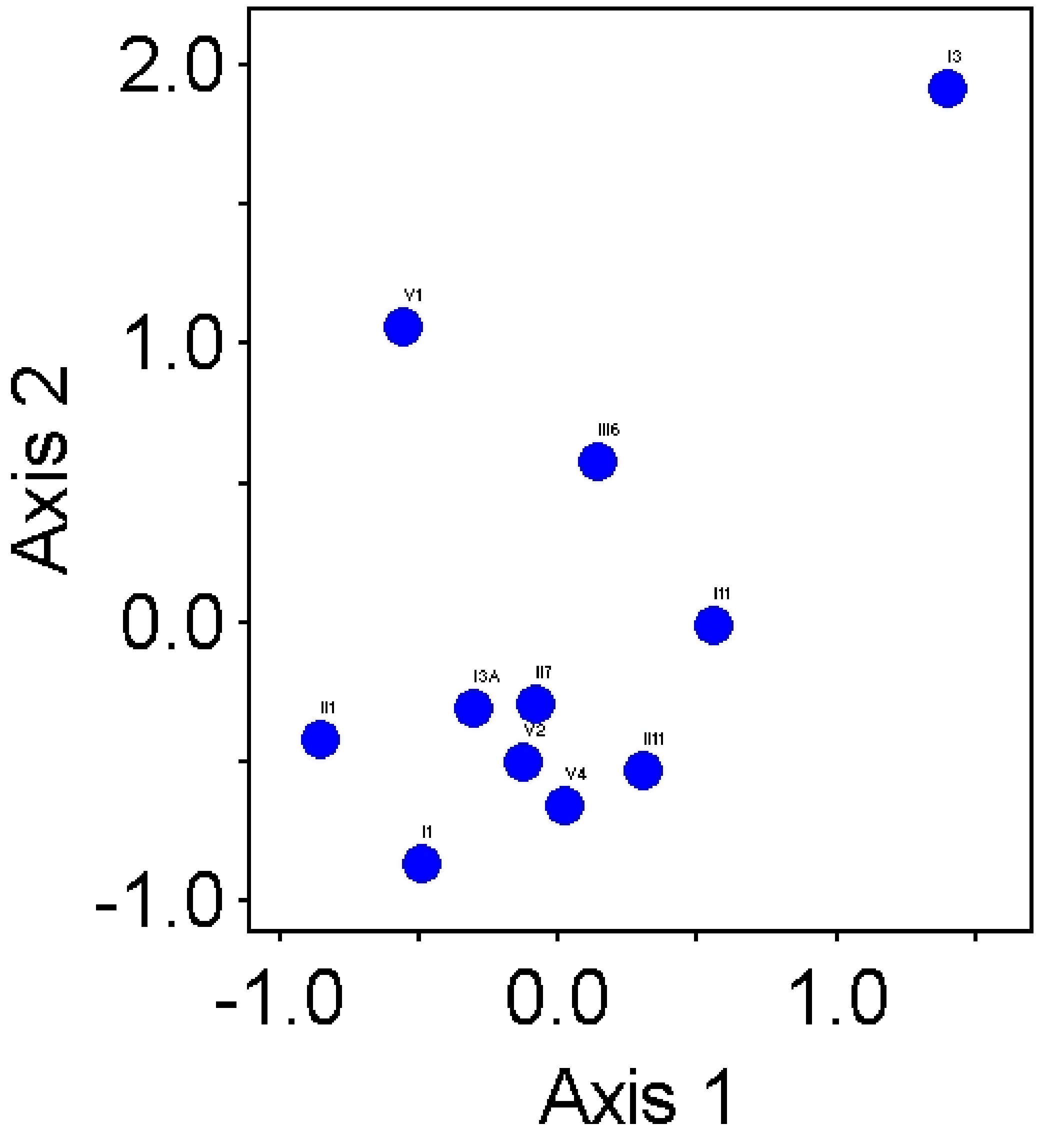


Figure 6.7. Non-metric Multidimensional Scaling ordination of phytoplankton communities in Bucks County streams using "alternative Relative Abundances" with rare taxa (<1%) within a site excluded. Axis 1 scores correlated (*r* and *p* values, respectively) positively with % Water in watershed 2005 (0.86, 0.001), % Emergent Wetland 2005 (0.61, 0.048), PON (0.72, 0.013), Chlorophyll *a* (0.61, 0.046), and negatively with SNOL (-0.78, 0.004), *E. coli*/100 ml (-0.73, 0.010), bcop/[bcop+eipcop] (-0.70, 0.015), ecop (-0.66, 0.028), and bone[bone+aone] (-0.61, 0.047). Axis 2 scores correlated positively with Chlorophyll *a* (0.85, 0.001), % Water in watershed 2005 (0.65, 0.030), < 30% impervious surface in industrial + commercial + residential area 2005 (0.62, 0.042), NH_4-N (0.66, 0.027) and % Bedrock (0.64, 0.034) and negatively with Anthracene (-0.75, 0.008), ecop/[ecop+epicop] (-.074, 0.009), and bcop/[bcop+epicop] (-0.72, 0.012). See Table 6.4 for abbreviations.

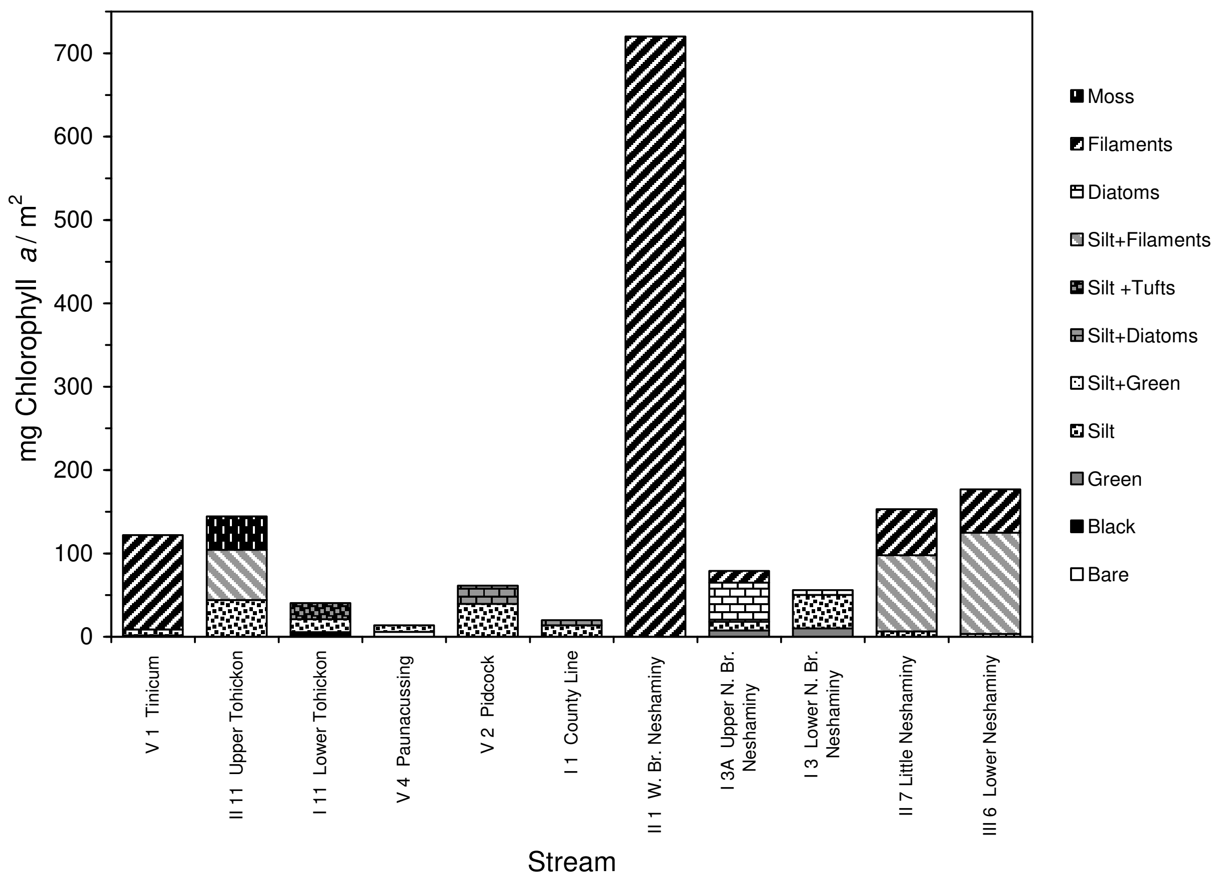


Figure 6.8. Benthic chlorophyll *a* concentrations weighted by cover type yielding an estimate of total weighted chlorophyll *a* per m^2 in the study stream reaches, summer 2007.

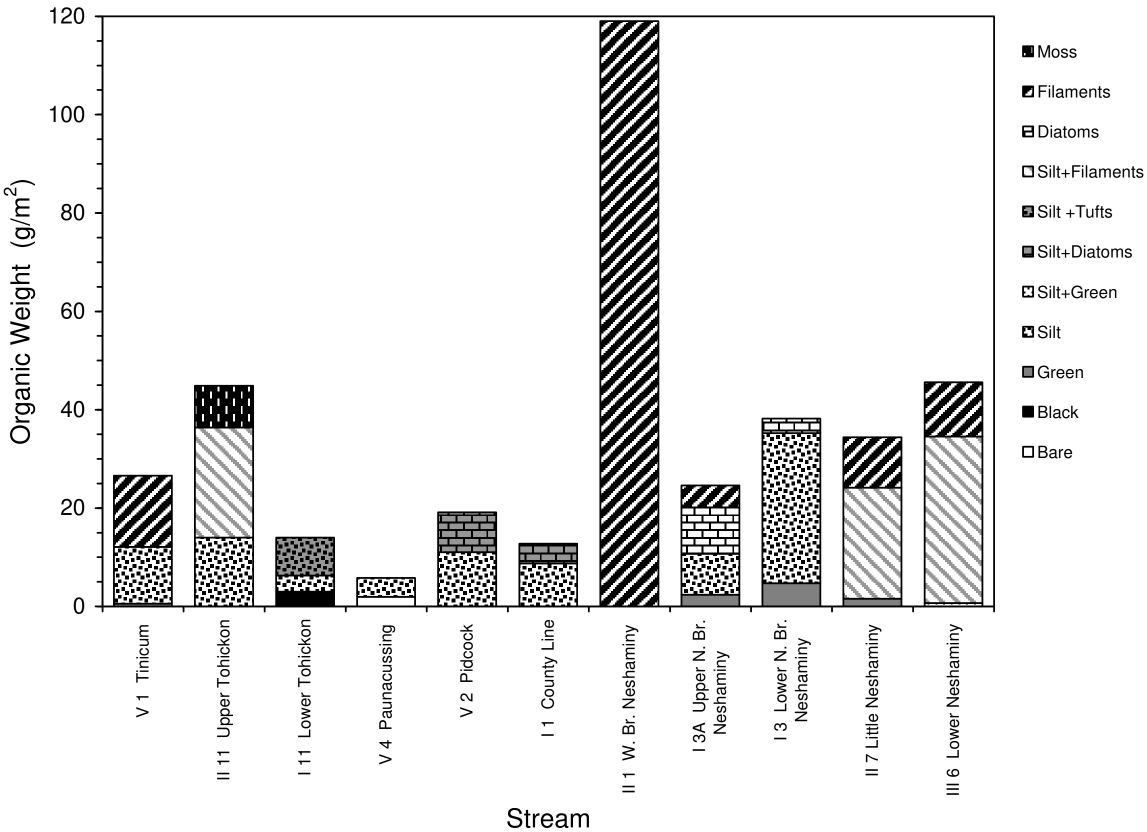


Figure 6.9. Benthic organic matter concentrations weighted by cover type yielding an estimate of total weighted periphyton- associated organic matter per m^2 in the study stream reaches, 2007.

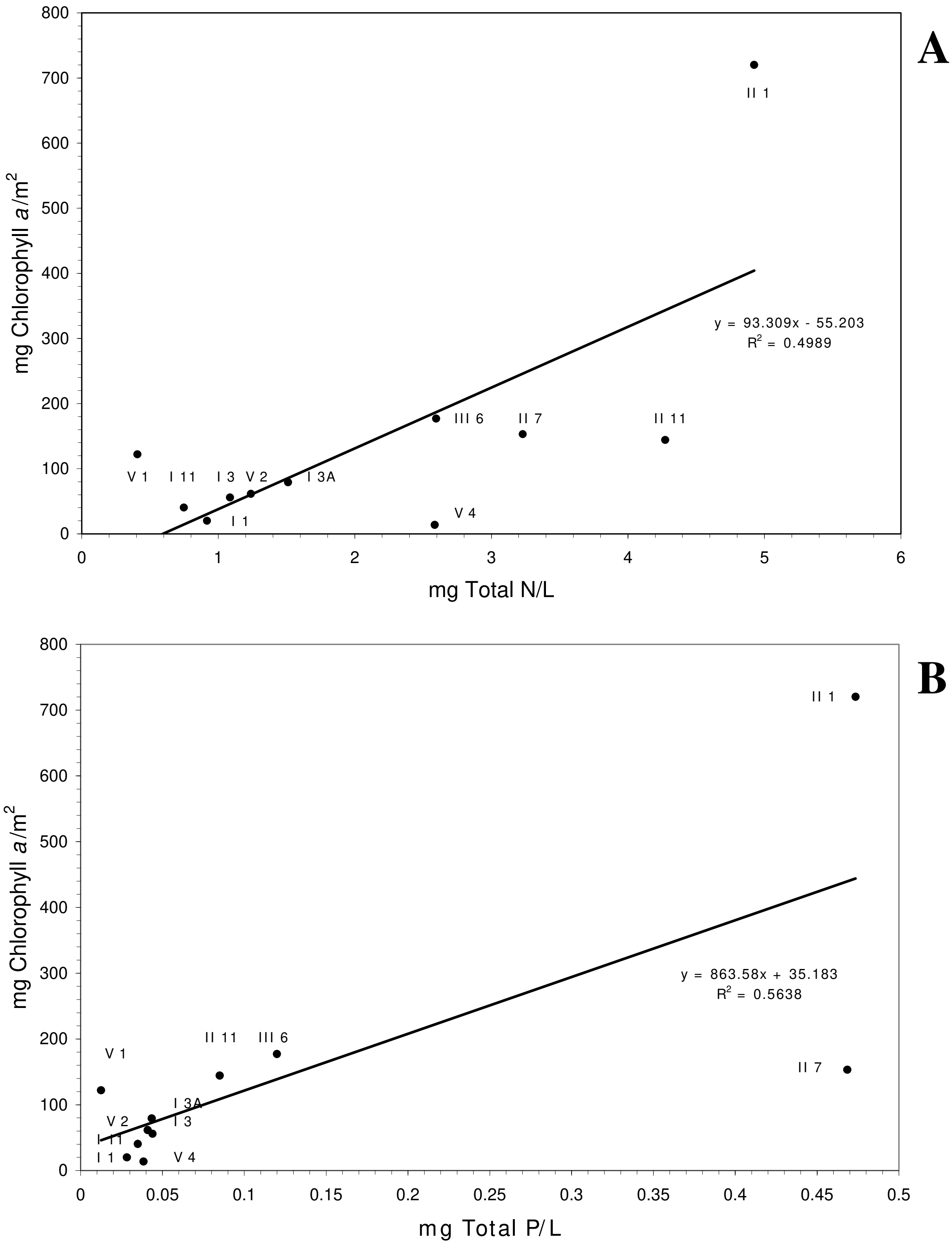


Figure 6.10. Periphyton and moss chlorophyll *a* concentration as a function of total N (panel A) and total P (panel B).

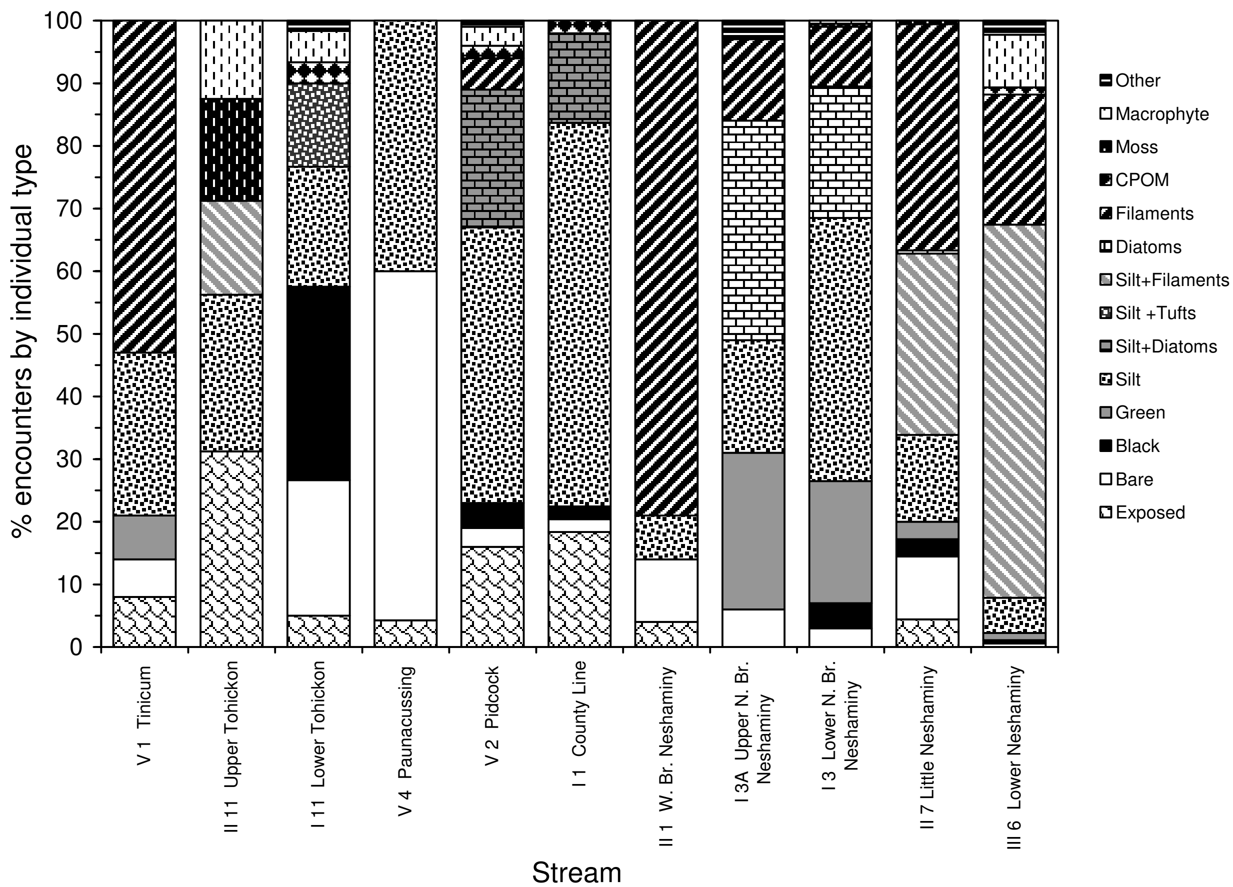


Figure 6.11. Cover types encountered in study reaches, summer 2007.

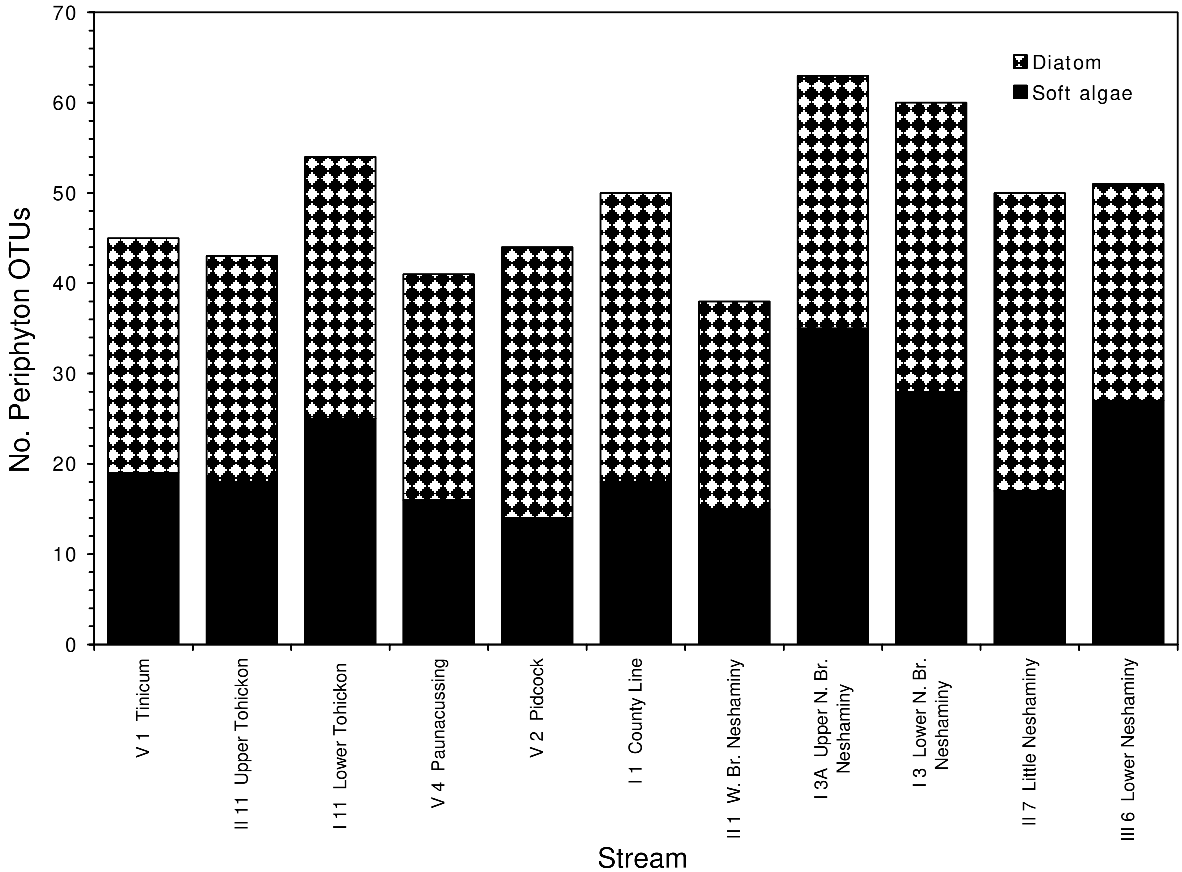


Figure 6.12. Number of periphyton Operational Taxonomic Units (OTUs, genus or higher grouping) in study streams, 2007.

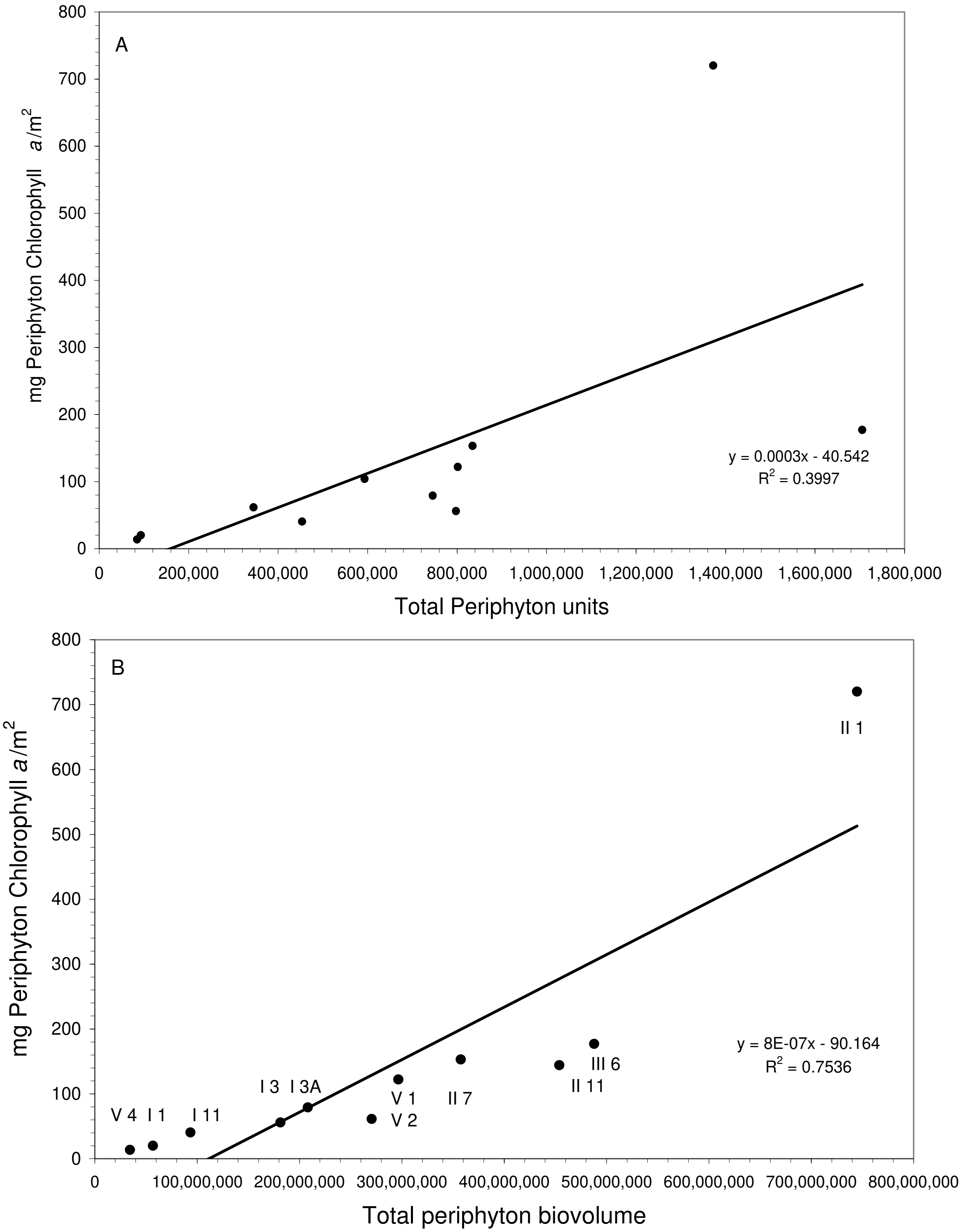


Figure 6.13. Relationship between periphyton chlorophyll a and number of periphyton operational taxonomic units and periphyton biovolume.

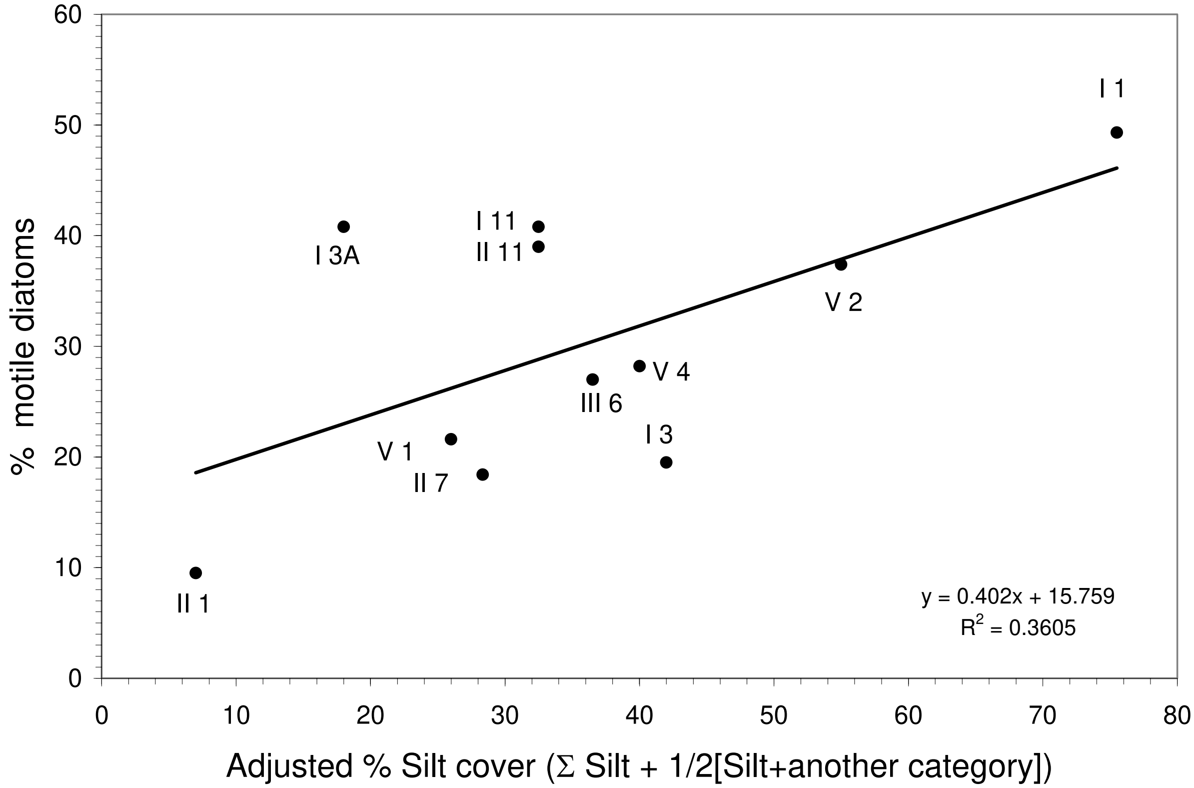


Figure 6.14. Percent motile diatoms as a function of the percent silt on the streambed.

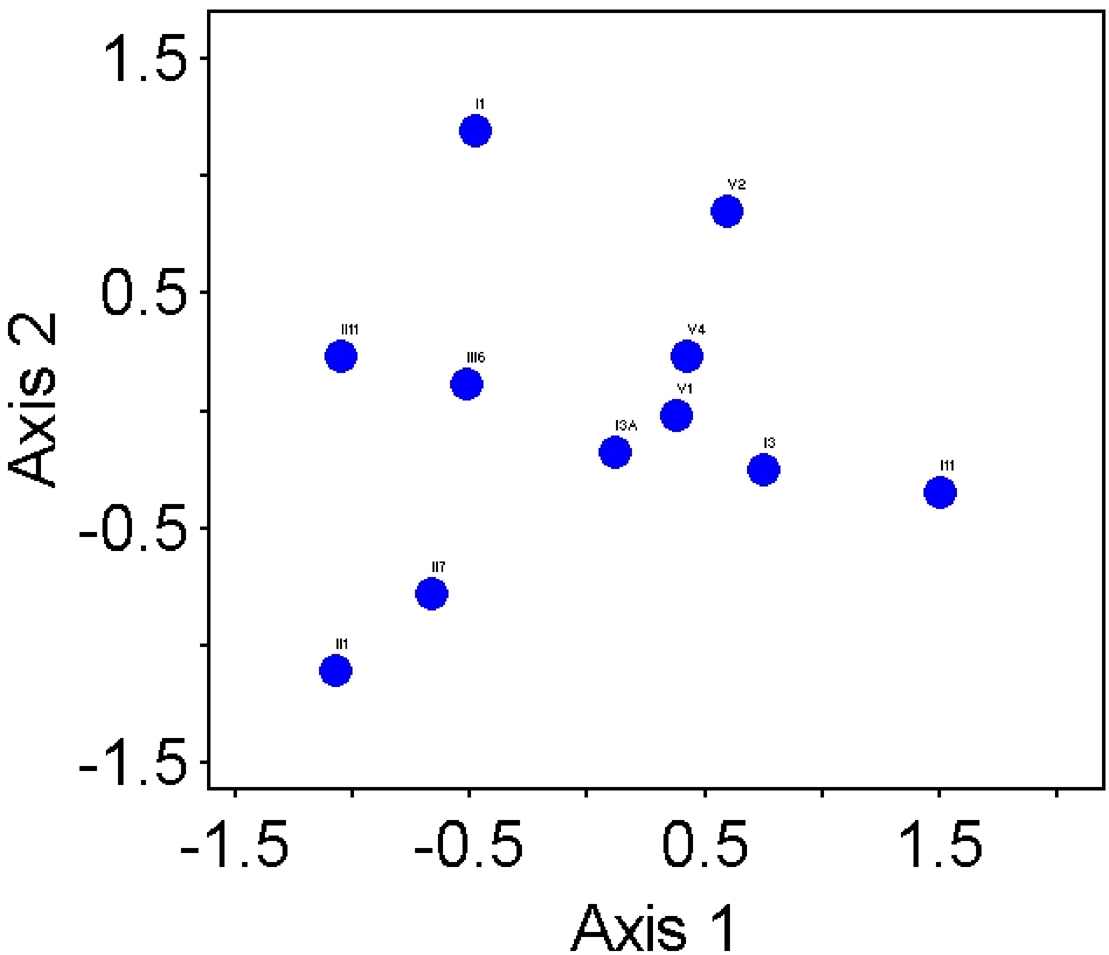


Figure 6.15. Non-metric Multidimensional Scaling ordination of periphyton communities in Bucks County streams using alternative Relative Abundances as presence/absence and excluding rare taxa (<1%) within a site. Axis 1 scores were negatively correlated with over 35 variables, the strongest of which were (*r* and *p* values in parentheses) specific conductivity (-0.90, <0.001), total alkalinity (-0.90, <0.001), numerous specific ions, total N (-0.72, 0.013), total P (-0.65, 0.013), E. coli densities ((-0.64, 0.032), population density 2000 (-0.69, 0.018), % impervious surfaces (-0.66, 0.027), roads density 2005 (-0.67, 0.024), fragrance materials (-0.68, 0.022), SNOL (-0.79, 9.003), bCOP ((-0.74, 0.009), bCOP/[bCOP+aCOP] (-0.77, 0.005), eCOP (-0.86, 0.001) and numerous other tracers (or ratios of tracers). Axis 1 scores were positively correlated with 4 variables the most important being % deciduous forest 2005 (0.60, 0.05) and % water 2005 (0.61, 0.046). Axis 2 scores were negatively correlated with 29 variables, the strongest of which were periphyton chlorophyll *a* (-0.67, 0.025), TKN (-0.67, 0.023), total P (-0.63, 0.038), % low density urbanized 2000 (-0.67, 0.025), % high density urbanized 2000 (-0.62, 0.042), % impervious surfaces 2000 (-0.70, 0.018), total road density 2005 (-0.61, 0.044), no. wastewater treatment plants 2007 (-0.67, 0.023), caffeine (-0.67, 0.026), fragrance materials (-0.69, 0.019), prediction of human sources of fecal steroids (-0.81, 0.002), bCOP/[bCOP+aCOP] (-0.64, 0.033), and numerous other tracers (or tracer ratios) and ions. Axis 2 scores were positively correlated with 4 variables, including <30% impervious in residential areas 2005 (0.89, <0.001), phenanthrene (0.70, 0.017), and volatile PAHs (0.70, 0.016).

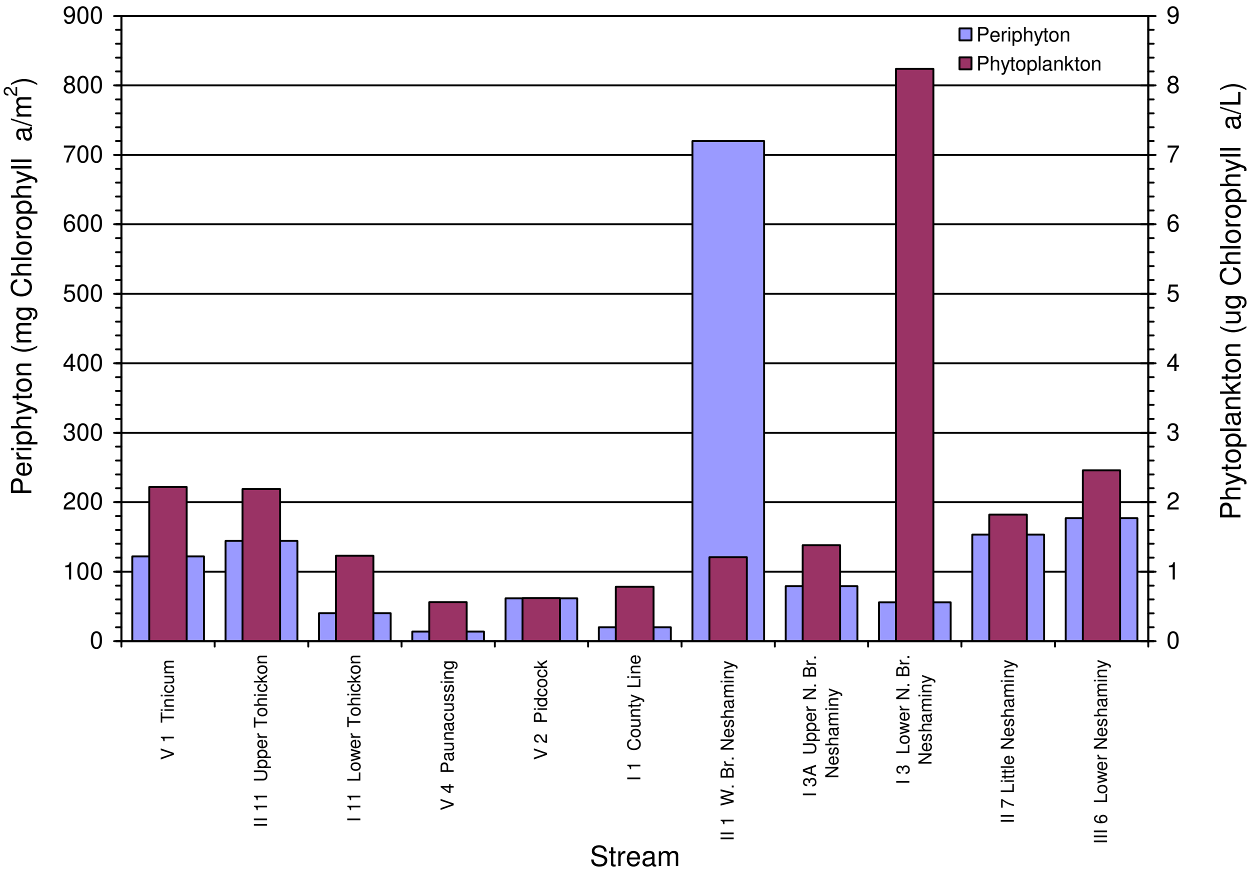


Figure 6.16. Summary of data concerning algal biomass in study streams, summer 2007.

Appendix

Listing of Plates:

Plate 1. Tinicum V1

Plate 2. Upper Tohickon II11

Plate 3. Lower Tohickon I11

Plate 4. Paunacussing V4

Plate 5. Pidcock V2

Plate 6. County Line I1




Plate 7. W. Br. Neshaminy II1

Plate 8. Upper N. Br. Neshaminy I3A

Plate 9. Lower N. Br. Neshaminy I3

Plate 10. Little Neshaminy II7

Plate 11. Neshaminy III6

Chapter 7. Aquatic Macrophytes

Overview

Aquatic macrophytes, or more simply aquatic vegetation, are divided into three groups based on how they attach to a substratum (adapted from Wetzel 2001). Emergent macrophytes are plants found in water-saturated or submersed soils; the plants themselves are generally not submersed and are generally found along stream banks rather than in the stream channel. Floating-leaved marcorphytes have root systems attached to submersed sediments with the rest of the plant floating on the water surface. Submerged plants are entirely under the water surface, but in the photic (light) zone. Macrophytes, and more generally stream and wetland vegetation, have been used as tools in evaluating human-induced environmental disturbance. Two local examples include a plant-based index of biological integrity for central Pennsylvania wetlands (Miller et al. 2006) and the use of stream vegetation as indicators of watershed disturbance in the New Jersey Pinelands (Zampella and Laidig, 1997). In this chapter, we describe and evaluate historic (1968-70) and current (2007) macrophyte survey efforts at 11 Bucks County stream sites.

Methods

The current macrophyte survey was conducted on Aug. 13 – 14, 2007. At least 1 h was spent surveying macrophyte growths over a 100 m length of each study stream and removing samples for identification, which included occassional microscopic examination in the laboratory. Abundances were estimated visually based on the number of plants or clumps of plants at the site. Abundance categories included present (1 – 3), scattered (4 – 10), numerous (11 – 25) and abundant (> 25). Specimens of most species were deposited in the Herbarium at the Academy of Natural Sciences. Identifications, all to the species level, were made according to Rhoads and Block (2007). Historically, emergent, floating and submerged aquatic plants were collected during the summer months of 1968 through 1970. Not all of the 11 study sites were visited in each year such that the results from all three years of survey work were combined in all analyses involving these data.

Percent similarity in macrophyte community composition was determined (i) between all streams within a study period and (ii) between the 1968-70 and 2007 study periods for a given stream site using equation (1):

$$PS_c = 100 - 0.5\sum_{i=1}^{s}|a_i - b_i| = \sum_{i=1}^{s}\min(a_i, b_i) \qquad (1)$$

where:
a_i = percentage of species i in stream A or community A
b_i = percentage of species i in stream B or community B

This same equation was used in evaluating similarity between agal communities (Chapter 6).

Results and Discussion

A total of 24 unique species (22 unique genera) were identified in the 2007 survey effort (Appendix 7.1). All study sites had at least one macrophyte taxon present. Only 2 of the 11 study sites had 5 or more taxa present and 4 of the 11 study sites had only 1 taxa identified during the survey (Figure 7.1). Only a single genus/species occurred at more that 2 sites (*Elodea nuttallii*; found at 4 sites); the majority of identified genera (13 of 22) were only found at a single site. The greatest diversity of taxa occurred in the Lower Neshaminy (III 6). The occurrence of numerous plants of *Callitriche stagnalis* in W. Br. Neshaminy (II 1) suggests the influence of a high nutrient load and is consistent with the abundance of filamentous algae found there. A few taxa considered as aquatic invasives (*Hydrilla* and *Myriophyllum*) were found in the current survey effort downstream of Lake Nochamixon on the Lower Tohickon (I11). Since they were not reported in the historic survey their occurrence is probably a consequence of the reservoir. Note however, that *Myriophyllum* was also found at the Lower Neshaminy site (III6) that has no immediate upstream reservoir.

In contrast, a total of 52 unique species (29 unique genera) were identified during the historic survey effort (Appendix 7.2). Four of the 11 sites had 10 or more identified taxa over the 3-year span of the historic study period (Figure 7.1). There was only a single site (V1 - Tinicum) with one identified taxon in the surveys conducted during 2 of the 3 years of the historic study period (site V1 was not surveyed in 1970). The distribution of taxa occurrences was not consistent over the 3-year historic study period. In 1969, only 24 taxa were identified across 10 of the 11 sites, while 59 taxa were identified at only 8 of the 11 sites in 1970. Ten of the 11 sites had a higher frequency of taxa occurrences during the 3-year historic period relative to the current, single year, period.

There was little to no similarity in macrophyte communities between sites within a study period or between study periods for a given study site. Only 2 pairs of sites (Lower N. Br. Neshaminy/Tinicum – I3/V1 and County Line/Pidcock – I1/V2) had percent similarity values ≥ 50 within the current study (Table 7.1). A vast majority of the site-to-site comparisons within the current survey effort had no similarity in community composition. Macrophyte communities were somewhat more similar historically, where 5 site pairs had percent similarity values ≥ 50 with only 11 pairs having no similarity in community composition (Table 7.2). Only 3 sites (Upper Tohickon [II11], W. Br. Neshaminy [II1], and Neshaminy [III6]) showed any similarity in macrophyte communities between the historic and current study periods (Table 7.3). This lack of similarity between study periods is supported by the fact that only 12 of the 29 genera identified in the historic period were found at any of the sites in the current study.

The lack of similarity in macrophyte community composition between study periods coupled with a similar lack of taxa overlap between the two periods has one of two very different explanations. The first is that there is a significant difference in methods, either in identification of macrophyte taxa or in site survey methods between the two periods, or both. No information was given in the original data reports for the historic study concerning identification or site survey methods providing no real means of evaluating methods. Some evidence suggesting a difference in methods is that in the historic dataset, 16 of the 29 (54%) identified taxa are considered emergent taxa, while only 8 of 22 (36%) taxa in the current data are considered emergent. By definition, emergent taxa generally do not occur in streams suggesting that the historical survey may have concentrated more on stream banks and less on in-stream habitat leading to a greater number of identified emergent taxa. There are also examples of differences in macrophyte taxonomy. For instance, two species found historically, *Anacharis canadensis* and *Anacharis occidentalis* are now placed in *Elodea*. Secondly, *Myriophyllum exalbescens* is likely a misidentification of *Myriophyllum spicatum.*

The other explanation for differences between the two study periods is that the character of these streams, at least in terms of macrophyte communities, has changed dramatically in the intervening years since the historic study took place. However, the direction of that change, in terms of better or worse stream health based on the macrophyte community data is not clear. In general terms, a reduction in taxa richness, as observed in the current study period data relative to the historic would indicate some stress on the ecosystem that eliminated certain taxa at the expense of other, perhaps more pollution-tolerant ones.

The macrophyte data also reflects differences in the physical site characteristics among the 11 Bucks Co streams. There are some streams such as Pidcock and County Line with small watershed areas (33 and 8 km^2, respectively, see Table 1.3 in Chapter 1) with significant canopy cover (>80% for both sites, see Chapter 6.3, Chapter 6). Neshaminy Cr. on the other hand drains a very large area (539 km^2) and has a canopy cover of < 50%. The greater light availability and potential for greater nutrient load at the larger Neshaminy Cr. site would suggest a habitat more suitable for macrophyte growth. Both sets of macrophyte data, at least in terms of taxa richness, bear this out (11 taxa for Neshaminy Cr. vs. 2 for Pidcock and 3 for County Line historically, 8 for Neshaminy and 1 each for Pidcock and County Line in the current study – see Figure 7.1).

Literature Cited

Miller, S. J., D. H. Wardrop, W. M. Mahaney, and R. P. Brooks. 2006. A plant-based index of biological integrity (IBI) for headwater wetlands in central Pennsylvania. Ecological Indicators 6:290-312.

Rhoads, A. F. and T. A. Block. 2007. **The Plants of Pennsylvania: An Illustrated Manual. 2nd ed**. University of Pennsylvania Press, Philadelphia.

Wetzel, R. G. 2001. Limnology. Lake and river ecosystems. Third edition. Academic Press, San Diego.

Zampella, R. A. and K. J. Laidig. 1997. Effect of watershed disturbance on Pinelands stream vegetation. Journal of the Torrey Botanical Society 123:52-66.

Table 7.1. Macrophyte community percent similarity between the 11 study sites based on genus-level taxa identification within the current sampling effort. Percentages > 50% are in bold.

		V1	II11	I11	V4	V2	I1	II1	I3A	I3	II7	III6
Tinicum	V1	-	0	0	0	0	0	0	25	**50**	25	38
Upper Tohickon	II11		-	25	0	0	0	0	0	0	25	0
Lower Tohickon	I11			-	0	0	0	0	0	0	0	13
Paunnacussing	V4				-	0	0	20	0	0	0	0
Pidcock	V2					-	**100**	0	0	0	0	0
County Line	I1						-	0	0	0	0	0
W. Br. Neshaminy	II1							-	0	0	0	0
Upper N. Br. Neshaminy	I3A								-	0	0	0
Lower N. Br. Neshaminy	I3									-	33	25
Little Neshaminy	II7										-	13
Neshaminy	III6											-

Table 7.2. Macrophyte community percent similarity between the 11 study sitesbased on genus-level taxa identification within the historic sampling effort (combined the 3 years of sampling effort). Percentages > 50% are in bold.

		V1	II11	I11	V4	V2	I1	II1	I3A	I3	II7	III6
Tinicum	V1	-	0	7	0	0	33	11	0	0	5	0
Upper Tohickon	II11		-	**50**	9	18	0	36	9	18	37	45
Lower Tohickon	I11			-	7	14	21	**50**	29	36	**58**	43
Paunnacussing	V4				-	0	0	11	0	0	5	9
Pidcock	V2					-	0	0	25	17	11	18
County Line	I1						-	33	**50**	33	16	9
W. Br. Neshaminy	II1							-	22	33	32	27
Upper N. Br. Neshaminy	I3A								-	**50**	16	18
Lower N. Br. Neshaminy	I3									-	26	36
Little Neshaminy	II7										-	47
Neshaminy	III6											-

Table 7.3. Macrophyte community percent similarity between the study periods for each of the 11 study sites based on genus-level taxa identification within both sampling efforts. Percentages > 50% are in bold.

		% Similarity between current and historic sampling
Tinicum	V1	0
Upper Tohickon	II11	18
Lower Tohickon	I11	7
Paunnacussing	V4	0
Pidcock	V2	0
County Line	I1	0
W. Br. Neshaminy	II1	33
Upper N. Br. Neshaminy	I3A	0
Lower N. Br. Neshaminy	I3	0
Little Neshaminy	II7	0
Neshaminy	III6	27

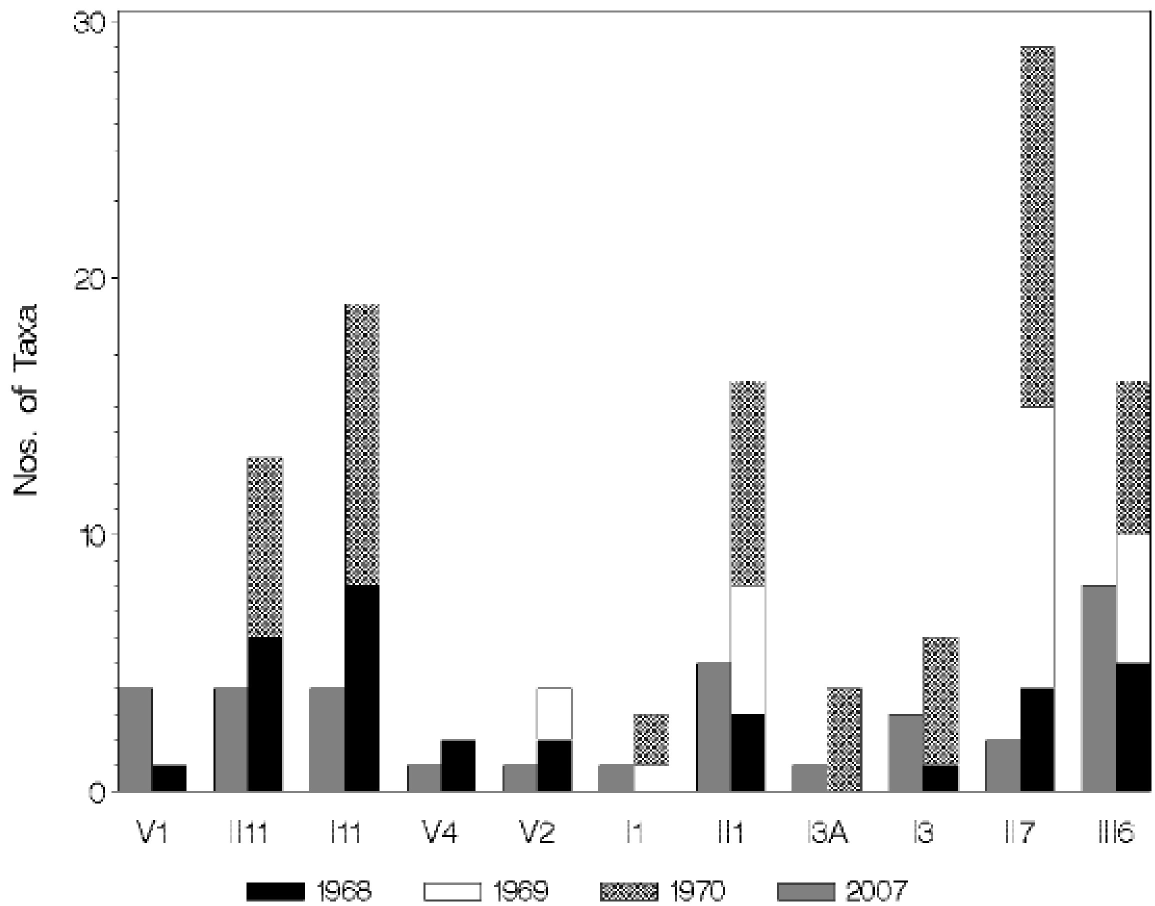


Figure 7.1. Frequency of occurrence of macrophyte taxa (genus-level) at each study site within each year grouped by study period (i.e. 1968-70 = historic, 2007 = current). Station I3A was not sampled in 1968 or 1969; stations V1, V2, and V4 were not sampled in 1970.

Appendix

Appendix 7.1. Taxa collected at the 11 Bucks County study sites from August 13-14, 2007. Pr = Present (1-3 plants or clumps of plants); Sc = Scattered (4-10); Nm = Numerous (11-25); Ab = Abundant (>25).

Taxa	V1	II11	I11	V4	V2	I1	II1	I3A	I3	II7	III6
Amblystegium tenax		Ab								Ab	
Callitriche heterophylla				Pr							
Callitriche stagnalis							Nm				
Carex torta	Ab							Pr			
Eleocharis tenuis							Pr				
Elodea nuttallii	Sc								Pr	Nm	Sc
Heteranthera reniformis							Ab				
Hydrilla verticillata			Sc								
Iris sp.		Pr									
Lemna minor					Pr	Pr					
Lindernia dubia											Pr
Ludwigia palustris							Sc				
Myriophyllum spicatum			Sc								Sc
Najas flexilis	Pr										
Najas minor											Pr
Nasturtium officinale									Pr		
Nuphar lutea		Ab									
Podostemum ceratophyllum											Ab
Polygonum punctatum							Pr				
Potamogeton crispus	Sc										Sc
Potamogeton foliosus	Pr								Pr		
Saururus cernuus		Ab	Ab								
Sparganium eurycarpum			Pr								
Vallisneria americana											Sc
Zosterella dubia											Sc

Appendix 7.2. Taxa collected at the 11 Bucks County study sites during summer months of 1968-1970. Pr = Present; Ab = Abundant. No quantitative definitions given for these abundance categories. Station I3A was not sampled in 1968 or 1969; stations V1, V2, and V4 were not sampled in 1970.

Taxa	V1	II11	I11	V4	V2	I1	II1	I3A	I3	II7	III6
1968											
Anacharis canadensis		Pr	Pr		Pr					Ab	Pr
Anacharis occidentalis									Pr		
Caltha palustris				Pr							
Ceratophyllum demeraum			Pr								
Heteranthera dubia forma terrestris			Pr								
Heteranthera reniformis			Pr								
Lemna minor		Pr		Pr						Pr	Pr
Lemna trisulca										Pr	Pr
Myriophyllum exalbescens		Pr	Pr							Pr	Pr
Nuphar fraternum							Ab				
Nymphaea odorata		Ab									
Pontederia cordata			Pr								
Potamogeton americanus		Pr	Pr								Pr
Potamogeton amplifolius											Pr
Potamogeton crispus					Pr					Pr	Pr
Potamogeton pusillus var. *typicus*			Pr							Pr	Pr
Potamogeton richardsonii			Pr								
Saururus cernuus		Pr									
Scirpus validus	Pr		Pr				Pr				
Typha latifolia			Pr				Pr				
Vallisneria americana											Pr
1969											
Anacharis canadensis					Pr					Pr	Pr
Eleocharis acicularis						Pr				Pr	
Heteranthera reniformis							Pr			Pr	Pr
Ludwigia palustris var. *americana*											Pr
Myriophyllum exalbescens										Pr	Ab
Nuphar microphyllum							Pr				
Polygonum coccineum							Pr			Pr	
Pontederia cordata										Pr	
Potamogeton americanus											Pr
Potamogeton crispus					Pr					Pr	
Potamogeton hillii											Ab
Potamogeton natans										Pr	
Sagittaria australis							Pr			Pr	
Sagittaria latifolia forma diversifolia							Pr				
Scirpus validus							Pr			Pr	
Sparganium sp.										Pr	
Vallisneria americana										Pr	

Appendix 7.2. Continued.

Taxa	V1	III11	I11	V4	V2	I1	II1	I3A	I3	II7	III6
1970											
Alisma plantago-aquatica			Pr					Pr	Pr		
Anacharis canadensis			Pr							Pr	
Bidens comosa										Pr	
Bidens connata var. *petiolata*										Pr	
Bidens sp.		Pr	Pr								
Callitriche deflexa var. *austini*										Pr	
Eleocharis acicularis			Pr				Pr	Pr	Pr		
Eleocharis tuberculosa							Pr		Pr		
Glyceria striata											Pr
Heteranthera reniformis			Pr				Pr		Pr	Pr	
Leersia oryzoides										Pr	Pr
Lemna minor		Pr	Pr				Pr			Pr	
Ludwigia palustris var. *americana*											Pr
Mentha aquatica										Pr	
Myriophyllum exalbescens										Pr	
Myriophyllum sp.		Pr	Pr								
Nuphar fraternum		Pr					Pr				
Nuphar ozarkanum		Pr									
Nuphar rubrodiscum							Pr				
Nuphar sp.		Pr					Pr				
Nymphoides peltatum							Pr				
Polygonum amphibium			Pr			Pr					
Polygonum lapathifolium											Pr
Polygonum opelousanun							Pr			Pr	
Polygonum punctotum			Pr					Pr			
Polygonum sp.							Pr		Pr		
Potamogeton americanus											Pr
Potamogeton crispus										Pr	
Potamogeton gramium			Pr								
Potamogeton natans								Pr			
Ranunculus reptans var. *ovalis*										Pr	
Rorippa palustris var. *hispida*		Pr							Pr	Pr	
Rorippa sylvestris											Pr
Sagittaria latifolia var. *obtusa*		Pr	Pr				Pr				
Scirpus validus						Pr	Pr				
Sparganium fluctuans										Pr	
Spartina pectinata										Pr	
Typha angustifolia		Pr	Pr								

Chapter 8. Education

Overview

To complement the research component, SWRC educators provided outreach opportunities to approximately 1,000 teachers, students and community organization volunteers to educate Bucks County residents about the importance of their water resources and watersheds.

Formal Education: School Outreach

Our outreach to schools focused on the Central Bucks and Palisades School Districts. In-depth, hands-on stream studies were conducted with over 700 middle and high school students. These programs focused on introducing students to their watershed, the sources of their drinking water, the importance of local streams, the quality of their local streams and methods to measure water quality. Where possible, students visited a stream within walking distance of their school to test the chemical and biological health of the stream. These results were than put into the context of the original and current research studies. Each lesson concluded with a discussion about potential local sources of pollution and everyday actions that people can take to be good stewards of their watersheds.

Where a stream was not accessible within walking distance of a school, the stream was brought into the classrooms, enabling students to still test the biology and chemistry of the water within the classroom.

Extensive mentoring assistance was provided to Palisades Middle School teachers who recently initiated an integrated watershed program through which students spend their entire year studying their local watershed. To assist the school, we provided training and watershed-based curriculum to the teachers and conducted hands-on activities with students. This included training and support in the use of the Leaf Pack Experiment to collect and analyze the stream macroinvertebrates as a measure of stream health.

An interview with SWRC scientist Dr. Tom Bott is posted at the address below as an introduction to students and educators about the Bucks County research project: www.stroudcenter.org/research/BucksCounty/interview.htm

Informal Education: Outreach to Communities

Community outreach efforts focused on reaching organizations active in watershed stewardship initiatives. This audience was targeted because they, in turn, can pass along and provide the information that they received to the broader Bucks County communities within which they work. Community partners that we have worked with include:

- Bucks County Conservation District
- Heritage Conservancy
- Peace Valley Nature Center
- Bucks County Trout Unlimited

Pennsylvania Fish and Boat Commission
North Neshaminy Watershed Association
Greenbelt Overhaul Alliance of Levittown
Aquetong Watershed Association

Workshops conducted include:

Techniques in watershed monitoring and education: Hosted by the Peace Valley Nature Center, this training provided informal environmental educators with and overview of the Bucks County research project, background in chemical, physical and biological monitoring, and techniques and activities to bring this information to the public and students.

Macroinvertebrate Monitoring: A full-day workshop held at Tyler State Park, in conjunction with the PA Fish and Boat Commission, for teachers and watershed association volunteers, this training introduced participants to stream macroinvertebrate monitoring techniques, identification, and data analysis to determine stream health.

Stream School: This two-day training introduced participants to stream ecology and monitoring.

Presentations to community organizations included:

Bucks County Research Initiative: Presentation on the research initiative at the 2008 Schuylkill Watershed Congress (Congress is attended by watershed volunteers and professionals throughout the region).

Water Quality in Bucks County: Presentation to the Neshaminy Alliance.

The importance of streamside trees: Presented to Bucks County Trout Unlimited

Citizen Scientists - Connecting Water from Forest to Faucet: Presented on behalf of the Bucks County Conservation District for the general public

Water Where You Want It: Presented to the North Branch (Neshaminy) Watershed Association

Appendix

Appendix 7.1. Article regarding the Citizen Scientist Training Program: Pay it Forward in Your Watershed project that appeared in the October 11, 2009 edition of the MyCommunity Trend local newspaper for the Newton/Richboro/Southampton communities in Bucks County. Educators from the Stroud Water Research Center participated in this project.

philly•com/MyCommunity
MyCommunity TREND
NEWTOWN • RICHBORO • SOUTHAMPTON
Sunday, October 11 Edition Vol. 48 No. 14 Zone BC-6
Part of the family that brings you the Inquirer

Citizen Scientists program asks students to pay it forward

Free classes will teach those who reside near small waterways how to keep the watershed green and clean

By Jessica Ercolino
Staff Writer

This year, the Bucks County Conservation District is "shedding" conventional methods of ecological education.

The Citizen Scientist Training Program: Pay it Forward in Your Watershed project is a way to educate individuals about maintaining streamside properties and encourage them to spread that knowledge, according to Mary Ellen Noonan, environmental educator at BCCD.

The five-week training session, expected to begin Nov. 5, will focus on the importance of riparian areas — areas located along a natural watercourse.

This is the second year the district has run a program of this sort, said Noonan.

Last year's course, titled "Riparian Buffer Maintenance for Streamside Property Owners," provided training to Delaware Valley College environmental design students, who then held free consultations in the community to demonstrate proper care for these areas.

"[The students] not only received the training, but also had a chance to interact with homeowners, giving them experience for the future when they enter the job market," Noonan said.

This year's training — open to all streamside property owners — is free, but those who participate must agree to "pay it forward" by training other property owners in streamside care.

"Last year was very successful, but the majority of the students graduated and moved outside of Bucks County," said Noonan. "I thought, 'I have to do something different next time.'"

Noonan will work with other educators and industry specialists — including a representative from the Stroud Water Research Center — to educate the community on the principles of making an area more ecologically sustainable.

As part of a discussion on the ecological benefits of water quality and the environment as a whole, participants will learn about point- and non-point source pollutants, invasive and native plants, impervious surfaces and storm water management.

In the fourth week, participants will take a field trip to a local property for a more hands-on lesson, according to a tentative schedule.

"With streamside buffers, it's one thing to talk about it, but it's another to go out and see.

See CITIZEN SCIENTIST page 6

Citizen scientists will be asked to keep watersheds safe

CITIZEN SCIENTIST from the cover

it," Noonan explained. "They'll discuss what they've learned — talk about what's wrong and right with the property and what can be done to improve it."

Many people don't realize the powerful effect a streamside buffer has on water quality, said the environmental educator.

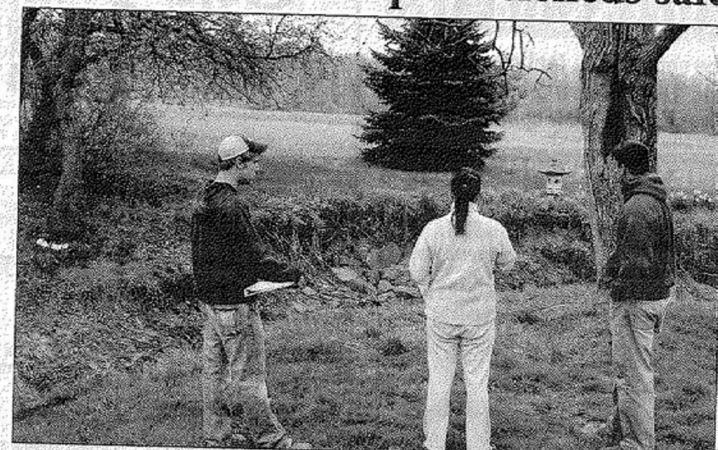
"The plants take up lots of things that pollute that water, such as excess fertilizer, road salt, oil, gasoline, etc.," she said. "They can tolerate it and use it in their growth."

Taking down trees and shrubs — the "cover" — leads to erosion on the stream bank, water impurities and increased risk of flooding, she added.

Removing the cover also affects the water temperature.

"The water gets hotter and there is not enough oxygen," she said. "That is not a good thing for a lot of the living things in the creeks and streams; they need that oxygen."

The Bucks County Conservation District's mission is to provide for the wise use, management and development of the county's soil, water and related natural resources, according to its Web site, www.buckscd.org.



Photos courtesy of the BCCD

Above, students from last year's watershed care training program consult with a homeowner who lives along a severely eroded streamside.

Funding for this and last year's programs came from the Pennsylvania Association of Conservation Districts, Noonan said.

Training sessions will be held at the Bucks County Conservation District office on Ferry Road in Doylestown.

The program can accommodate up to 15 participants. Those interested in attending should contact Noonan at the Bucks County Conservation District as soon as possible, 215-345-7577, ext. 101, or maryellennoonan@buckscd.org.